IIASA

THE TENNESSEE VALLEY AUTHORITY EXPERIENCE

PROCEEDINGS OF THE FIRST CONFERENCE ON CASE STUDIES OF LARGE SCALE PLANNING PROJECTS

October 28 - November 1, 1974

Volume 1

Hans Knop, Editor

CP-76-2

CP-76-2
Volume 1

THE TENNESSEE VALLEY AUTHORITY EXPERIENCE

PROCEEDINGS OF THE FIRST CONFERENCE ON CASE STUDIES OF LARGE SCALE PLANNING PROJECTS

October 28 - November 1, 1974

Hans Knop, Editor

International Institute for Applied Systems Analysis
2361 Laxenburg, Austria

PREFACE TO THE TVA CONFERENCE PROCEEDINGS

Hans Knop

The choice of the Tennessee Valley Authority as the subject for the first IIASA Conference on the experience of large-scale planning projects may appear to be somewhat surprising. The TVA has been controlling rivers and generating electric power over a vast area of the southeastern United States for nearly forty years. So much has been written about the TVA that one might suppose there was little left to discuss.

As it turned out, however, the experience of the TVA was an ideal subject for systems analysis, one aspect that has received relatively little attention. As Project Leader of the Planning and Management in Large Organizations Group, I was pleased with the selection of the TVA rather than some similar large organization recently completed or in the development stage. It is usually difficult to get enough accurate information about a new organization. For one thing, it is likely to be in a state of flux: what was true yesterday may be no longer true tomorrow. Furthermore, to discuss matters fully and frankly for fear they may reveal secrets or expose themselves to criticism for some aspects that have not been thoroughly worked out.

As the reader reviews the proceedings of this Conference, he will find that the TVA was indeed candid in its representation of the methods and activities being pursued, and was also entirely willing to discuss its weaknesses and shortcomings.

We found the TVA to be a dynamic organization, responsive to change while still maintaining its basic philosophy of improving the living standards for the people of the region through a program of integrated regional development. The task has not yet been fully completed, but the progress of the last forty years represents a significant achievement for the TVA.

The present two volumes mark the first case study of large-scale planning projects. This work will be followed up by a similar Conference dealing with the Bratsk-Ilimsk Experience in the Siberian Region of the Soviet Union, the Lublin Development Project of Poland, the Shinkansun Program in Japan, and other projects as they become identified. It is intended that comparisons and generalizations can be made which would aid the National Member Organizations of IIASA and the scientific world in general in developing effective management techniques for similar cases.

The TVA presentations are printed in the form they were actually prepared in. IIASA has not attempted to edit them, and they have been published here as received from the TVA. This procedure has resulted in variations in the quality of print and type. We sincerely apologize for this inconvenience and hope that this does not present any problems.

LIST OF PARTICIPANTS

AUSTRIA

Academy of Science

Dieter BOEKEMANN

Institut fuer Stadt- und Regional-
planung der Technischen Hochschule
Wien
Karlplatz 12
1040 Vienna

Ewald BRUNNER

Interdisziplinaeres Institut
fuer Raumordnung
Hoschschule fuer Welthandel
Hasenauerstrasse 42/8
1190 Vienna

A. KOHLBACHER

Office of the Chancellor
Buero fuer Raumplanung,
Section V
Hohenstaufengasse 3
1010 Vienna

Uwe SCHUBERT

Interdisziplinaeres Institut
fuer Raumordnung
Hochscule fuer Welthandel
Hasenauerstrasse 42/8
1190 Vienna

Annemarie STARKE

address as above

Walter STOEHR

address as above

Helmut WINTERSBERGER

Office of the Chancellor
Buero fuer Raumplanung,
Section V
Hohenstaufengasse 3
1010 Vienna

Alan LABOWITZ
Legal Advisor to IAEA
Blutgasse 3
1010 Vienna

George A. MORGAN
Hackofergasse 18
1190 Vienna

AUSTRIA (cont'd)

Dwight PORTER

US Mission to the IAEA
Schmidgasse 14
1080 Vienna

Y. CHO

UNIDO
Industrial Programming Section of the Industrial Policies and Programming Division
POB 837
1011 Vienna

Karl HOENIGMAN

Verbundgesellschaft-Oesterreichische Elektrizitaetswirtschafts A.G.
Postfach 67
Am Hof 67
1011 Vienna

Rurik KRYMM

IAEA Division of Nuclear Power
Kaertner Ring 11
1010 Vienna

T. J. ROBERTS

address as above

BRAZIL

Alfredo Melo SOUZA-FREITAS

Ministerio do Interior
Brazilia

Jack SCHECHETMAN

FINEP
Av. Pres. Vargas, 482
Rio de Janeiro

BULGARIA

National Centre for Cybernetics and Computer Techniques

Blagoj UZUNOV

c/o The National Centre for Cybernetics and Computer Techniques
Slavjanska 8
Sofia

Lubomir DACHEV (interpreter)
address as above

CANADA

Canadian Committee
for the IIASA

A.R. DOBELL

Deputy Secretary
Planning Branch
Treasury Board Secretariat
160 Elgin Street
Ottowa, Ontario K15 0R5

Ranjit KUMAR

Directore
Centre for International Programs
Seneca College of Applied Arts
and Technology
1750 Finch Ave. East
Willowdale, Ontario M2N 5T7

T.A. NORDSTROM

British Columbia Hydro and Power
Authority
970 Burrad Street
Vancouver, B.C.

C. E. ZWICKER, Chief

Economics Studies Division
Department of Energy, Mines
and Resources
299 Carling Ave.
Ottowa, Ontario K1A 0E4

CSSR

Committe for the IIASA
of the Czechoslovak
Socialist Republic

Pavel MAJERSKI

Deputy Minister for Technology
and Investment

Vaclaw RENDL

Office of the Prime Minister

Nikolai SLOCHA

Vice Minister of the State
Planning Committe

Tibor VASKO

Committee for the IIASA of the
Czechoslovak Socialist Republic
Slezska 9, Vinohrady
Prague-2

FRG

Max Planck Society

U. DAEUNERT

Bundesministerium fuer
Forschung und Technologie
Postfach 120 370
53 Bonn - 12

Gerhard KOLB

Programmgruppe Systemforschung
und Technologische Entwicklung
der Kernforschungsanlage Juelich GmbH
Postfach 365
D - 517 Juelich - 1

Dietrich KOECHER

Bundesministerium fuer Wissenschaft

Guenter MARQUIS

Rheinisch-Westfaelisches
Elektrizitaetswerk A.G.
Kruppstrasse 5
43 Essen

Herbert RUDOLF

Bundesministerium fuer Wissenschaft

STOECKER

Programmgruppe Systemforschung
und Technologische Entwicklung
der Kernforschungsanlage
Juelich GmbH
Postfach 365
D - 517 - Juelich - 1

ZIEGLER

Bundesministerium fuer
Forschung und Technologie
Postfach 120 370
53 Bonn - 12

FRANCE

Association Francais pour le
Developpement de l'Analyse de
Systemes

Albert ANDRE

Agence Financiere du Bassin Seine
Normandie
10-12 Rue du Capitain Menard
F-75732 Paris Cedex 15

GDR

Academy of Sciences

Willi HAETSCHER

Direktor fuer Wissenschaft
und Technik Institut fuer Energetik
Leipzig

Werner KALWEIT

Vice Chairman of the Academy of
Sciences of the German Democratic
Republic
Berlin

Ortwin KRAUSE

Institut fuer Pflanzenernaehrung
Naumurgerstrasse 98
69 Jena

Hans MOTTEK

Professor mit Lehrstuhl an der
Hochscule fuer Oekonomie
Berlin

Guenther PREISSLER

Abteilungsleiter am Institut
fuer Wasserwirtschaft
Berlin - Niederschoeneweide

Helmut SCHULZ

Wissenschaftlicher Mitarbeiter
im Ministerium fuer Wissenschaft
und Technik
Berlin

Lothar ROEMER

Interpreter

ITALY

Italian Committee for
Liason with IIASA

Marcello BERNARDINI

Water Research Institute
Via Reno 1
Rome

Francesco BRIOSCHI

Instituto Elettrotechnica
ed Elettronica
Piazza Leonardo da Vinci 32
Milan

ITALY (cont'd)

Benedine KNOXE

I.R.S.A.
Via Reno 1
Rome

JAPAN
The Japan Committee
for the IIASA

Hideo KIKKAWA

Faculty of Engineering
Tokyo Institute of Technology
Tokyo

Kuniyoshi TAKEUCHI

Research Associate
Faculty of Engineering
Tokyo Institute of Technology
Tokyo

POLAND

Academy of Sciences

A. JASKOWIAK

Vice Minister of Agriculture
Warsaw

J. OWSINSKY
Institute for Management and Control
00-818 Warsaw KRN 55

W. STANISZ
Director of Agrochem
Warsaw

A. Straszak
Institute for Management and Control
00-818 Warsaw KRN 55

UK

The Royal Society

Keith NEWLANDS

British Steel Corporation
(International) Ltd.
33 Grosvenor Place
London, SW1X 7JG

USA

National Academy of Sciences

Charles W. HOWE

Professor and Chairman
Department of Economics
University of Colorado
Boulder, Colorado 80302

John V. KRUTILLA

Resources for the Future, Inc.
Natural Environments Program
1755 Massachusetts Avenue, N.W.
Washington, D.C. 20036

Thomas K. McCRAW
Department of History
University of Texas
Austin, Texas

Stephen ROSENTHAL
University of California
Berkeley, California

Harvey WAGNER
McKinsey & Co.
New York, N.Y.

USSR

The Academy of Sciences

G. V. BESPACHOTNYI

Head of a laboratory of the
Research Institute of Cybernetics
USSR Ministry of Agriculture

S. P. CHEBOTAREV

Research Scolar
Institute of Control Sciences

Leonid EVENKO

The Academy of Sciences
c/o State Committe for USSR
Council of Ministers for
Science and Technology
11 Gorky Street
Moscow

I. M. FILIPPOVA

Senior Research Scholar
Institute of Applied Geophysics

USSR (cont'd)

The Academy of Sciences

L. I. GRAMOTEJEVA

Deputy Director of the Institute
of Economic Research of the
USSR State
Planning Committee

V. J. KARELIN

Dean of the Faculty of Hydrotechnics
Institute of Civil Engineering

V.L. LISITSYN

Deputy Chairman of the State
Planning Committee of the Russian
Soviet
Soviet Federal Republic
c/o State Committee for USSR
Council of Ministers for
Science and Technology
11 Gorky Street
Moscow

V. S. MARTYNOVSKYI

Member of the USSR
Ministry of Agriculture Board

G. A. MESHTCHERIAKOV

Head of the Department
Institute of Management Sciences

B. Z. MILNER

Head of a Department
Institute of the USA Studies

E. V. MINAJEV

Deputy Chief of the
Research and Technology Dept.
USSR Ministry of Energetics

I. M. NAZAROV

Head of a Department
Institute of Applied Geophysics

G. C. PLEKHOV

Chief Specialist of the USSR
State Planning Committe

USSR (cont'd)

RAMAN

Chairman of the State Planning Committee of the Latvian Soviet Socialist Federal Republic
c/o State Committee for USSR Council of Ministers for Science and Technology
11 Gorky Street
Moscow

E. S. SHERSHNEV

Deputy Director of the Institute of the USA Studies

L. SUMAROKOV

Committee of the Latvian Soviet
c/o State Committee for USSR Council of Ministers for Science and Technology
11 Gorky Street
Moscow

V. TREITIAKOV

Head of a Laboratory
Institute of Control Sciences

L. TRETIJAKOV

c/o State Committee for USSR Council of Ministers for Science and Technology
11 Gorky Street
Moscow

O. V. TROFIMOV

Deputy Chief of the V/O "Sojuzsystemprom"
USSR Ministry of Instruments Manufacturing, Automation and Control Systems

A. A. KAFYROV

I.M. SEMENOVA

I.V. SMIRNOV

N.S. SUSLOVA

E.V. VYSHINSKAIA

Interpreters

TVA GROUP

B. J. BOND

Assistant Director
Division of Agriculture Dev.

C. D. BUFFINGTON

Supervisor, System Dev. & Data Processing-Division of Forestry, Fisheries & Wildlife

M. I. FOSTER

Director, Division of Navigation Development & Regional Studies

Hubert HINOTE

Supervisor, Economic Analysis Sec. Navigation Economics Branch

P. A. KRENKEL

Director, Division of Environmental Planning

E. H. LESESNE

Director, Division of Water Control Planning

T. L. MONTGOMERY
Chief, Air Quality Branch, Division of Environmental Planning

J. L. NEVINS

Agricultural Economist, Division of Agriculture Dev.

Lynn SEEBER

General Manager, TVA

W. O. WUNDERLICH

Supervisor, Water Resource Mgt. Methods Staff, Division of Water Control Planning

W. T. ZUMWALT

Director, Division of Power Systems Operations

IIASA PARTICIPANTS

In Charge of Scientific Coordination of Conference:	H. KNOP
Director	H. RAIFFA
Secretary to IIASA	A. BYKOV
Energy Project	R. AVENHAUS G. BAECHER J. R. BEATTIE J. P. CHARPENTIER M. GRENON J. GROS W. HAEFELE C. MARCHETTI A. MURPHY W. NORDHAUS D. SCHADE P. TSVETANOV H. VELIMIROVIC N. WEYSS
Handbook Project	R. LEVIEN V. RAKHMANKULOV
Integrated Industrial Systems Project	O. BERNARDINI A. CHELIUSTKIN J. HATVANY H. HUEBNER D. KELLEY I. LEFKOWITZ B. MAZEL G. SURGUCHEV
Large Organizations Project	H. KNOP V. TOKHADZE
Methodology Project	D. BELL J. BIGELOW J. CASTI W. JEWELL T. KOOPMANS T. KOOPMANS (Mrs) C. WINKLER

Urban and Regional Project	E. BLUM R. McKINNON H. SWAIN
Water Project	I. BELYAEV I. GOUEVSKY Z. KACZMAREK P. KORYAVOV T. OSTROM Y. ROZANOV J. SCHMIDT E. WOOD
Ecology Project	R. HILBORN D. JONES H. STEHFEST C. WALTERS

WORKING AGENDA

for

TVA Conference

Monday, October 28

		Plenary Session I
		IIASA Co-Chairman: H. Raiffa
	a)	TVA presentation: L. Seeber
	b)	IIASA discussion paper: Z. Kaczmarek
	c)	Scientific Rapporteur: Evenko
9:30 - 10:45	I.	"History of TVA" (GM-1)
	1.1	Circumstances Leading to the Creation
	1.2	Purposes and Goals
11:00 - 12:15	II.	"What Has Been Accomplished in the First Forty Years" (GM-2)
		Plenary Session II
		IIASA Co-Chairman: T. Koopmans
14:15 - 15:30	I.	"The Regional Economy and National Relationships" (NDRS-1)
	a)	TVA presentation: M. Foster
	b)	IIASA discussion paper: T. Koopmans
	c)	Scientific Rapporteur: Methodology
16:00 - 17:30	II.	"Tennessee Valley Regional Simulation Model" (NDRS-2)
	a)	TVA presentation: H. Hinote
	b)	IIASA discussion paper: R. McKinnon
	c)	Scientific Rapporteur: Swain

Tuesday, October 29

Plenary Session III

IIASA Co-Chairman: H. Knop

9:00 - 11:15 "Organizational Aspects of TVA" (GM-3)

a) TVA presentation: L. Seeber
b) IIASA discussion paper: H. Knop
c) Scientific Rapporteur: Rosenthal, Owinski

Technical Sessions (concurrent)

Session I

11.30 - 13.00 A. Economic Submodels

IIASA Co-Chairman: A. Cheliustkin/ I. Lefkowitz

1. "Industrial Planning Models" (NDRS-3)

a) TVA presentation: M. Foster
b) IIASA discussion paper: O. Bernardini
c) Scientific Rapporteur: D. Kelly

14:30 - 16:00 2. "Trade and Service Planning and Multicounty Overviews and Techniques of Land-Use Analysis" (NDRS-4)

a) TVA presentation: H. Hinote
b) IIASA discussion paper: H. Swain
c) Scientific Rapporteur: H. Swain

B. Integrated Water Control System

IIASA Co-Chairman: Z. Kaczmarek

16:30 - 18:00 1. "The Water Control System and Changes in Multipurpose Use" (WCP-1)

a) TVA presentation: E. Lesesne
b) IIASA discussion paper: I. Gouevsky
c) Scientific Rapporteur: I. Gouevsky

Session II

Regional and National Agriculture and Fertilizer Development

TVA Co-Chairman: B. Bond

11:30 - 13:00 1. "Regional and National Trends, Land and Human Resource Use and Agricultural Models" (OACD-1,2,3)

a) TVA presentation: B. Bond
b) IIASA discussion paper: W. Nordhaus
c) Scientific Rapporteur: Energy

Tuesday, October 29 (continued)

14:30 - 16:00	2.	"Transfer of Knowledge in Fertilizer Research and Development" (OACD-4,5)
	a)	TVA presentation: B. Bond/J. Nevins
	b)	IIASA discussion paper: C. Marchetti
	c)	Scientific Rapporteur: Energy
16:30 - 18:00	3.	"Fertilizer Production and Distribution Submodels" (OACD-6)
	a)	TVA presentation: J. Nevins
	b)	IIASA discussion paper: D. Bell/C. Winkler
	c)	Scientific Rapporteur: Methodology

Wednesday, October 30

Plenary Session IV

9:00 - 10.30	IIASA Co-Chairman: W. Haefele	
	"TVA Decisions Relating to the Provision of Ample Electrical Energy for the Region" (GM-4)	
	a)	TVA presentation: L. Seeber
	b)	IIASA discussion paper: W. Haefele
	c)	Scientific Rapporteur: Energy

Technical Sessions (concurrent)

Session III	A.	Integrated Water Control System (continued)
		IIASA Co-Chairman: Z. Kaczmarek
11:00 - 12:30	2.	"Water Resource Planning and Management Submodels" (WCP-2,4)
	a)	TVA presentation: E. Lesesne
	b)	IIASA discussion paper: I. Belyaev
	c)	Scientific Rapporteur: Belyaev, Ostrom
14:00 - 15:30	3.	"Water Resource Planning and Management Submodels" (WCP-3,5)
	a)	TVA presentation: W. Wunderlich
	b)	IIASA discussion paper: P. Koryavov
	c)	Scientific Rapporteur: P. Koryavov

Wednesday, October 30 (continued)

	B.	Environmental Planning and Management
		IIASA Co-Chairman: C. Walters
16:00 - 17:30	1.	"Environmental Quality Management Program" (DEP-1)
	a)	TVA presentation: P. Krenkel
	b)	IIASA discussion paper: D. Jones
	c)	Scientific Rapporteur: D. Jones
Session IV		Electrical Energy System
		IIASA Co-Chairman: R. Avenhaus
11:00 - 12:30	1.	"Power System Development Including Major Decisions and Technological Change Affecting Development" (OP-1)
	a)	TVA presentation: W. Zumwalt
	b)	IIASA discussion paper: J.P. Charpentier
	c)	Scientific Rapporteur: R. Avenhaus
14:00 - 15:30	2.	"Short- and Long-Term Load Forecasting Models" (OP-2)
	a)	TVA presentation: W. Zumwalt
	b)	IIASA discussion paper: J.P. Charpentier
	c)	Scientific Rapporteur: R. Avenhaus
16:00 - 17:30	3.	"Power Generation Additions Model" (OP-3)
	a)	TVA presentation: W. Zumwalt
	b)	IIASA discussion paper: J. Gros
	c)	Scientific Rapporteur: R. Avenhaus

Thursday, October 31

Technical Sessions (concurrent)

Session V		Environmental Planning and Management (continued)
		TVA Co-Chairman: P. Krenkel
9:00 - 10.30	2.	"Environmental Monitoring" (DEP-2)
	a)	TVA presentation: P. Krenkel/T. Montgomery
	b)	IIASA discussion paper: H. Stehfest
	c)	Scientific Rapporteur: H. Stehfest

Thursday, October 31 (continued)

11:00 - 12.30	3.	"Reservoir Ecology and Water Quality Management" (DEP-3)
	a)	TVA presentation: P. Krenkel
	b)	IIASA discussion paper: J. Schmidt
	c)	Scientific Rapporteur: J. Schmidt
14:00 - 15:30	4.	"Atmospheric Dispersion Model(s)" (DEP-4)
	a)	TVA presentation: T. Montgomery
	b)	IIASA discussion paper: A. Murphy
	c)	Scientific Rapporteur: Energy
16:00 - 17:30	5.	"Reservoir System Optimization Modelling" (WCP-6)
	a)	TVA presentation: W. Wunderlich
	b)	IIASA discussion paper: E. Wood
	c)	Scientific Rapporteur: E. Wood
Session VI	A.	Energy System Submodels (continued)
		IIASA Co-Chairman: W. Nordhaus
9:00 - 10:30	4.	"Transmission System Planning Model" (OP-4)
	a)	TVA presentation: W. Zumwalt
	b)	IIASA discussion paper: N. weyss
	c)	Scientific Rapporteur: Energy
11:00 - 12:30	5.	"Power System Operations Model" (OP-5)
	a)	TVA presentation: W. Zumwalt
	b)	IIASA discussion paper: J. Gros
	c)	Scientific Rapporteur: Energy
	B.	Forestry and Mineral Resources
		IIASA Co-Chairman: H. Swain
14:00 - 15:30	1.	"Forest and Wildlands Development and Resource Allocation Submodels" (FFWD-1,2)
	a)	TVA presentation: C. Buffington
	b)	IIASA discussion paper: C. Walters
	c)	Scientific Rapporteur: C. Walters
16:00 - 17:30	2.	"Research and Development in Surface Mining Reclamation" (FFWD-3)
	a)	TVA presentation: L. Seeber
	b)	IIASA discussion paper: G. Baecher
	c)	Scientific Rapporteur: Energy

Friday, November 1

Plenary Session V

IIASA Co-Chairman: H. Raiffa

9:00 - 10:30 "Economic Future and Quality of Life in the Region and TVA's Role" (Jobs, Energy, Environment, Food and Fiber) (GM-5)

a) TVA presentation: L. Seeber
b) IIASA discussion paper: R. Levien/ A. Bykov
c) Scientific Rapporteur: V. Rakhmankulov

11:00 Plenary Session VI

IIASA Co-Chariman: H. Raiffa

Conclusions and closing of the Conference

WELCOMING ADDRESS TO TVA CONFERENCE

H. Raiffa, Director IIASA

Distinguished guests: Welcome to Baden. Baden is a lovely Austrian spa, famous for being close to the metropolis of Laxenburg, home of the International Institute for Applied Systems Analysis, abbreviated I I A S A and pronounced "Yasah." At a time like this it is also appropriate to pronounce our initials as "Eh ah sa" which in Japanese means "Good Morning."

This Conference on the "TVA Experience" is the first of a series of conferences on Retrospective Case Studies of Integrated Planning Projects. By constructively examining the past we hope to identify key issues that can help planning efforts in the present and in the future. That planning is a theme of this series of conferences is not surprising for IIASA. This is one subject matter which is crucially important for all societies, one in which both socialist and non-socialist countries can learn a great deal from each other, and one in which international activities will play an increasing role in the future.

Let me say a few words on how we decided on the TVA. It was about a year ago that we decided to inaugurate a series of conferences on Retrospective Case Studies of Integrated Planning Projects and I began searching for a suitable initial case. I asked Dr. Ananichev, a senior administrator of the USSR Committee on Science and Technology if he knew a suitable institution in the United States for such a case study. We discussed major US Corporations, IBM, General Motors, US Steel and so on but none of these seemed suitable for our purpose. It was Dr. Ananichev, who enthusiastically suggested the TVA. I approached the US National Academy of Sciences and asked the liaison committee to think about the desirability of featuring the TVA experience and, if they were favourable to the idea, to sound out the TVA chairman, Mr. Aubrey Wagner and the General Manager, Mr. Lynn Seeber. Their response was so immediate and so enthusiastic that it became infectious, and so here we are together in Baden ready to steep ourselves in this fascinating case study.

Our Council Chairman, Professor Gvishiani, Deputy Minister of the Soviet State Committee on Science and Technology, and I discussed at length the philosophy of this series. First of all, we wanted to share experiences of planning efforts in socialist, non-socialist and mixed economies. Secondly, we wanted to use this medium to bring the scientist and systems analyst closer to the practitioner and user of systems analysis.

Professor Gvishiani and I decided on the format of this series. Each conference would concentrate on one case study. Papers would be distributed in advance, and wherever possible, each paper would have two discussants: one discussant from the scientific staff of IIASA, the second discussant from a practitioner representing a contrasting ideological viewpoint. Thus in this Conference we shall call on Soviet experts, as well as experts from other socialist countries, to discuss these papers. The aim is to examine similarities as well as differences. In no way, whatsoever, is this to be interpreted as a contest between systems. To think so is to miss the spirit of IIASA. There is so much that we can learn from each other. We can profit both from mistakes as well as successes and I congratulate the TVA Authorities for their willingness to be reviewed by such a varied and distinguished audience.

At our next Conference in this series we shall reverse the roles. We shall look at an integrated planning case study of the USSR and have discussants primarily drawn from the capitalist countries. Once again the spirit will be one of learning from each other, which is one of the philosophical cornerstones of our IIASA experience. And if I can be a bit immodest, I believe this spirit is working well within our Institute.

On behalf of IIASA, and I am sure on behalf of this audience I want to thank Mr. Seeber and his associates from the TVA for their dedication to this project. They have invested a great deal of time, of effort, and of money to make this Conference possible. We are indebted to you all.

This Conference will cover a wide spectrum of topics and issues. The audience here is also a very heterogeneous one so I expect the coverage of topics cannot please each one of you. In some cases there will be too much detail and in others not enough, depending on the viewpoint of the listener. However, we have a week to discuss these issues--both in formal plenary sessions and in technical sessions, and at lunch, over cocktails, at Heurigers, and in strolls through the Baden countryside.

Now many of the questions you pose may not be answered in depth. After all, we have with us today just a few of the researchers and staff members of the TVA. But we should not look at the experience of this week as the final involvement of IIASA with the TVA. We hope that at the end of this Conference, IIASA represenatives will discuss with Mr. Seeber and his staff, ways of continuing our joint interests. Sometime after the Conference we will bring out a set of Proceedings, which will include the papers presented here, the remarks of discussants, and abbreviated version of the open debate, and, in addition, selected written contributions by our participants and post-Conference reflections by members of the TVA who could not be here today. Perhaps a selected group of IIASA representatives may wish to pay a visit to the TVA. So, we should view this week's Conference as part of potentially more extensive collaboration between IIASA and TVA.

Now a word to our discussants and audience. Mr. Seeber assures me that he welcomes the opening of a dialogue and that we should feel free to criticize. I hope that our criticisms will be constructive in tone. I ask you also to keep in mind that these papers were not prepared by academics writing for scholarly journals but by members of an ongoing organization with day-to-day operating responsibilities. Our guests have worked under severe time pressure and have fulfilled their obligations admirably and on time. The prepared papers have been distributed widely and translated into several languages. Having the perspective of what happens at other international conferences, I am very impressed.

Let me take this opportunity also to express my thanks to the US Academy of Sciences, which has worked diligently as a liaison between IIASA and the TVA. Mr. Hinote, of the TVA, was responsible for coordinating the activities on the TVA side, and Professor Knop, from the German Democratic Republic and leader of our Large Organizations Project was responsible for coordinating activities on IIASA's side.

I would like to mention just a few names of our distinguished guests today. We are honored by the presence of Ambassador John P. Humes, the US Ambassador to the Republic of Austria, of Ambassador Porter from the US Mission to the IAEA, of Dr. Lisitsyn Deputy Chairman of the State Planning Committee of the Russian Soviet Socialist Republic, of Dr. Raman, Chairman of the State Planning Committee of the Latvian Soviet Socialist Republic, of Dr. Dobell of the Canadian Treasury Board Secretariat. From the Czechoslovak Socialist Republic we have Diploma Engineeer Pavel Mejerski, Deputy Minister of Technology and Investment, Dr. Rendl from the Office of the Prime Minister, Dr. Nikolai Slocha, Vice Minister of the State Planning Committee and my dear friend Dr. Vasko, our Council Member from Czechoslovakia. We also have with us today Mr. Jaskowiak, the Vice Minister of Agriculture of Poland, and we are delighted to have our Council Member from Poland Prof. Kulikowski and Prof. Straszak, Director of the Institute for Management and Control. Also here today is Engineer Uzanov, from the National Center for Cybernetics and Computer Techniques in Bulgaria and Prof. Dr. Kalweit, the Vice Chariman of the Academy of Sciences of the GDR.

In conclusion, I would like to read to you a telex I have just received from Dr. Philip Handler, President of the Academy of Sciences of the United States:

Attention: Director Howard Raiffa

For more than four decades, The Tennessee Valley Authority has been a unique national research center as well as an enterprise for planning and guiding the development of the entire region of the United States. Through this period, the TVA has been in the forefront of developing a systems approach to research development, serving as a national center for creating techniques in resource-management, water resource development, flood prevention, conservation, electrification, and broad energy considerations.

The TVA Conference should provide many insights valuable to IIASA and those of its related projects which are in relatively early stages of development. At the same time, the unique interaction at IIASA with both your conference guests and resident scientists offers the positive benefit of dynamic interchange for the TVA. TVA's noteworthy commitment to the IIASA Conference reflects the strong support for your work in the United States.

On behalf of the National Academy of Sciences, please extend our best wishes to your participants for a most successful week at IIASA and our congratulations as IIASA embarks upon its third year.

Sincerely,
Philip Handler
President

National Academy of Sciences,
Washington D.C.

79137 IIASA a

VOLUME I

TABLE OF CONTENTS

PART 1

HISTORY AND ACCOMPLISHMENTS OF THE TVA

HISTORY OF TVA

The Tennessee Valley Authority was established by Act of the United States Congress in 1933 to help the people of a region put natural resources to work in overcoming deep-rooted problems of poverty and inadequate opportunity.

The major principles upon which TVA was based had long been known, but the uniqueness of TVA lay in its mission to develop the region's resources as a unified program, rather than as separate and competing entities. For the first time, water, land, minerals, and forests were seen as one interrelated set of opportunities for improving the living standard of a region's people.

In only four short decades, this striking concept of unified resource development has left an indelible mark on the Tennessee Valley region and its people. From a predominantly agricultural region, the Valley has become a predominantly commercial and manufacturing region. From a land pocked with erosion where rivers constantly threatened destruction by flood along their banks, it has become a region of green pastures, expanding forests, and beautiful lakes. Its people have new opportunities for a secure and productive future.

Many of these changes were taking place elsewhere in the United States, but none were as pronounced as in the Tennessee Valley. Many factors of national scope had their influence on the region. None, however, was more profound than the revitalization of the region's natural resources and its effect on the life-style of the people.

Description of the Tennessee Valley Region

The Tennessee Valley region is located in the heartland of the southeastern United States. Including the drainage area of the Tennessee River and adjacent territory served by the TVA power system, it is an area of 2,000 square miles--nearly three times the size of Austria. The 1970 population of this area was about 6.7 million.

The drainage basin of the Tennessee River is a landlocked area of nearly 41,000 square miles and encompasses portions of seven states--Virginia, North Carolina, Georgia, Tennessee, Alabama, Mississippi, and Kentucky. It is a watershed of contrasts. Rugged mountains and green forests dominate the eastern portion of the Valley; rolling hills, open fields, and woodlands lie to the west.

In terms of flow, the Tennessee is the fifth largest river in the United States. Water from its headwaters in the mountains of western Virginia and North Carolina, eastern Tennessee, and northern Georgia flows over 900 winding miles to the mouth of the river at Paducah, Kentucky, where the Tennessee empties into the Ohio River.

Origins of TVA

The TVA idea was the logical outcome of a long ferment of American thinking about the Nation's resources and how to conserve and develop them. Three hundred years of American settlement had been wasteful; resources were regarded as practically inexhaustible.

During the early 1900's Gifford Pinchot, Chief U. S. Forester, came up with a capsule idea that was expressed practically in the TVA Act many years later. Pinchot considered that his own specialty, forestry, was inseparably related to other natural resources--streams and inland navigation, waterpower and flood control, soil and erosion, minerals, fish and game. He concluded that these were not separate problems, but instead "made up the one great central problem of the use of the earth for the good of man."

The thinking of Pinchot and others stimulated the creation in 1908 of a National Conservation Commission representing the states, the Federal Government, and private interests. In an exhaustive report containing an inventory of the resources of the country, the commission pointed to the relationship between the land and water and to the need for unified development.

The concepts and principles written into the TVA Act sprang from these beginnings. They did not come from any neat, preconceived set of theories about politics or government; they evolved from the reflective observations, studies, and experiences of scientists and the informed concern of laymen. They found expression not only in the reports of the National Conservation Commission, but in congressional acts and Presidential messages.

Muscle Shoals, Alabama

The Tennessee River was considered early in the trend toward development of the country's natural resources. In 1899, Congress authorized the private development of a power site on the river at Muscle Shoals in northwestern Alabama, but development was delayed while the Government and private interests wrangled over who should realize the benefits of such a project.

Two nitrate munitions plants and Wilson Dam were eventually constructed at Muscle Shoals during World War I. Immediately after the end of the war, great pressure was brought upon the Congress to dispose of the properties to private interests, either by sale or lease.

Affronted by the attempts of private interests to get the Government property for little or nothing, Senator George Norris of Nebraska proposed in a number of bills that the Muscle Shoals properties be operated publicly. As the proposals for private lease or purchase were rejected, the Norris bills gained increasing support.

By 1933 the climate of the country had changed from the prosperity of the 1920's. The United States was locked in the grip of a great economic depression, and the Valley was one of the nation's hardest-hit regions. Unemployment was the rule rather than the exception. Farms were scarred by erosion. The once great virgin hardwood stands in the forests were nearly gone. Succeeding years had brought destructive floods of increasing violence, but efforts to contain them were limited mainly to the banks of streams, with little effort aimed at control. The power that might have been claimed from the falling waters still ran unused to the sea.

In this setting. Congress passed a Norris bill to create a Tennessee Valley Authority in May 1933. The TVA was an invention in modern government, the creation of an administrative agency which would have the broad responsibility for dealing with the various resources as parts of a single overall problem. The knowledge and technology for dealing with the separate problems of resource development were already in the hands of the foresters, the soil scientists, the chemists, and the engineers. TVA's job was to set them all working together.

The Valley in 1933

Farming was man's chief work in the Tennessee Valley when TVA was established. Of a regional population of some 3 million people, over one-half lived on farms, and of this group, one-half lived on and farmed land they did not own. Six of every 10 workers were employed on farms at an average wage of $190 a year, while the per capita income of the Valley region as a whole was $168, only 45 percent of the national average.

Farm income came mainly from corn and cotton and tobacco--row crops that left the topsoil exposed to the beating rains that fall in winter on uncovered land. Of a total of 14 million acres of open land, about half was abandoned or severely damaged by erosion. On the land which did provide crops, productivity was low.

Manufacturing employment in 1933 made up only 12 percent of the labor force, as compared with almost 22 percent for the Nation. Many of the manufacturing jobs were in low-pay industries. A major restraint on manufacturing in the region was the railroad freight rate structure. Rates on goods manufactured in the South were about 40 percent higher than those on goods manufactured north of the Ohio River, although railroad unit costs were about the same. Conversely, freight rates on raw materials were favorable, leading to the exportation of raw materials from the region to be processed elsewhere.

While income was low, the Valley birthrate was high--one-third above the national reproduction rate. There were 114 dependents (persons under 20 or over 65) for every 100 producers, as against a national average of 90. The lack of non-agricultural jobs and the competition for those which existed, the condition of the land, and the low standard of living created a tide of migration from the region to the northern industrial centers.

The scars on the land also existed in the woodlands. Heavy timber harvests, unchecked forest fires, and general neglect had taken its toll. Too often timber cutters had taken the good trees and left the defective ones to reproduce the next generation--survival not of the fittest but of the unwanted. Timber growth was not sufficient to replace what was harvested.

The Tennessee River was at one and the same time the region's scourge and its greatest opportunity. Major floods were frequent and the Tennessee contributed substantially to disastrous flooding on the lower Ohio and Mississippi Rivers. Little used by shippers, the river carried only 32,700,000 ton-miles in 1933, most of it sand and gravel. The installed generating capacity was less than 500,000 kilowatts, much of it idle.

The human resource of the Valley was also in a state of neglect. Almost 3 percent of the population was illiterate, and the labor force was generally unskilled or of low skills. The people generally suffered from malnutrition; pellagra, tuberculosis, and malaria ran virtually unchecked through the population.

Farmers were tied to antiquated agricultural practices learned from their forebears. Lending institutions were highly conservative, and little capital was available for regional development. State and local governments showed little farsightedness in providing schools, roads, health services, and planning and regulatory agencies to promote and guide development.

The TVA Act

The TVA Act of May 18, 1933, was a response to conditions then existing in the Tennessee Valley region--idleness of investment, unemployment, exploitation, neglect, inefficiency, and waste. More than a remedy, it was a significant step in a national move toward a wider use of resources. It was evidence of the determination, in the national interest, to help a region discover its potential and begin to realize it.

TVA was a new approach, a new idea, toward developing the resources of a region. Its broad goal was not simply the limited objectives of producing and distributing power and producing and selling fertilizer, but the physical, economic, and social development and improvement of the whole area.

The TVA Act provided a general, but clear-cut assignment, to develop the Tennessee River for navigation, flood control, and power, leaving the details to TVA. The act created TVA as a government corporation which would operate in an atmosphere of reasonable autonomy granted by Congress to the TVA Board of Directors.

TVA would plan its programs with respect to the people of the region. Planning would be loose and flexible, resting upon mutual consent and voluntary cooperation to achieve results in action. Implicit in the act was the philosophy that TVA would do its job in a spirit of partnership with the people of the Tennessee Valley region.

In addition, the act was based upon the policy of regional decentralization of resource development functions, and located the offices of TVA within the region. TVA would be a regional Federal agency that lived where it worked.

The relationship between land and water resources was recognized in the statute--that poor water use could interfere with the proper use of land, and improper use of land could interfere with the effective use of water; and that the proper development of one would aid and support the proper development of the other.

The act authorized the use and improvement of the fertilizer plants at Muscle Shoals, and provided both for experiments in the production of improved fertilizers and in the use of new and improved processes, and for plant scale demonstrations of those products and processes.

Finall , the act laid down the fundamentals of a public power program. TVA would establish a comprehensive Federal public power policy for a region based on service to "preference" customers at low rates using publicly-owned facilities and operated on business principles.

Harnessing the River

The TVA Act contemplated (1) the integrated control of the Tennessee River and its tributaries and (2) the use of this controlled system to accomplish a number of purposes.

The Tennessee River was recognized early to have great potential for barge transportation. It was used extensively as a trade route by the American Indians; by the Spanish, French, and English explorers and traders; and by the early settlers from the American colonies. In 1824, John C. Calhoun, then Secretary of War, recommended its improvement as part of a broad program of national waterway development.

Dams on the Tennessee's tributaries would also aid navigation and flood control on the Ohio and Mississippi Rivers. It was hoped that the same works used for navigation and flood control could be employed to generate electric power, and that substantial benefits from the three purposes could be achieved by a single integrated system much more economically than if each purpose were pursued without relation to the others.

As studies progressed, it proved possible to work out a single plan for the economical development of the Tennessee River system so that floods would be tamed, a great system of navigation made possible, and the natural power of the river rendered available. In addition, other important values almost automatically came into being, such as the development of one of the outstanding recreational areas in the United States.

Planning for River Development

The TVA Act of 1933 and later amendments authorized the agency to create and maintain a nine-foot navigation channel along the main Tennessee River. Early TVA planners recognized that seven strategically placed high dams, in addition to existing facilities, would create a series of navigation pools stretching 650 miles and ranging from 302 feet above sea level at the confluence of the Tennessee and Ohio Rivers to 810 feet above the sea at Knoxville, Tennessee. Navigation locks would allow river traffic to step upward or downward through the pools.

Since the Tennessee is a river of extremely variable natural flow, the engineers determined that regulation of the river for controlling floods could best be assured by provision for storing water during the wet season and releasing it during the dry months. This would create a series of dams and storage reservoirs for the headwater tributaries. These reservoirs, primarily for controlling floods, would also aid navigation on the main river by releasing, during the dry season, water stored during periods of heavy rainfall.

The natural fall of the Tennessee and its tributaries also made feasible the installation of turbines for electric power generation. If in the process of operating the reservoirs a conflict arose between power, navigation, or flood control, the TVA Act provided a priority for navigation and flood control, followed closely by the generation of electricity.

Implementing the Plan

TVA began construction of its first tributary dam on the Clinch River northwest of Knoxville, Tennessee, five months after passage of its enabling legislation, naming it Norris for the Senator whose vision and persistence had inspired the dramatic experiment in unified resource development. A few months later, construction of Wheeler Dam was started on the main river. By 1936, Wheeler and Norris were closed, and construction had shifted to Pickwick Landing, Guntersville, and Chickamauga Dams on the main river and Hiwassee Dam on the tributary of the same name.

TVA's solid groundwork in resource development and organization enabled it to shift smoothly and quickly to support the increased electric power demands of World War II. Cherokee Dam on the Holston River and Watts Bar Steam Plant were undertaken on emergency schedules. Cherokee Dam was built in less than 16 months--Norris Dam had taken 3 1/2 years.

By the end of 1941, TVA was closing Cherokee Dam and had four additional dams under construction on the Hiwassee River system. By mid-1942, TVA had 12 dams and a steam plant under construction at the same time--employment reached a peak of 42,000, a total never approached since. By 1945, power generation totaled nearly 12 billion kilowatt hours, more than 6 times the electricity produced in 1939.

Spurred on by post-war demands for power, TVA rapidly closed on its objective of harnessing the Tennessee River. By 1958, the river control system was essentially complete. Thirty-one major dams straddled the Tennessee and its tributaries. These included 20 dams constructed by TVA, Wilson Dam completed by the Federal Government in 1924, four dams purchased from private interests, and six dams owned by the Aluminum Company of America but operated for power by TVA.

Flood Control

The first fruits of flood control were realized a few days after the closure of Norris Dam in March 1936. A flood rolled down the river toward Chattanooga, Tennessee, the Valley city which had suffered most from the raging waters of the Tennessee. The flood gates at Norris were ordered closed and flood stage at Chattanooga was reduced over 4 feet, sparing the city an estimated $2.1 million in flood damages.

The flood control system received a thorough, early test in three successive years--1946, 1947, 19748--when the eighth, ninth, and tenth highest floods in Chattanooga history occurred. Reductions ranged from 10.1 to 12.6 feet and damages averted during the three floods totaled nearly $33 million.

In 1957, the system was subjected to the longest rainstorm of its history--20 days in January and February. Without the protection of the reservoir system, Chattanooga would have suffered the second highest flood of its history. A record flood crest reduction of nearly 22 feet prevented damages of $112 million.

Meanwhile, however, more than a hundred Valley communities along smaller streams faced local flood problems. In most instances it was impractical to construct engineering works to control this localized flooding, so TVA began in 1953 a pioneering program of technical help to these communities in planning long-range flood damage prevention programs, stressing the importance of flood plain regulations in zoning ordinances. Today, about 90 communities have adopted such regulations.

The value of the reservoir system for flood control was demonstrated dramatically in March 1973 when the most intense rainstorm in TVA history dumped 5 to 10 inches of rain over most of the Tennessee Valley, generally in less than 48 hours. Without the regulation of high flows by TVA dams upstream, the Chattanooga stage would have reached 52.4 feet, the fourth highest of record, and over half the city, including most of the business district, would have been flooded with resulting damages of $488 million. Instead, flood stage was reduced 15.5 feet and flood damages averted totaled $465 million.

Navigation

The relatively few navigation improvements that existed on the Tennessee River in 1933 did not provide dependable year-round navigation depths for commercial river traffic. Depths were as little as 3 feet from Wilson Dam to Decatur, Alabama, and were only 1 1/2 feet from Chattanooga to Knoxville.

By November 1952, TVA dams had created an unbroken stairway of lakes which afforded a navigable channel 650 miles long with a minimum depth of 11 feet. TVA had estimated in 1940 that by the end of the 1950's river traffic on the Tennessee could reach 7 million tons annually. That estimate, questioned by skeptics, turned out to be low. In 1959, river traffic totaled 12 million tons of freight with savings to shippers of about $25 million, which was 5 1/2 times the total expense for the waterway that year, including depreciation.

The growing use of this waterway was reflected in the mushrooming expansion of industry along its shores. Where industrial projects in the previous two decades had amounted to only about $60 million, private industry invested $669 million in the 1950's in more than a hundred waterfront plants and expansions, taking advantage of the navigation, power, and improved water supplies. By 1970, cumulative private waterfront investment exceeded $2 billion and river traffic topped 25 million tons.

Restoring the Soil

TVA took its first steps toward healing the eroded and scarred Valley lands near the end of 1933 by consulting with state experiment stations, agricultural colleges of the region, and the U.S. Department of Agriculture on fertilizer needs. It was decided that research should be concentrated on phosphate development.

By late 1934, long-idle facilities at the Muscle Shoals munitions complex were put to work on fertilizer production, and the first electric phosphorous furnace began operation. The next spring, Valley farmers, guided by their extension services and county agents, began applying phosphate and lime to their lands in the first of thousands of farm test-demonstrations. Meanwhile, Civilian Conservation Corps camps began planting TVA seedlings and undertook other erosion control measures.

The people of the Valley, taking advantage of the opportunities afforded by TVA research and developement, took increasing responsibility and initiative in developing their land resources. State agricultural extension services bore an increasing part of the cost of the test-demonstration program. State forest and fish and wildlife agencies greatly expanded their staffs and activities. Demonstration parks originally started by TVA were taken over by the states, and new parks were established. Counties and cities followed suit.

Chemical research at Muscle Shoals continued to enhance TVA's contributions to agriculture. In 1950, two basic fertilizer materials, ammonium nitrate and 48 percent superphosphate, had dominated production at Muscle Shoals. By 1960 these established materials were being replaced by a variety of new high-analysis granular and liquid fertilizers.

Cooperatives and private dealers were enlisted in the task of promoting fertilizer knowledge through a nationwide sales program, supplementing the farm test-demonstrations. The fertilizer industry, which often had viewed TVA as a competitor, began to rely increasingly on Muscle Shoals technology and the expanded fertilizer markets stimulated by the agency's educational work. By 1960 industry had obtained more than 200 licenses to use Muscle Shoals developments.

A 1960 Valley-wide forest inventory also showed that the woodlands, responding to better production and management encouraged by TVA and other agencies, had increased 8 percent in area and 16 percent in growing stock. Forest industry in the Valley had reached a half-billion-dollar annual product value. In five years, this figure would jump to nearly $700 million.

By 1970, the fertilizer reseach and demonstration program included active educational work in 46 states. A total of 323 companies from coast to coast held more than 500 licenses to use TVA developments. At the request of the Agency for International Development, two dozen teams of TVA specialists went to 13 underdeveloped countries to advise them on the use of fertilizers to increase food production, and a series of training courses was held at Muscle Shoals for fertilizer officials from nations that have food supply problems.

Power

While the first dams were being built, TVA's power program got under way, starting with the electricity provided at Wilson Dam. Announcement of TVA's electric rate schedules in 1933 was met with predictions that they were too low to succeed. There was not a market for TVA power, the critics said, because the region was already amply supplied.

City after city voted to buy and distribute TVA power. Except in a few instances, however, they were unable to purchase existing privately-owned distribution systems. Tupelo, Mississippi, with a publicy-owned system, became TVA's first customer early in 1934. The same year, in Alcorn County, Mississippi, the first rural electric cooperative began operation.

Lawsuits and injunctions by power companies and their supporters impeded the wide use of TVA power. The "Ashwander Case" reached the U.S. Supreme Court, which in early 1936 upheld the constitutionality of power sales from Wilson Dam.

While TVA and the Valley awaited the decision, private power interests adopted an "objective rate plan," with the result that rates went down and electricity consumption and the profits of the private electric utilities went up. TVA helped rural and farm people organize cooperatives, and this signaled a new contest. Farmers who for years had begged for service were suddenly besieged by power company salesmen.

In a final court action, the "18 company case," a special three-judge Federal Court upheld the constitutionality of the TVA Act. The companies lost in the Supreme Court, which held they had no legal grounds for the suit.

This decision and the report of a specially appointed Joint Investigating Committee early in 1939 opened the way for the TVA power program. In August of the same year negotiations were concluded for purchase of the Tennessee Electric Power Company by TVA, 22 municipalities, and 11 cooperatives. With this purchase, TVA became the supplier of power for an integrated service area.

Meeting Increased Power Demands

TVA responded to the power demands of the 1940's by bringing hydroelectric plants on line at record construction rates and revamping long-range plans to provide a maximum amount of generating capacity in the shortest possible time.

A normal schedule for Fontana Dam was 5 or 6 years. Working around the clock, TVA crews placed 3 million cubic yards of concrete and had the project producing power in less than three years.

Following the 1940's local municipal and cooperative electric systems embarked swiftly on agressive programs to extend service and expand the usefulness of TVA electricity. In five years the number of consumers increased from 600,000 to 1,100,000 and average home use of electricity nearly doubled.

Rural lines sprung up along gravel roads as more than 311,000 rural residents got electric service for the first time. Eighty percent of the region's farms had service by 1950, compared with only 28 percent in 1945 and only 3 percent in 1933.

As more power became imperative, TVA proposed to build a large coal-fired steam plant to "firm up" the variable supply available from waterpower. Opposition, led by the National Association of Electric Companies, delayed construction for a time, but Congress finally approved the necessary funds and TVA commenced construction of Johnsonville Steam Plant in 1949.

Government need for electric power dominated the period after 1950. Between 1950 and 1957, atomic plants and other Federal installations multiplied their use of TVA power 15-fold, while industrial use continued to climb. At the same time, TVA recognized that the potential for further hydroelectric projects in the Valley was small when compared to these power demands.

In 1959, Congress authorized TVA to sell bonds and notes to raise construction funds for new power facilities. No longer dependent on Congressional appropriations for the necessary funds, the TVA power system was free to build adequate power facilities on an orderly schedule to keep pace with growing use of electricity.

As TVA pushed toward the 1970's, the number of electric customers passed the 2-million mark. Well over a half-million homes were heated electrically, about 30 percent of all homes in the region. Average residential use reached 14,000 kilowatt-hours a year, still double the national average. The homes and farms of the region in 1970 used nearly 200 times as much electricity as they had used in 1933.

Continuing growth in the region's use of electricity required increases in generating capacity of about a million kilowatts. In 1967, TVA began construction of Brown's Ferry Nuclear Plant in north Alabama, with a capacity of nearly 3,500,000 kilowatts in three units.

Environmental Challenges

The growing size of power facilities required more vigorous effort to deal with the environmental effects of power operations. Increasing demands for coal, and the development of giant earth-moving machinery, resulted in expanded strip mining nationally. TVA established demonstrations of strip mine reclamation methods and urged passage of effective state reclamation laws. In 1965, it began including in its contracts a requirement that mine operators supplying strip-mined coal for TVA minimize the initial undesirable effects of this mining and reclaim and revegetate the stripped area.

To maintain air quality around its coal-burning plants, TVA designed generating units it built in the 1960's to include electrostatic fly ash collectors, and began adding them to earlier plants that had less efficient mechanical collectors. New plants were equipped with stacks up to 1,000 feet tall to avoid potentially harmful concentrations of furnace emissions at ground level. In cooperation with the national air pollution control program, TVA began installing experimental equipment at two plants to test processes for removing sulfur dioxide from furnace gases.

TVA strongly believes that national environmental standards must be high and geared to future needs, insofar as those needs can be identified. At the same time, environmental standards that are arbitrarily rigid and restrictive, and not realistically related to human welfare, can increase protection costs to the point where the ability of TVA and others to meet future power demands economically will be seriously impared. TVA is working with other Federal agencies and the national electric industry to find methods of meeting needed environmental values without passing on unnecessary costs to power consumers.

In 1967, the long-time downward trend in the Tennessee Valley's average residential electric rate turned upward, when rapidly-rising costs for fuel, interest, labor, and materials forced TVA and the local power distributors to begin increasing their rates. Even with the increases, however, TVA has the lowest residential electric rates in the nation, with the exception of a few hydro-based stations in the Pacific Northwest.

Recreation and Development

As population growth and leisure activities placed greater demands on recreation resources, TVA assumed a more active role in recreation planning. In 1961, TVA proposed that the Federal Government create a national outdoor recreation center in western Kentucky-Tennessee where an increasingly urbanized people could enjoy nature and learn about resource conservation. A unique site was available in a 40-mile-long strip of woodland between TVA's Kentucky Lake and the lake to be created by Barkley Dam on the Cumberland River, then being built by the U. S. Army Corps of Engineers. The proposal was approved, and by 1970 the land had been acquired for this "Land Between the Lakes" project, opening a variety of recreation and environmental education facilities to the public.

As TVA encouraged state, local, and private interests to develop recreation facilities on the lakes, this secondary "bonus" from reservoir development grew into one of its major benefits. During the 1950's recreation use of these lakes grew from 13 million visits a year to 40 million, and the value of recreation developments and equipment expanded from $20 million to $100 million.

TVA also began putting increasing emphasis on development tailored to the needs of specific areas within the Valley, working through local leadership. By 1966, citizen organizations or special state agencies had been established in 15 Valley areas to advance economic growth through fuller use of all available local resources.

Looking to the Future

The challenges which face TVA today are far more complex than the urgent and obvious needs of the 1930's, but the planned, unified approach to resource development and use still remains the key.

The most basic of these challenges today is to control the environmental impact of an industrialized Valley economy without sacrificing the fundamental improvements in living standards that have been gained over the years. Jobs for a growing labor force must be provided, but without an accompanying increase in air and water pollution, without creating unmanageable city congestion, and without foreclosing the opportunity for more people to live, work, and enjoy the Tennessee Valley in gratifying surroundings.

Developmental planning on a regional scale is the mechanism for charting growth and development in proper perspective. In the Tennessee Valley, most of the past growth has occured in medium-size towns, and development is at a stage where economic growth can still occur without the congestion that has resulted in some sections of the United States. TVA has already begun steps to achieve such quality development.

Through its "Operation Townlift" programs, old, established towns are given planning assistance in local efforts to revitalize these communities. In another approach, TVA will be testing many of the new technologies needed for successful community planning at the proposed new city of Timberlake on Tellico Lake, which will be created by the closure of Tellico Dam on the Little Tennessee River in 1977. Timberlake is designed to be an environmentally attractive town while providing jobs and income, a viable alternative to overcrowded metropolitan areas.

Water resource planning and management continue to be critically important to the region's future. Hydro power from the TVA reservoir system supplies only about 20 percent of today's demand, but this electricity is generated at extremely low cost from the inexhaustible waterpower resource, and much of it is vitally important peaking power generated when demands are greatest.

The Tennessee River waterway is an increasing factor in the region's economic health, with barge shipments setting new tonnage records for the past 12 years running. TVA continues to work closely with state and local organizations to help realize the waterway's full potential, and to improve waterway facilities as the growing use requires.

Many communities with varying degrees of flood problems lie outside the influence of the TVA reservoir system, and TVA's local flood relief program stresses the importance of flood plain zoning for such areas. This program also includes small-scale engineering works in some instances where such projects are economically and physically feasible. Four of these projects--improved channels at Coeburn, Virginia, Oliver Springs and Sevierville, Tennessee, and two flood detention reservoirs above Bristol, Virginia-Tennessee--have accrued flood control benefits of $5.6 million, almost 90 percent of their $6.3 million cost.

In 1974, TVA power sales topped 106 billion kilowatt-hours--about 3 1/2 times as much as 20 years ago. The increasing use of electricity has been the vital lever which made possible more efficient service at lower cost per kilowatt-hour. But today's large demand for electricity also produces new problems in maintaining a reliable power supply, at a cost the consumer can afford, while meeting the stringent environmental protection standards America has established for the 1970's.

To meet the growing demand, TVA now must plan generating plants years ahead of the time they will be needed. Unit 1 of Browns Ferry Nuclear Plant is now in commercial operation. Additional nuclear power plants are now under construction or planned on the TVA system to help meet the region's growing power demand through this decade.

Nuclear power will be an important new source of the future, but uranium reserves will be exhausted in a matter of decades without a more efficient way of using them than the existing generation of nuclear plants. A new kind of reactor, the fast breeder, offers the hope of extending the uranium supply to centuries.

The first large-scale breeder reactor power plant in the United States will be built on the TVA system at a site near Oak Ridge as a national demonstration project sponsored by the Atomic Energy Commission and the electric power industry. TVA and Commonwealth Edison Company of Chicago, Illinois, have jointly established a project organization to build and operate the plant. The project is expected to be completed in the 1980's.

Beyond the fast breeder is the prospect of electricity generated through thermonuclear fusion. Other possibilities for future energy supply lie in the synthetic production of crude oil, the gasification of coal, and solar energy.

TVA is supporting research in some of these fields and is participating in the organization of a new national electric utility program to provide financial support for power research and development on a far larger scale than past industry efforts.

Despite all the advances in fertilizer research and development since 1933, there are still opportunities for equally valuable improvements in future fertilizer products and processes. Work in coming years at the TVA National Fertilizer Development Center at Muscle Shoals is expected to include new products offering still higher plant nutrient content than today's materials, new nitrogen fertilizers that can be used more efficiently on crops with less hazard of stream pollution, better manufacturing techniques, and more effective ways for the industry to control air and water pollution in fertilizer production.

TVA has moved to meet the growing environmental challenge both in its regional work and in its own operations. TVA is presently involved in a major expansion of its program for upgrading air pollution control facilities at its coal-burning steam plants. In addition to improvements in fly ash control equipment, this program includes special air and weather monitoring installations at several plants for a new system of operational controls to keep ground level concentrations of sulfur dioxide in the vicinity of these plants within ambient air standards.

TVA is spending about $42 million to install a full-scale experimental "scrubber" system for sulfur dioxide removal on a 550,000-kilowatt generating unit at Widows Creek Steam Plant to help in developing this technology.

Work is also in progress on a $45 million cooling tower system for Browns Ferry, and these and other measures are being planned for other new power plants as necessary to permit reliable operation within water temperature limits set for condenser water discharges. In cooperation with the U. S. Environmental Protection Agency, construction has also begun at Browns Ferry on a research facility to measure the effects of temperature on aquatic life under controlled conditions. Experimental work has begun on beneficial uses of warm water discharges in cooperation with Oak Ridge National Laboratory.

TVA strip mine reclamation requirements have been strengthened through experience. New provisions include a requirement that detailed reclamation plans be submitted in advance, and approved by reclamation specialists, before bids for strip-mined coal are considered.

TVA has undertaken a variety of experimental and demonstration projects to help deal with the growing problems of trash and junk. Assistance is being provided to local governments in closing dumps, establishing sanitary landfill operations, and setting up solid waste collection systems to serve rural areas. A TVA program to help establish local junk car cleanup programs has attracted national attention.

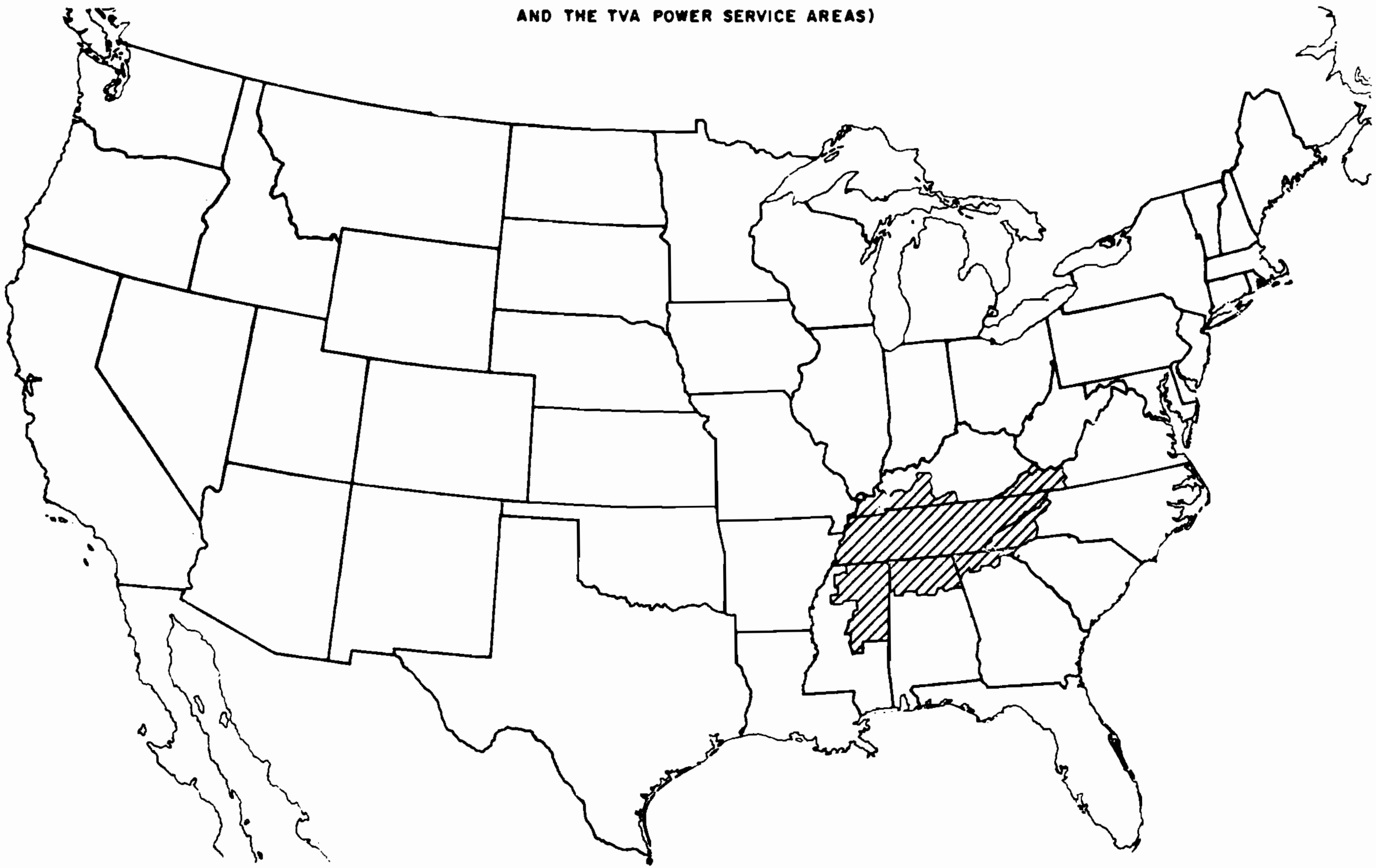
People in Partnership

The needs of the Tennessee Valley region and its people have changed in 41 years, and the Congressional leaders who drafted the legislation creating TVA could not have foreseen a breeder reactor project or sulphur dioxide research. But they did have the foresight to create a unique approach to unified resource development--one that means as much in meeting the challenges of the future as it did in helping overcome the problems of the 1930's.

But the wise use of resources depends on people, and the partnership between TVA and the people of the Tennessee Valley has been, since the very beginning, a team effort that has helped to provide new jobs, new hope, and a new and better way of life for the entire region. This partnership has been the Tennessee Valley's greatest resource over the past four decades, and is its greatest hope for the future.

THE TENNESSEE VALLEY REGION

(CONSISTS OF 201 COUNTIES COMPRISING THE TENNESSEE RIVER WATERSHED AND THE TVA POWER SERVICE AREAS)



What Has Been Accomplished

In The First Forty Years

Introduction

In 1933, TVA recognized its job as a job of building--a job of building back the strength of a great region by providing the tools needed to build up a resource base that the region's people could then use to build better lives for themselves and for generations to come.

By applying what was basically a very simple concept--the concept of developing each and every one of the region's resources in a single, unified program--TVA and the people of the Tennessee Valley have been able to reverse the downward economic spiral which existed in the region in 1933.

TVA built a system of dams that makes the Tennessee one of the most useful rivers in the world, controlling its floods and turning its 650-mile-long main stem into a waterway for barge freight. The power harnessed by these dams resulted in an electric system that generates electricity to serve 2.4 million homes, farms, businesses, industries, and other users. TVA turned an idle and obsolete government munitions plant into a national fertilizer development center, giving farmers a tool for building new farming systems that conserve soil and water as they raise farm income.

These resource development programs played a part in bringing striking changes to the Valley region. The improved resource base has enabled the Valley to make a revolutionary transition from a low-income agricultural economy to the present economy in which manufacturing and commercial employment are dominant. As people have moved from farm work to better paying jobs in trade or industry, farming has become more efficient. There are fewer farms, but more of them provide good incomes.

But the need for expanded job opportunities in the region is not over. Even with today's low birth rate, population projections indicate the region may need another 1,400,000 jobs by the end of this century to accommodate a 50 percent increase in the labor force. That need must be met, but without the metropolitan congestion and extensive environmental deterioration which has accompanied industrialization in other parts of the United States.

The accomplishments of the people of the Tennessee Valley over the past four decades are fitting testimony to the concept of unified resource development.

TVA strongly believes that adherence to this concept in the future will further the development of the region without sacrificing the hard earned gains of the past.

From Agriculture to Industry

The most dramatic change which has taken place in the Tennessee Valley over the past 40 years has been the shift of the region from a low-income agricultural economy to the industrial-based economy of the present. In 1933, only 12 percent of the region's employment was in manufacturing, but since that time the number of manufacturing jobs has increased almost five times and industrial employment now occupies one-third of the region's work force.

At the same time, agriculture has been revitalized with 6 percent of the work force now on farms producing more food and fiber than 63 percent of the work force did in 1933. TVA-developed fertilizers have transformed idle land to lush pastures, which in turn hold erosion to a minimum. The basic row crop agriculture of the 1930's has given way to an emphasis on livestock farming. As a result, the value of farm products marketed by Valley farms grew by almost 675 percent over the period 1939-1969, to more than $850 million annually. Livestock and livestock products account for 75 percent of this total.

The impact of this agriculture-to-industry transition on personal incomes in the region shows a steady gain in relation to the national average. Total personal income was $25.6 billion in 1973, almost 30 times the 1933 figures; over the same period, national personal income increased about 20-fold. The region's average annual per capita personal income was $168 in 1933, about 45 percent of the national average. In 1973 it was $3,366, about 75 percent of the national average and 20 times the average for the region in 1933. Over the same period, the national average has increased 13-fold.

Developing the River

TVA pioneered in building the first system of multiple-purpose dams and reservoirs to control a river the size of the Tennessee. Today, 33 major dams harness the river and its tributaries for navigation, flood control, and the generation of electric power to a degree without parallel. Barge freight tonnage has increased from less than a million tons in 1933 to 29 million tons in 1973; savings to shippers on shipments using this waterway total $755 million over this period, over 4½ times the operating costs for the waterway.

From 1933 to 1973, private industry has invested more than $2.4 billion in Tennessee River waterfront plants, terminals, and distribution facilities. Ninety-nine percent of this investment has occurred since the 9-foot navigable channel was completed on the main stream in 1945. These new and larger industries have provided more than 41,000 jobs for area residents, and many thousands more indirectly in the supporting economy.

The same river control system that provides for navigation on the Tennessee also holds the once-devastating floodwaters of the region in check. Cumulative flood damages averted by the TVA reservoir system in the Tennessee and lower Ohio and Mississippi River basins exceeded $1.2 billion in 1973, nearly five times the total cost of the flood control system. These benefits also include $150 million in increased values on six million acres of land protected along the lower Ohio and Mississippi Rivers.

Rebuilding the Forests

Three-fifths of the Tennessee Valley is forested, and forestry has been an interlocking part of the unified development of land and water resources. In 1933 the Valley's virgin timber stands were nearly gone, and most forest land was in poor condition from years of overharvesting, unchecked fires, and general neglect.

TVA established a forestry organization to work with the states, landowners, and industries to reverse these trends. The general goals of TVA's work in forestry include optimum watershed protection, forest productivity, and environmental enhancement of the region. TVA works with the state forestry and agricultural agencies to encourage reforestation, forest protection, better timber management, more efficient wood utilization, and strip mine reclamation. Other work is directed toward development of superior trees through genetic research.

Reforestation in the Valley totaled almost 1.3 million acres last year. Product values have grown from $100 million in 1937 to about $1 billion in 1973. Jobs in the forests and in forest products industries provide employment for more than 50,000 persons with annual payrolls exceeding $250 million. Of the Valley's 21.6 million acres of forest growth, less than 80,000 acres are without fire protection, and the rate of burn has been reduced from 10 percent to 0.12 percent.

Fertilizer Research

Modern fertilizers account for a major share of today's farm output, but four decades ago fertilizer use in the United States was low. The country's plant nutrient use averaged less than 1.4 million tons a year. The fertilizers that were available were low in analysis, averaging about 18 percent plant nutrients. Most were of poor physical quality, tending to be dusty when handled and to cake when left in bags for several weeks.

TVA has had a big hand in changing this situation. Congress specified in the TVA Act that the agency's fertilizer program be a nationwide effort, and TVA established the National Fertilizer Development Center at Muscle Shoals, Alabama--the Nation's primary source of new fertilizer technology. New products and new production processes developed at NFDC and introduced to farmers and the fertilizer industry have helped to raise agriculture to new levels of output.

The research embraces work in laboratories and experimental plants and testing in greenhouses and field plots. Educational programs in cooperation with farmers, land-grant universities, and the industry have sped new developments to those who can use them. Results show up in several ways:

--The fertilizer industry has changed from a byproducts business to an aggressive multimillion dollar chemical industry.

--The average nutrient content of fertilizers has more than doubled--to over 43 percent. This means big savings to farmers since transportation and handling account for 30-40 percent of the final cost of fertilizers.

--TVA's development of higher analysis products and improved manufacturing processes, plus educational programs with industry and farmers, has helped cut the cost of plant nutrients to the farmer.

--American farmers are using more fertilizer than ever before. Plant nutrient use now totals more than 17 million tons a year, 12 times what it was 40 years ago.

Products that are the backbone of the American fertilizer industry today--such as triple superphosphate, ammonium nitrate, and diammonium phosphate--were brought to the forefront largely through TVA programs. Most of the newer products coming on strong today--fluid fertilizers, superphosphoric acid, the polyphosphates--either stem from TVA research or have been strongly influenced by it. Other advances are in the making.

To insure that the new technology will be available to all interested users, TVA patents its process developments. It then grants royalty-free, nonexclusive licenses to any company that wants to use a TVA-developed process. More than 480 plants in 39 states are using TVA processes. Technology developed at Muscle Shoals is used somewhere in the production of three-fourths of all fertilizers made in the United States.

The National Fertilizer Development Center continues to create new products for farmers and to introduce more efficient production methods to the industry. American consumers are the primary beneficiaries of the resulting improvements in agriculture. However, the advanced technology and its agronomic and economic application have become significant tools for assisting developing nations toward agricultural self-sufficiency and improved levels of nutrition.

The Recreation "Bonus"

Recreation, once barely considered as an economic factor in the development of the Tennessee Valley, is today a major business. More than 60 million recreation visits are made to TVA lakes each year. The value of recreation-oriented developments on TVA lakes is estimated to be $437 million.

When the dams of TVA turned the river into a series of lakes, the fish population multiplied at least 50-fold and is presently estimated at about 60,000 tons. Sport fishermen each year catch 7,000 to 10,000 tons of game fish; commercial fishermen take another 3,700 tons of rough fish. The economic impact of the sport and commercial fishing now runs close to $95 million a year.

TVA has provided more than 190,000 acres of land and water to Federal and state agencies for waterfowl management areas and refuges. Very few waterfowl wintered in the Valley before TVA. A recent winter survey showed some 93,000 geese and 340,000 ducks came to TVA reservoirs.

The Tennessee Valley states now have alert, progressive park commissions and fish and game bodies where none existed a generation ago. Most of the Valley states also have strong, on-going programs in the field of conservation; their planning organizations rank among the best in the United States.

Rural Electrification

The early formation of rural electric power associations in the Tennessee Valley has helped guide the way for a national program of rural electrification, which was established a year after the Alcorn County EPA in Mississippi began distributing TVA power in June 1934. In 1933, only 3 percent of the farms in the Tennessee Valley had electricity, but today the figure is nearly 100 percent.

Emphasis is now being placed on helping the farmer make more effective use of electricity in ways that will increase his income, ease his physical tasks, and provide more comforts in his home, with particular emphasis on electrical safety. Workshops for high school vocational teachers are being held in the Tennessee Valley to further implement these programs.

One of the major efforts to demonstrate sound planning of modern electrical equipment and practical installations of this equipment is the Electrofarm Program. Cosponsored by TVA and power distributors, this program enables farmers to see and study good electrical farm planning and efficient ways to use electricity at nearby farms. There are some 265 Electrofarms scattered throughout the TVA power service area.

Low Rates and High Use

In the 1930's, many in the privately-owned electric industry held that power rates could not be lowered until costs were reduced. The authors of the TVA Act believed that if rates were made low enough, electricity would be used in abundance and this would lead to lower unit costs. But rate reductions would have to come first.

This low-rate, high-use theory initiated by TVA four decades ago has proved to be an outstanding success, both in its contribution to economic and social progress and in its financial results. The TVA Act requires the power system to be financially self-supporting, and since the very early years it has met this test.

Before TVA, rates were about the same in the Valley as elsewhere in the United States and the average home consumption was also about the same--600 kWh per year at about 6 cents per kWh. In 1974, the average residential rate in the Valley--about 1.5 cents per kWh--is about 60 percent of the national average. Residential use--now some 15,080 kWh per year--is about twice the national average.

Faced with today's need to conserve energy resources, TVA has placed increasing emphasis on efficient use of electricity in its consumer information effort. TVA and the power distributors have for some time offered advice to all power customers, architects, contractors, and engineers on efficient ways to install and use electric equipment and appliances.

This consumer information effort, ranging from the proper selection, use, and care of a kitchen appliance to fully adequate home and building insulation, seeks to improve energy conservation and save the consumer money on his power bill. Industrial customers are encouraged to conserve energy and save power costs by improving the power factor in their plants. And because it is twice as efficient as any other heating system, the heat pump is strongly encouraged for use in new housing and commercial buildings.

The Future

The future of the Tennessee Valley is indicated by trends already in evidence.

Industrial development has taken on characteristics which are unique in the country and which hold the promise of indefinite expansion while avoiding the problems of super-size urbanism which have beset many other areas of the industrialized world. Job growth in most of the United States has experienced its greatest increase in metropolitan areas. The reverse is true in the Tennessee Valley, as 80 percent of the new manufacturing jobs and over half the other new nonfarm jobs have been created outside its major cities.

A number of factors have contributed to this advantageous situation in the Valley. Abundant water of good quality is available throughout the length of the developed river. Electric power has been extended into the countryside as well as the cities at virtually the same low cost. Fertilizer science and its application on farms have made agriculture more prosperous and expanded agribusiness.

Perhaps most significant, however, was the unexpected attraction of private industry to the "transport complexes" created by the extension of the United States' inland waterway system far into the Tennessee Valley heartland. With this development, the region achieved a new flexibility in transportation. Its significance is underlined by the fact that waterborne commerce to and from the Tennessee Valley now reaches ports in 21 states in the eastern continent.

An accompanying development outside the region has been the growth since World War II of population and general economic activity in areas to the south and southwest of the Valley. Where before the region was fringed by industrial activity and metropolitan markets primarily to the north and to a lesser extent to the east, now the Valley is virtually surrounded by regions of dynamic growth.

Encouraging Population Dispersion

The Tennessee Valley region has become a strategic location in mid-continent, its new transport flexibility giving it new capability for assembling raw materials for industry and serving newly accessible markets economically. The potential arising from these circumstances relates not only to industrial development but to a large growth in tourism attracted by the appealing combination of mountains, lakes, and forests.

New job opportunities are being created in a manner that disperses population growth rather than concentrating it in the larger cities. The problems of metropolitan areas are thus avoided or diminished. Moreover, as economic growth continues in the region, stemming outmigration, the problems of the great population centers to the north are diminished to that extent.

TVA encourages this trend of dispersion and has initiated a number of programs designed to that end. One important thrust arises from the fact that transport complexes, where they do not now exist, often can be created. The construction of Melton Hill Dam and Reservoir in the early 1960's extended the Tennessee waterway to the foothills of the Cumberland Mountains. An industrial site on this channel has now attracted industries demanding high skills and therefore contributing substantial payrolls to the local economy.

On the Yellow Creek embayment of Pickwick Reservoir in Mississippi, a port facility has been completed recently along with a rail spur connecting that part of the waterway to a trunk railroad system. Adjacent land has been acquired by the state for industrial purposes, all in a predominantly rural area.

The Tellico Dam and Reservoir project will extend navigation some 33 miles up the Little Tennessee River and open several thousand acres of shorelands to potential industrial development. The project is scheduled for completion in 1977.

Upgrading Outlying Areas

One important impediment to the achievement of these developmental goals in the Tennessee Valley region has been the lag in the growth of trades and services in the outlying areas. For the individual, this may mean a lack of a wide spectrum of necessities and conveniences normally available in the cities, such as good doctors and hospitals located nearby. For the businessman, there is another range of services needed--attorneys, banking facilities, insurance, and many others. A third area of need concerns the adequacy of government services such as fire and police protection, or good schools and adequate water and sewage systems.

One of the principal programs designed to respond to these needs has been TVA's initiative to create new towns and modernize older ones. The shores of Tellico Reservoir will be the setting for a demonstration in new community development associated with the major industrial, recreational, and residential growth expected after the completion of Tellico Dam.

At the request of local planning agencies, TVA is sponsoring a water-oriented community which, over a 20-year development period, is expected to house some 30,000 people. The creation of Timberlake will depend on a partnership involving the closest cooperation between many local, state, and Federal agencies, as well as private developers and investors.

TVA's "Townlift" program seeks similar objectives by making new towns out of old. Many of the region's small- and medium-size towns were built in another era and are unequipped to serve the new industry, commerce, and tourism which is taking place in the region. The Townlift program is designed to unite both the public and private sectors of the community and state in defining the opportunities available and revitalizing efforts to seize those opportunities. Generally, Townlift assistance involves multidiscipline teams consisting of city planners, architects, economists, and engineers who have expertise in urban problem-solving. Last year, 37 communities received Townlift assistance.

Problems of water supply in local areas were pioneered in the 1960's in the Beech River area in west Tennessee. Dams built to check serious local flooding created reservoirs which are being used not only for recreation but as a source of water for cities and industries. Two dams are under construction on the Duck River in middle Tennessee where flooding is also a problem and water shortage in the future threatens industrial growth. Four counties in the area have begun, with Federal help, a water grid system which will link five major cities in the area and serve rural areas as well, relying on the new reservoirs as a source of supply.

Improving Government Services

In the field of government services, the greatest progress is being made in assisting counties and other rural jurisdictions in devising systems for collecting and disposing of solid wastes. The sanitary landfill, supervised by state health agencies, has been the chief means of disposal. TVA is presently supplying technical assistance on landfill design and operation to cities, counties, and planning and development districts in all seven Valley states.

Adequate health care is one of the most needed services in rural areas, yet one of the most difficult to provide. In the 1930's, malaria was a major barrier to development of the region's human resource. The mosquito-borne disease affected a third of the area's population near some of the swampy areas along the Tennessee River. TVA organized a cooperative program with state health agencies to suppress the malaria mosquito, educate the public about the disease, and promote protective measures and treatment. As a result, malaria not only failed to increase, it began to decline and finally vanished.

The emphasis of this program is on natural control methods--eliminating breeding spots by preparing shorelines before new reservoirs fill, removing water from low areas, mowing shoreline vegetation, and fluctuating reservoir levels in a way that interferes with mosquito habitats. In areas where chemical control is needed in addition to these naturalistic methods, TVA uses a degradable larvicide that has no detectable side effects on fish and wildlife.

TVA also has a number of sophisticated "tools," acquired for its own use, which it is now using in cooperation with public and private medical organizations in the region to extend health care to people who do not now have it. The most extensive adaptation of these "tools" has been demonstrated in cooperative projects with Vanderbilt University medical students and other groups who examine hundreds of persons, using a TVA-designed Mobile Health Clinic, at community "health fairs" in areas where medical care is inadequate.

Conservation Education

One of TVA's main areas of education concern has been the field of conservation education. The present-day phase of this work began 10 years ago with the creation of Land Between The Lakes, a 170,000-acre outdoor recreation demonstration in western Kentucky and Tennessee. A thousand of these acres is devoted to a conservation education center where teachers can bring their classes for a week of study in an outdoor setting and where teachers can learn ways of teaching in the outdoors, using their own school campuses or even vacant lots at home as their outdoor classrooms.

The success in Land Between The Lakes has led to a Valleywide TVA program offering assistance and guidance to school systems and community action groups who are interested in setting up environmental education programs and facilities. One of the most successful of these projects has been in the Bear Creek watershed in northwest Alabama, where a cooperative environmental education program for a 14-county area has been formed. Similar efforts are being made with the

Elk River watershed area in south central Tennessee. Planning assistance also is provided for school systems outside the Tennessee Valley.

Improving the Land Resource

Agriculture and forestry are part of the general effort to capitalize on the region's growing advantages stemming from greater accessibility to markets and improved transportation. Rugged terrain and other factors limit the size of farms, and most of them are too small for large-scale economic production. The average farm in the Valley is about 115 acres.

While encouraging consolidation of farms wherever possible, TVA at the same time encourages specialty crops and livestock which can utilize small acreages effectively. Western North Carolina has been most successful in this specialty field. A multimillion dollar annual business in trellis tomatoes has gained wide acceptance. The North Carolina Extension Service has broadened this program to include strawberries and blueberries and, on some of the mountaintops, Fraser fir for Christmas trees and hybrid rhododendron for suburban landscaping.

At Muscle Shoals a greenhouse has been built to conduct small-scale studies of the potential for using waste heat from electric power generating plants to grow horticultural crops. Use of warm water also extends the growing season for catfish, improves feed utilization, and shortens the time required to reach marketable size. TVA has been doing basic research in this area at its Gallatin Steam Plant for the past four years, and results are promising.

One of the important aspects of TVA's forestry program is designed to restore the magnificent stands of hardwood species for which the region was once famous. In the early years, TVA studies centered on black walnut, Chinese chestnut, filbert, Persian walnut, pecan, hickory, honey locust, persimmon, and jujube. Later the emphasis shifted to development of superior pines. Others have taken up the work with pines, and now TVA scientists are concentrating on research in tree genetics to develop superior tree planting stock in high-value hardwood species.

Continuation of the Unified Approach

Just as it was in the past, the thrust of the future in the Tennessee Valley involves the full range of resources--water and land, the river and its working power, along with the soil and its great productivity. At the same time, the interrelationship of the problems confronting the region today makes the need for an integrated, unified approach to the solution imperative. Thus, TVA's unified approach to resource development, tested by four decades of experience, is more vital today than ever before.

TVA's pioneering efforts in multiple-purpose river development, in electric power generation and distribution, in fertilizer development and all other resource-related fields, have established the framework for planned economic growth. It remains to create the kind of high-quality environment that will promote fullest development of the human resource in an emerging industrial society.

IIASA DISCUSSION PAPER

Z. Kaczmarek

I have great pleasure in opening, on behalf of IIASA, the discussions at this very interesting and valuable Conference. The Conference is especially interesting to me because, as we all know, water problems played such an important role in the development of the Tennessee region. I am concerned with water resources here at the Institute. Of course it is rather difficult to discuss in general the historical aspects which were presented here, so let me then limit myself to one general remark, and also to some questions to you, Mr. Seeber.

In keeping with the spirit of IIASA and its Charter, methodological research and development within several Institute Programs spring from and are aimed at the word "application". It seems to me then, that the retrospective studies and analysis made at this TVA Conference could be of great benefit to IIASA itself and also to the National Member Organizations. Let me express the hope that this Conference which is the first on regional development planning, will be successful and that it will also be followed by similar presentations made by other national organizations dealing with large-scale planning projects.

Now the questions; my first question is concerned with the following problem: the regional efficiency approach takes into account only the aggregate benefits and costs for the region as a whole. On the other hand, there should be, and there probably are, several conflicts between different types of activities, for example, between plants and water supply or energy generation. Another example is fertilization and quality of environment and so on. Such conflicts are addressed directly to the question of the distribution of benefits and costs between various organizations or groups. How are such conflicts analyzed and solved in the Tennessee region?

My second question deals with the relationship between the Tennessee region and the "external world". There is no doubt that there should be various constraints and influences in the Tennessee Valley caused by the political, social and economic situation in the US as a whole as well as in the entire world. How are these influences taken into account? How has the external world influenced planning and implementation of the TVA resource development program? I think we have an opportunity to discuss some details at the technical sessions and for this reason I would like to finish now and go on to these problems.

TVA COMMENTS ON DISCUSSION BY Z. KACZMAREK

Because of its unique unified resource development responsbility within the Tennessee Valley region, the TVA is the only organization of its kind in the United States specifically created to apply the principles of a balanced perspective to the myriad, interlocking problems man faces as he attempts to work with, rather than against, nature. The TVA approach is one of balance--an approach that seeks to provide the greatest good for the greatest number of people over the longest time.

It has been TVA's philosophy throughout its history that whenever legitimate needs conflict, an effort must be made to arrive at a decision that is in the best interest of the overall public good, not just a select group. This is accomplished not only by a careful analysis of the respective benefits and costs of each potential action, but by the consideration of <u>all</u> factors.

For example, the TVA has always looked at water resource in the Tennessee Valley on a case-by-case basis, trying to arrive at a decision as to which use is the highest and best for each stream and in the interest of the overall public good. This balancing results in a decision to not build a dam on some streams, and to build dams on others. In several instances, the TVA has been strongly supported by the citizenery of a particular area to construct such a project, but after balancing the overall benefits, the decision was reached that a dam was not justified. In cases such as this, the TVA has worked with the local groups to find other measures for meeting water resource needs.

"External" Influences on the TVA

As a corporate agency of the Federal Government, the TVA is directly accountable to the Congress of the United States, and is both directly and indirectly influenced by the actions of the legislative body. The Senate must confirm appointments made to the TVA Board of Directors by the President, and the Congress has the right to alter or amend the TVA Act, which it has done on several occasions.

In 1959, the financing of the power operations of TVA was drastically changed by amendment to the Act authorizing TVA to issue electric power bonds to finance additions of generating and transmission facilities to meet increased demands for electric power. Prior to the 1959 amendment, capital for additions to the system had, for the most part, come from appropriations and reinvestment of power revenues. The amendment provides TVA with full financial freedom to plan ahead, finance, and build additions to the power system as they are needed. At the same time, it does not free TVA from the duty of reporting its power plans to Congress and explaining the basis for its judgments to that body.

The congress maintains close contact with the TVA through the budgetary and appropriations procedure. Non-power programs of the TVA are supported by appropriated funds, either wholly or to a large degree. Each year the TVA submits its budget and plans for various projects and activities to the President's Office of Management and Budget, where it is subject to review and change before being presented to the Congress by the President as part of the total Federal budget.

Congress may indirectly exercise its control over the TVA budget by setting a ceiling on all government-wide expenditures for a specific period and will reflect such a ceiling in its review of the TVA budget by making such changes as necessary. The TVA budget is also subject to the appropriations processes of Congress. At hearings before committees, members may subject TVA activities to close scrutiny and the TVA Board and staff members may be closely questioned concerning any aspect of the budget. The actions of Congress, by withholding or increasing funds or including specific directions in the appropriations language, may alter the TVA's proposals.

The TVA's operating program also brings it into contact with many other Federal agencies for the purposes of cooperation and coordination. The TVA is presently conducting studies in cooperation with the Environmental Protection Agency, an independent Federal agency, to compare the feasibility of various processes of sulfur oxide removal from coal-fired generating plant stack gases. Many other examples of cooperation and coordination between the TVA and other Federal units could also be cited.

The TVA Act envisaged a broad spectrum of cooperation with the states and local government agencies in the region, and the authority it provided in this regard has been used by the TVA to build strong relationships with states, municipalities, counties, cooperative associations, and private interests in carrying out the objectives of the Act. The creation of the TVA strengthened rather than supplanted the roles of state and local governments, and this continues to be a primary objective of the TVA.

A cooperative approach to regional resource development has done much to strengthen the position of the state and local government both in the region and in the regional program. Most of the TVA's programs, with the exception of physical plant construction, are dependent upon the cooperation of the Valley's people. They must be convinced, through education and demonstration, that their participation in Valley development is worthwhile. This necessity has influenced the attitudes and practices of TVA personnel at all levels of the organization, with the result that comprehensive development has become a reality.

SUMMARY OF DISCUSSION TOPICS

PART 1

In the discussions which followed the presentations, the following people took part:

W. Kalweit	GDR
H. Kikkawa	JPN
V. Karelin	USSR
K. Newlands	UK
K. Hoenigman	Austria
T. Vasko	CSSR
K. Takeuchi	JPN

The main problem topics discussed were:

- The mechanism for strategy making within the TVA since 1933 for establishing priorities of TVA goals.
- The planning of the TVA goals and concrete performance measures of these goals.
- Authority of the TVA for implementing its plans.
- Research and Development activity in the TVA.
- Resolution of conflicts between different programs of the TVA and, for example, navigation and energy.
- The influences of external socio-economic environment on TVA activity.
- Management of large-scale programs.
- Economic evaluation of large-scale programs (including cost-benefit analysis, etc.).
- Establishment of other federal organizations similar to the TVA.
- Activities of the TVA in the field of education.
- Coordination of annual TVA appropriations and funds with the program plans, including long-term plans.
- Distribution of revenue inside the TVA from the sale of energy.
- Guarantees by the TVA against the danger of future nuclear plants.
- The mechanization of democracy in the TVA.

PART 2

ECONOMIC SUBMODELS OF THE TVA

THE REGIONAL ECONOMY AND NATIONAL RELATIONSHIPS

When the Tennessee Valley Authority was created in 1933 the United States was experiencing its most serious depression. The Tennessee Valley region was probably even more depressed than the Nation and it was frequently referred to as the Nation's economic problem number one. However, to those who visualized TVA, the region's vast human and natural resources, including the river and its potential for development, it was also the Nation's number one economic opportunity. The creation of TVA was one of many programs instituted by the Federal government to relieve widespread unemployment and deprivation. Unlike many of the programs, however, the TVA Act provided not only for an attack upon these immediate problems but also for long-range solutions to the economic problems of the region through regional planning and human and natural resource development programs. It marked the first time in our history that a national commitment was made for a regional approach to the solution of social and economic problems.

The strategy priorities called for the early securing and improving the physical resources along with the production of electric energy and the enlargement of the industrial capacity. However, increased emphasis was also given to manpower and other human resource development programs and to regional and local planning and economic development activities.

Before examining the relative demographic and economic relationships between the United States and the Tennessee Valley region, it should be helpful to look at the physical relationships.

The region of the Tennessee Valley is a 92,000-square-mile area in the southeastern United States. The land base is 3.1 percent of the United States, excluding Alaska and Hawaii. The location and relative size are shown by the map in figure I. Today the region's land base is about 54 percent in forests; 40 percent in cropland and other agricultural use; and 4 percent in urban use. In terms of national perspectives the region contains 5 percent of the Nation's forest land; 3 percent of the Nation's Class I and II agricultural land; and 4 percent of the land in urban type use.

Chart 1 shows some of the principal economic indicators for the Tennessee Valley region and their relationship to the Nation in 1933 and 1973. The first pair of bars reveals that the population of the region has not grown as fast as the Nation and, as a result, the region's proportion of the Nation's total population fell from 4.1 percent in 1933 to 3.3 percent in 1973. Although the proportion of the region's population living in urban areas is not as large as the Nation's, its urban population is growing faster. During the forty years from 1930 to 1970, the population of the region increased by almost 1.8 million to a total of 6.7 million. In 1930, little more than a fourth of the people lived in urban places. Following national trends, this proportion increased each decade to nearly 50 percent in 1970.

Much of the growth has been in the region's smaller- and medium-sized cities. During the sixties the urban population grew two and a half times as fast as the overall increase for the region. The number of incorporated urban places increased by 29 to a total of 184 and their population increased to 46 percent of the region's total. Only seven of these cities have populations of 50,000 or more.

FIGURE I

THE TENNESSEE VALLEY REGION IN RELATION TO THE UNITED STATES

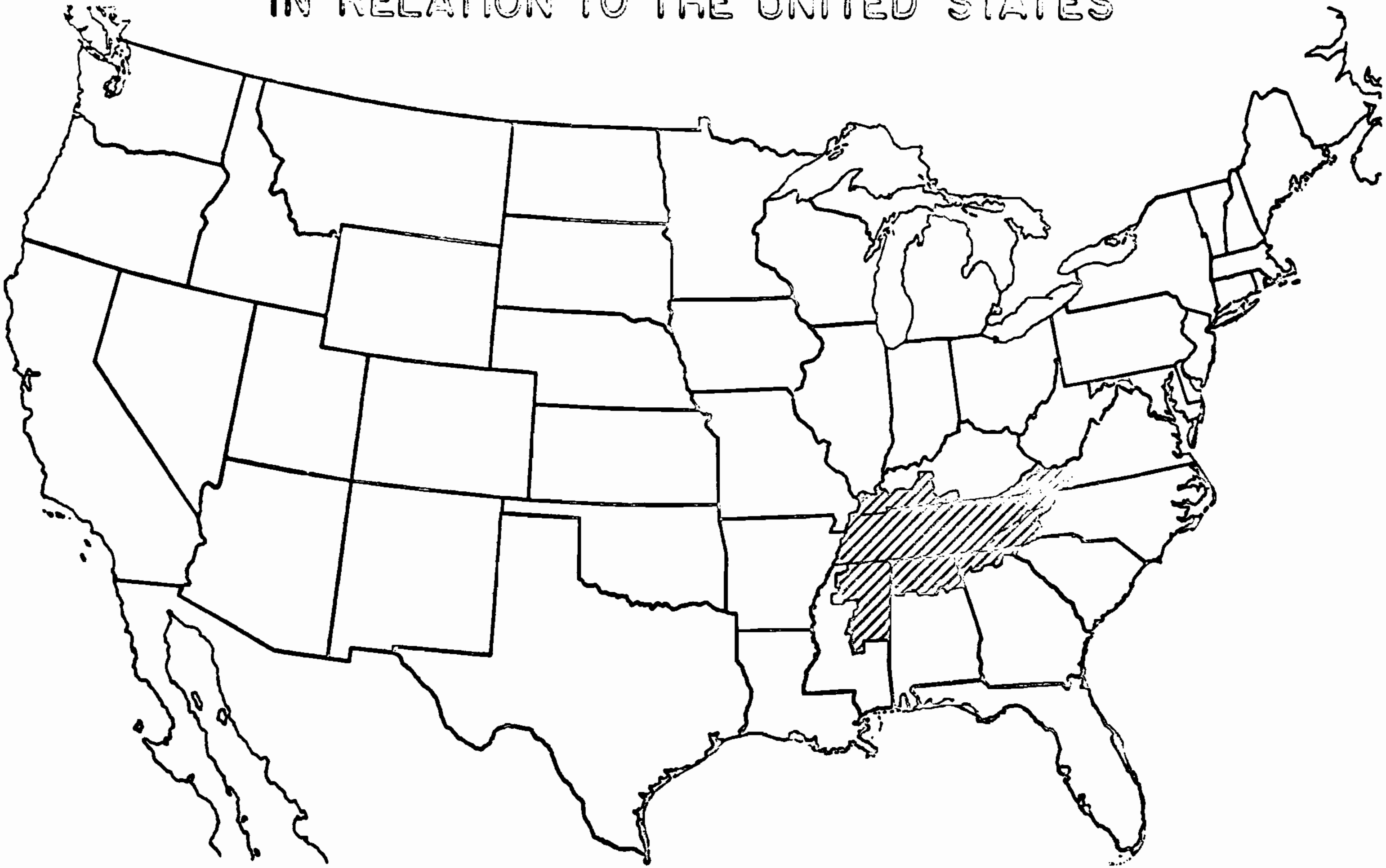
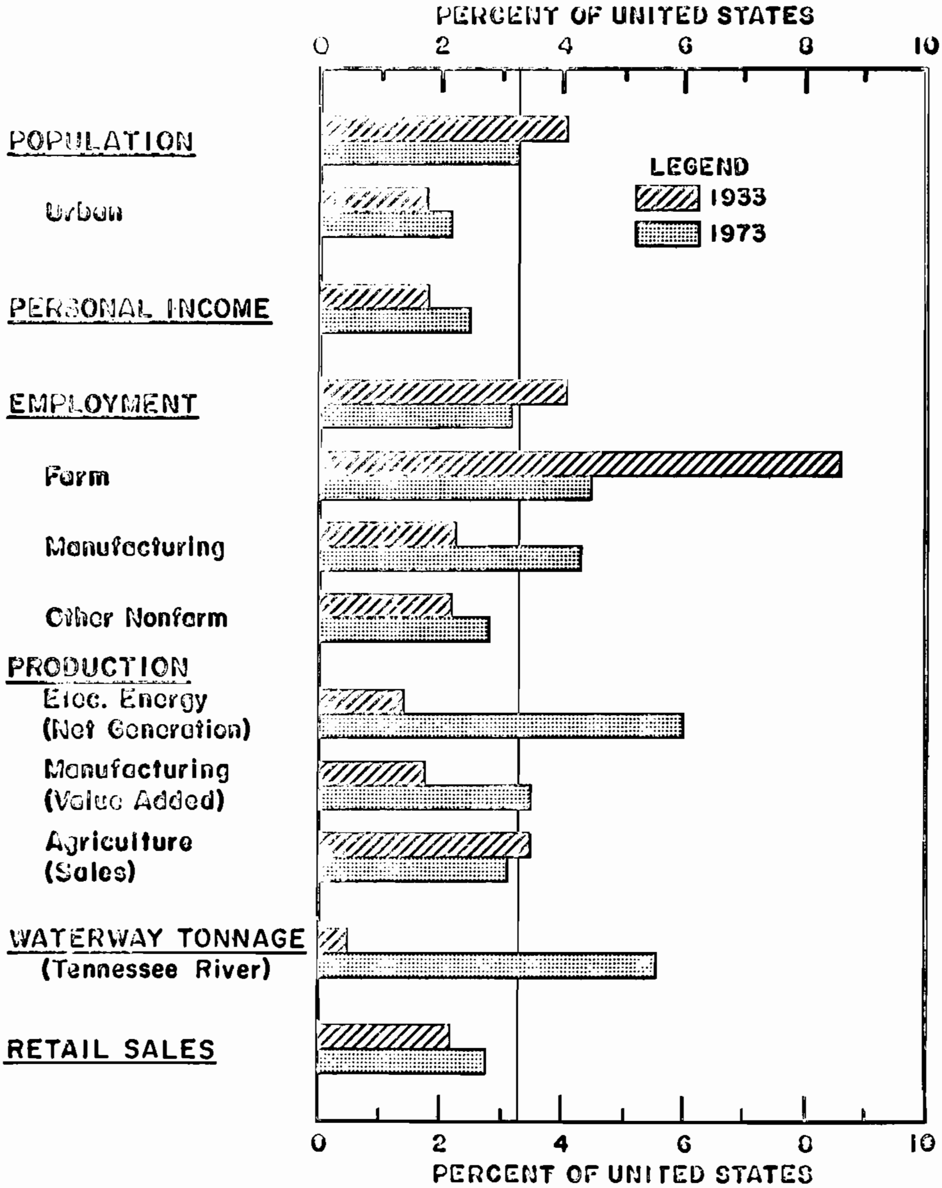


CHART I
TENNESSEE VALLEY REGION IN RELATION TO UNITED STATES (ACCORDING TO SELECTED INDICATORS)



The increase in the number of urban communities and the rapid growth of their populations have been spurred by gains in manufacturing and other nonfarm employment that have surpassed the national growth rates. These factors have also contributed to the region's increasing share of personal income which increased from 1.8 percent of the national total in 1933 to 2.5 percent in 1973.

The slower growth of population in the region, that is its inability to retain a larger portion of the natural increase of its population, was due mainly to the rapid adjustments taking place in the agricultural sector of the economy. In relation to its share of population, the region in 1973 had a slight shortfall of employment but maintained an excess in its share of the Nation's farm workers. The drop in the region's share of the Nation's farm workers from 8.6 percent in 1933 to 4.5 percent in 1973 represented a decrease of 716,000, from 870,000 to 154,000--a decline of 82 percent as compared with a decrease of 66 percent for the Nation.

Although the declines in farm employment held its relative gains in total employment to levels substantially less than gains for the Nation, the region has consistently outperformed the Nation in growth of the nonfarm sector of its economy. Industrial development, generated by the planned development and use of the region's resources, provided the primary stimulus.

In 1933 manufacturing employment in the region was only 2.3 percent of the national total; today it is 4.3 percent. The 169,500 manufacturing workers in the region in 1933 represented 12 percent of its total employment. Today one out of every three workers in the region is employed in manufacturing--a proportion greater than for the Nation as a whole--and manufacturing employment now totals 858,800. The 40-year gain of almost 690,000 was an increase of 407 percent compared with a national gain of 168 percent. The gain of 690,000 for the region was 5.5 percent of the increase of 12.4 million new manufacturing jobs registered by the Nation during the same period. As a result of the integrated resource development program, the region is a much more attractive place for the location of industry but, as in the past, its success in achieving maximum benefit from its developed resources will depend to a great extent upon the existence of a strong and growing national economy.

The population growth and increased incomes generated by this expansion of industry have stimulated growth in construction, trade and service activities, and greater demand for improved and a wider variety of governmental services.

Each 100 new manufacturing jobs have resulted in the addition of 103 workers in trades and services, which increased from 176,200 in 1933 to 887,000 in 1973. This was a gain of 403 percent for the region compared with a national gain of 272 percent.

The regional employment growth in government employment between 1933 and 1973 was due primarily to the increase in the number of employees of state and local governments, including schools and municipal utility systems. The increase of 377,000 represented a gain for the region of 260 percent. The comparable national increase was 213 percent.

Changes in technology have led to a reduction of employment in mining--from 23,800 in 1933 to 17,300 in 1973. Even with the decline in employment, however, minerals, especially coal, are being recovered in increasing quantities each year. Contract construction, a somewhat volatile industry, has nonetheless experienced a relatively sustained growth in employment in the region, from 17,700 in 1933 to 128,400 in 1973.

Regional employment in these groups, labeled "Other Nonfarm" in chart 1, has not yet caught up to national averages but it is growing, having increased from 2.2 percent of the national total in 1933 to 2.8 percent in 1973.

The remaining indicators in chart 1 relate to production, waterway traffic, and retail sales. These provide additional insight into the relationship of the national and regional economies.

In 1933 electric energy generated in the Tennessee Valley region was only 1.5 billion kWh--about 1.4 percent of total generation in the Nation. In 1973 generation by TVA totaled 111.8 billion kWh or 6 percent of the national total. This growth, in addition to providing electric energy for virtually every home and farm in the region, has been a major factor in industrial development and the continuing growth of an increasingly more productive manufacturing labor force. The region's share of the Nation's manufacturing production increased from less than 2 percent ($250 million) in 1933 to 3.5 percent ($13 billion) in 1973. In terms of constant (1967) dollars, manufacturing production was 14 times greater than in 1933, whereas manufacturing employment was only 4 times greater.

Even though the figures show that the region has lost ground relative to the Nation in farm production, declining from 3.5 percent of the national total in 1933 to 3.1 percent in 1973, this is only a part of the picture. In constant dollars, farm production was 3.5 times the amount in 1933 and this production was achieved with less than one-fifth (18 percent) as many workers. Agriculture, therefore, makes an even greater contribution today to the total product of the region than it did in 1933. It is still of great importance.

The navigable waterway has been a significant factor in the economic development of the region. In 1933 less than one million tons of waterway freight were transported. This, consisting mostly of stone, sand and gravel, and forest products, was less than 1 percent of total tonnage that moved on the Nation's inland waterway system. In 1973 about 29 million tons, 5.6 percent of the national total, moved along the Tennessee River. Transported were such diverse products as chemicals, coal and coke, grain and grain products, petroleum products, and iron and steel. Much of the traffic is generated by demand for the movement of raw materials and finished products for the burgeoning industries along the waterway. Private investment in waterfront industry in 1973 was $329 million, the largest yearly total ever recorded for the Tennessee River. From 1933 through 1973 private industry has committed to investments of more than $2.4 billion in Tennessee River waterfront plants, terminals, and distribution facilities.

Although the region is somewhat behind the Nation in retail sales, the growing demand for goods and services, primarily the result of rising incomes, is reflected in the region's increasing proportion of total sales in the Nation.

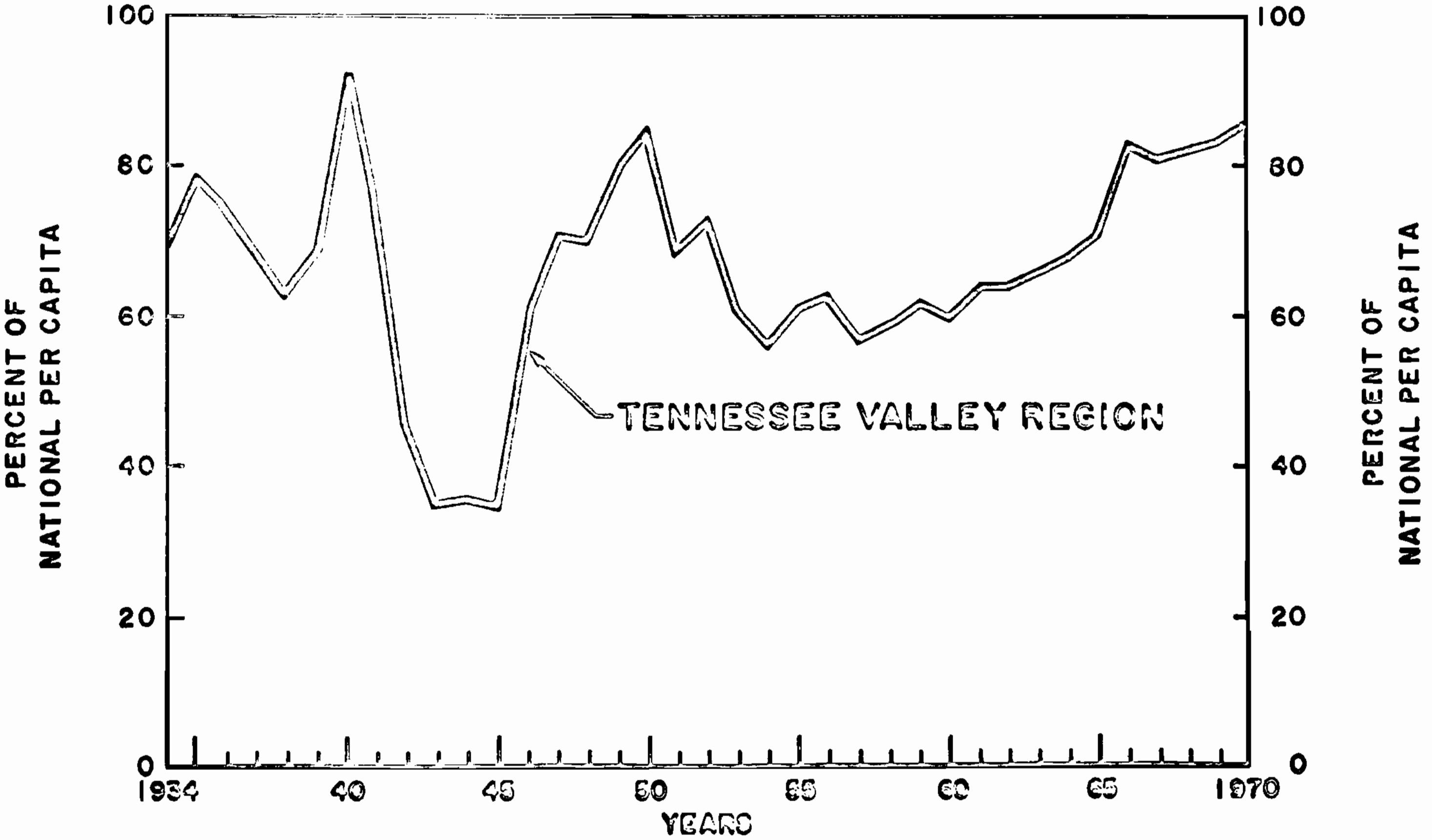
Two other indicators merit consideration in assessing the relationship of the region to the national economy. One of these is Federal expenditures. From TVA's inception through 1970 total expenditures by Federal agencies in the region amounted to $64.1 billion. This, however, was only 2.4 percent of such expenditures allocated to states, and less than 10 percent of the regional total was for TVA. Over the 37-year period the expenditures amounted to $16,759 per capita for the Nation and $10,822 for the region--just 65 percent of the national average. The Tennessee Valley region, therefore, has by no means received favored treatment in terms of Federal government expenditures. In fact, if such expenditures had been allocated to states and regions on the basis of population, the region would have received $31.5 billion more or a total of $95.6 billion.

As shown in chart 2, Federal expenditures in the region reached a peak of 93 percent of the national per capita expenditure in 1940, a result of defense generated programs. Following a rapid decline during the early 1940's, expenditures increased under the stimulus provided by the Korean conflict to 85 percent of the national per capita average in 1950. Expenditures again declined during the early 1950's and leveled off during the last half of the decade at about 60 percent of the national per capita average.

During the more recent 10-year period expenditures rose gradually from 60 percent of the national per capita average in 1960 to an average in 1970 of 86 percent--about the same level as in 1950. Low point for the region was in 1943 and 1945 when its proportion of the national per capita average was only 35 percent.

The second indicator reflects the impact of the growth of income on contributions to the national treasury by residents of the region. Federal income tax collections from individuals in the Tennessee Valley region in 1969 amounted to $2.2 billion. This was 1.7 percent of the national total compared to less than 1 percent in 1933. Collections from the Tennessee Valley region would have been only $1.0 billion in

CHART 2
FEDERAL EXPENDITURES PER CAPITA
TENNESSEE VALLEY REGION
AS PERCENT OF NATIONAL AVERAGES



1969 if the ratio of the region to the Nation had remained at the 1933 level.

The preceding discussion has dealt with the growth of the economy of the region and its changing relationship to the Nation. These changes, particularly the ability of the region to generate new employment opportunities, are reflected also in the impact they have had on migration. The region has long experienced a net outmigration of people, but as shown in the following table this pattern has changed greatly during the last few years. In the forties we had an increase of 360,000 nonfarm jobs, but close to 60 percent of these were offset by the decline in farm jobs. As a result there was a large net outmigration of people--about 625,000. In the fifties we had a smaller increase in nonfarm jobs and a larger decline in farm employment. This resulted in an even larger net outmigration (more than 700,000) than in the forties. But during the sixties, the increase in nonfarm jobs accelerated to a total of more than 660,000. At the same time the decline in the number of farm workers was less than in the previous two decades. As a result the region had a net increase of nearly half a million new jobs and a smaller net outmigration--only 143,000.

EMPLOYMENT CHANGE AND NET POPULATION MIGRATION
TENNESSEE VALLEY REGION

	Net Change in Employment			Net Population Migration
	Nonfarm	Farm	Net Increase	
		(Thousands)		
1940-1950	359.8	-206.5	153.3	-625.0
1950-1960	288.9	-228.4	60.5	-701.0
1960-1970	663.2	-201.9	461.3	-143.0
1970-1973	325.0	-1.0	324.0	

The first third of the seventies saw a leveling off of farm employment and continuing substantial gains in nonfarm jobs. This is expected to lead to further reductions in net migration and a consequent impact on population growth. Although migration figures are not available for this period, an indication of the impact is revealed by the fact that from 1970 to 1973 the region for the first time in its recent history registered a relative gain in population that exceeded the national average.

A major part of the success of the region during the sixties and early seventies has been its ability to provide the bulk of the new jobs in the areas of greatest need. During recent years almost half the increase in manufacturing jobs and 85 percent of the increase in other nonfarm jobs in the Nation have been in the major metropolitan areas. In contrast, the region had 80 percent of its new manufacturing jobs and over half of its other new nonfarm jobs outside the major metropolitan areas.

This growth, however, has not been spread evenly throughout the region. About three-fourths of the region's 201 counties have per capita incomes that are less than 70 percent of the national average. Twenty-eight of these have incomes that are no more than 45 percent of the national average. This is a familiar number for it was the position of the region relative to the Nation back in 1933. Much, then, remains to be done. However, the development of the regional resource base by TVA has provided the tools and the opportunity for successful local and subregional economic development programs; and the success of the region has been the result of numerous cooperative development programs and actions involving local and state groups throughout the region.

Future progress for the region will depend to a great extent upon our success in efforts to improve the economic position of those areas that have lagged somewhat behind.

Through our studies of the trends and current status of the region's economy, and through our program planning and evaluation procedures, we have observed the development of the region into an economy which now more nearly resembles the Nation than was the case in 1933. The following exhibits present a graphic picture of the long-term trends and changing relationships between the region and Nation.

A view of the long-term trends in the region's population and employment is shown in chart 3. Population has had a gradual but relatively sustained growth. The most revealing picture, however, is the very rapid growth in nonfarm employment and the accompanying decline in farm employment as indicated by the difference between the nonfarm employment and total employment curves. It should be noted also that the region now has about 37 percent of its population employed as compared with 38 percent for the Nation. As recently as 1960 the proportions were 29 percent for the region and 33 percent for the Nation.

Comparison of employment trends, by major categories, in the region and Nation are shown in charts 4 through 7. Nonfarm employment in the region (chart 4) has shown a consistently more rapid rate of growth than the Nation. Greatest gains for the region relative to the Nation came during the 1960's and thus far in the seventies. It will be recalled that the decade of the sixties is also the period when the region had its greatest numerical increase in nonfarm jobs and when outmigration was reduced to only about one-fifth of the number in either of the two immediately preceding decades.

CHART 3
POPULATION AND EMPLOYMENT IN THE TENNESSEE VALLEY REGION (1933-1973)

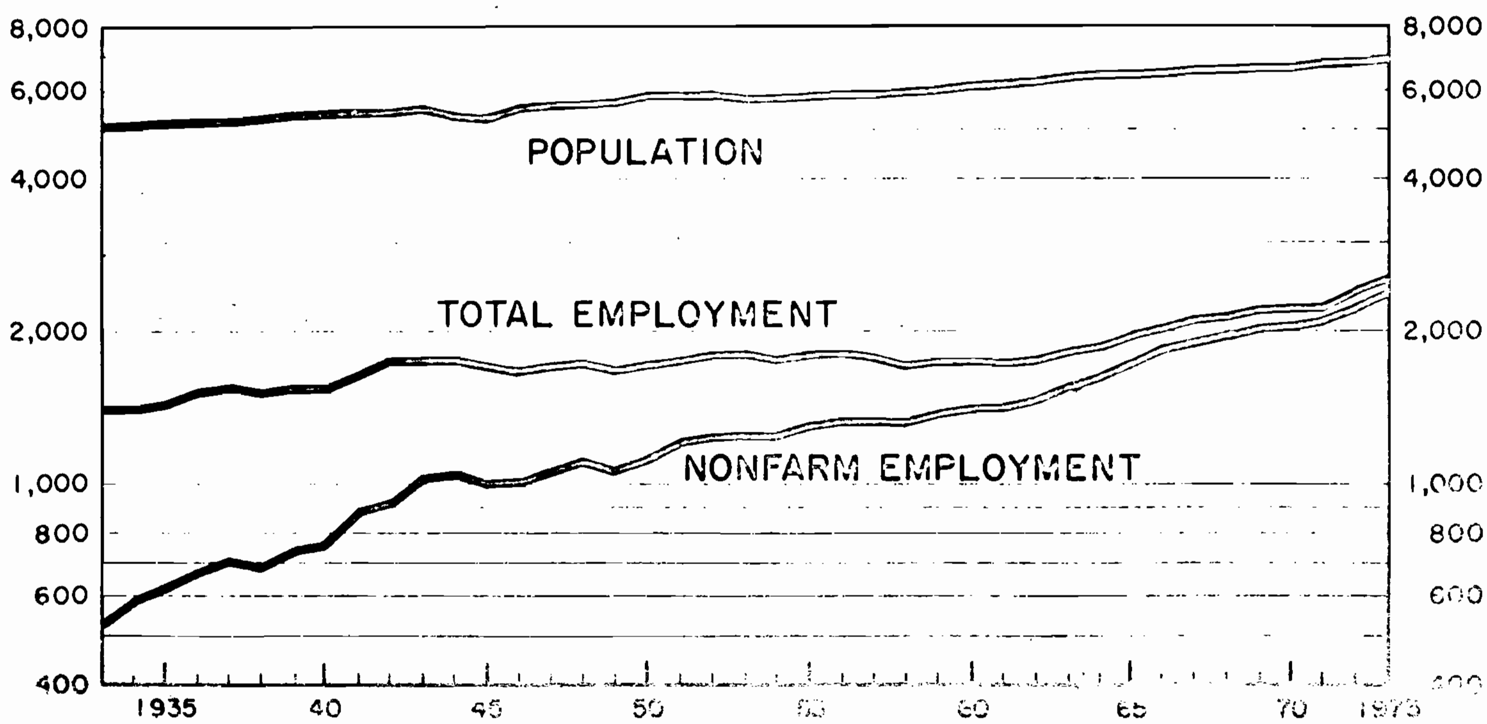
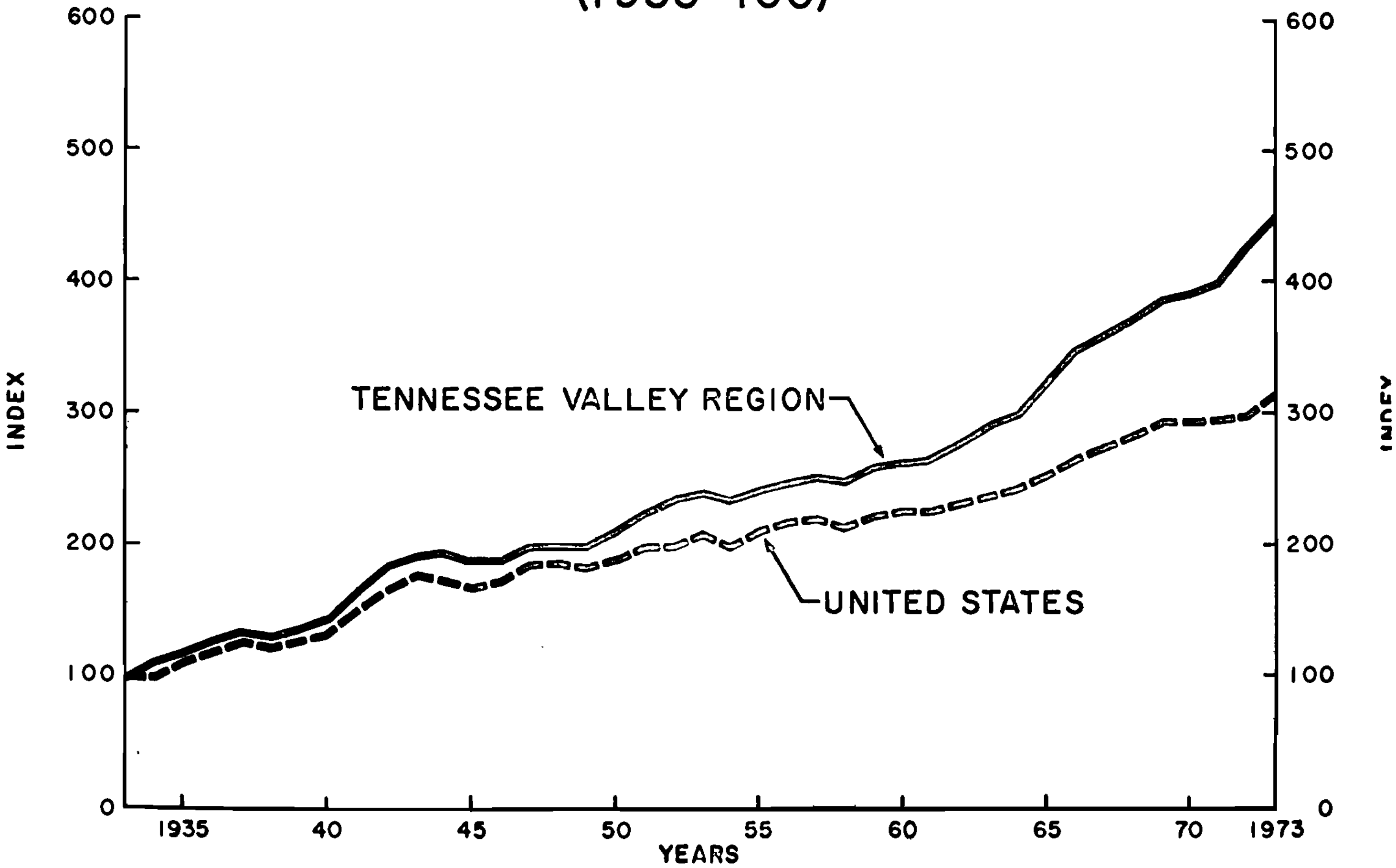


CHART 4
INDEX OF TOTAL NONFARM EMPLOYMENT
(1933=100)



Since the late 1940's, manufacturing employment (chart 5) in response to the resource development programs has grown faster than in the Nation. Here also the impressive record of the region in the years since 1960 is apparent.

The region's gain in trade and service employment (chart 6) was equally as impressive as its growth in manufacturing. In comparison with national trends, however, the differential rates of growth in trade and services were not as large as in manufacturing. The substantial improvement since 1960 for the region as compared with the Nation is attributable to the increased demand for services occasioned by rising regional incomes.

These employment changes have led to a redistribution of the region's work force into a structure that more nearly resembles that of the Nation. (See chart 7). Employment in agriculture in the region dropped from 62 percent of total employment in 1933 to 6 percent in 1973--less than two percentage points above the national proportion of 4.4 percent. Manufacturing employment has grown from 12 percent of employment in 1933 to more than one-third in 1973. This is more than 8 percentage points above the national proportion and reflects a heavier concentration of the region's employment in labor-intensive manufacturing industries.

Trade and service increased from about 13 percent of the region's total employment in 1933 to almost 35 percent in 1973. This, however, is somewhat less than the national proportion of 42 percent in this category, again a reflection of the relatively lower incomes in the region.

CHART 5
INDEX OF MANUFACTURING EMPLOYMENT
(1933=100)

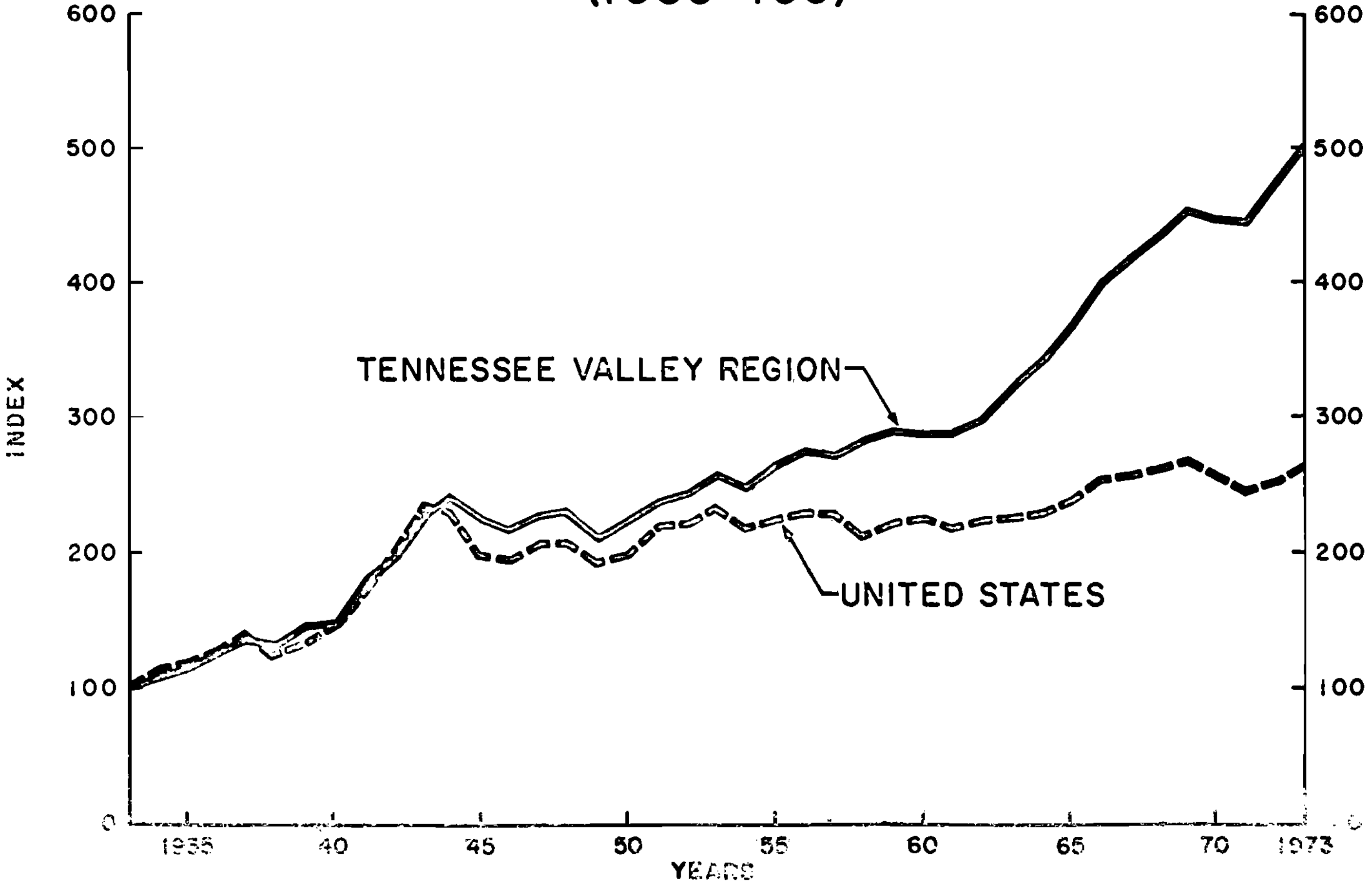


CHART 6
INDEX OF TRADE AND SERVICE EMPLOYMENT
(1933=100)

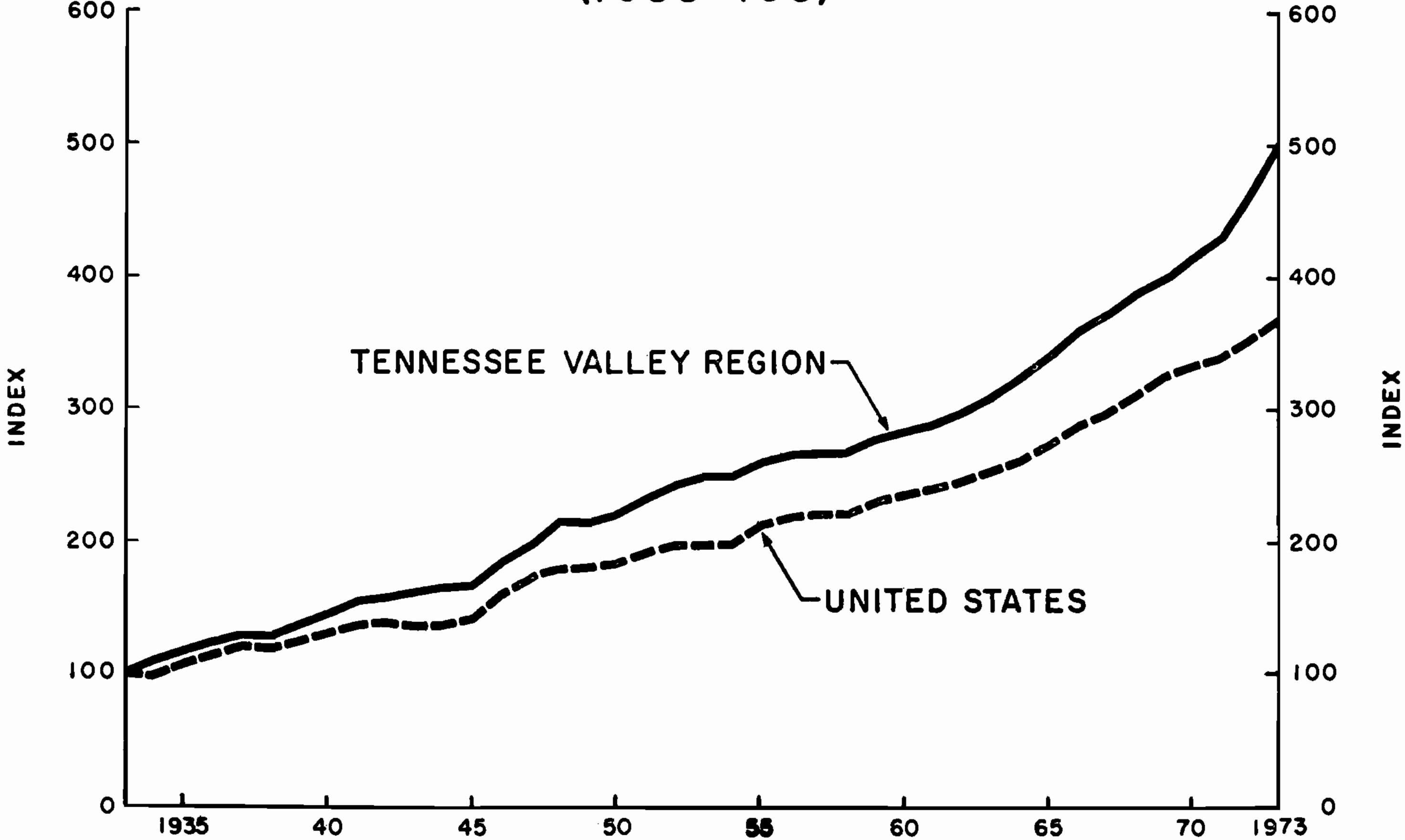
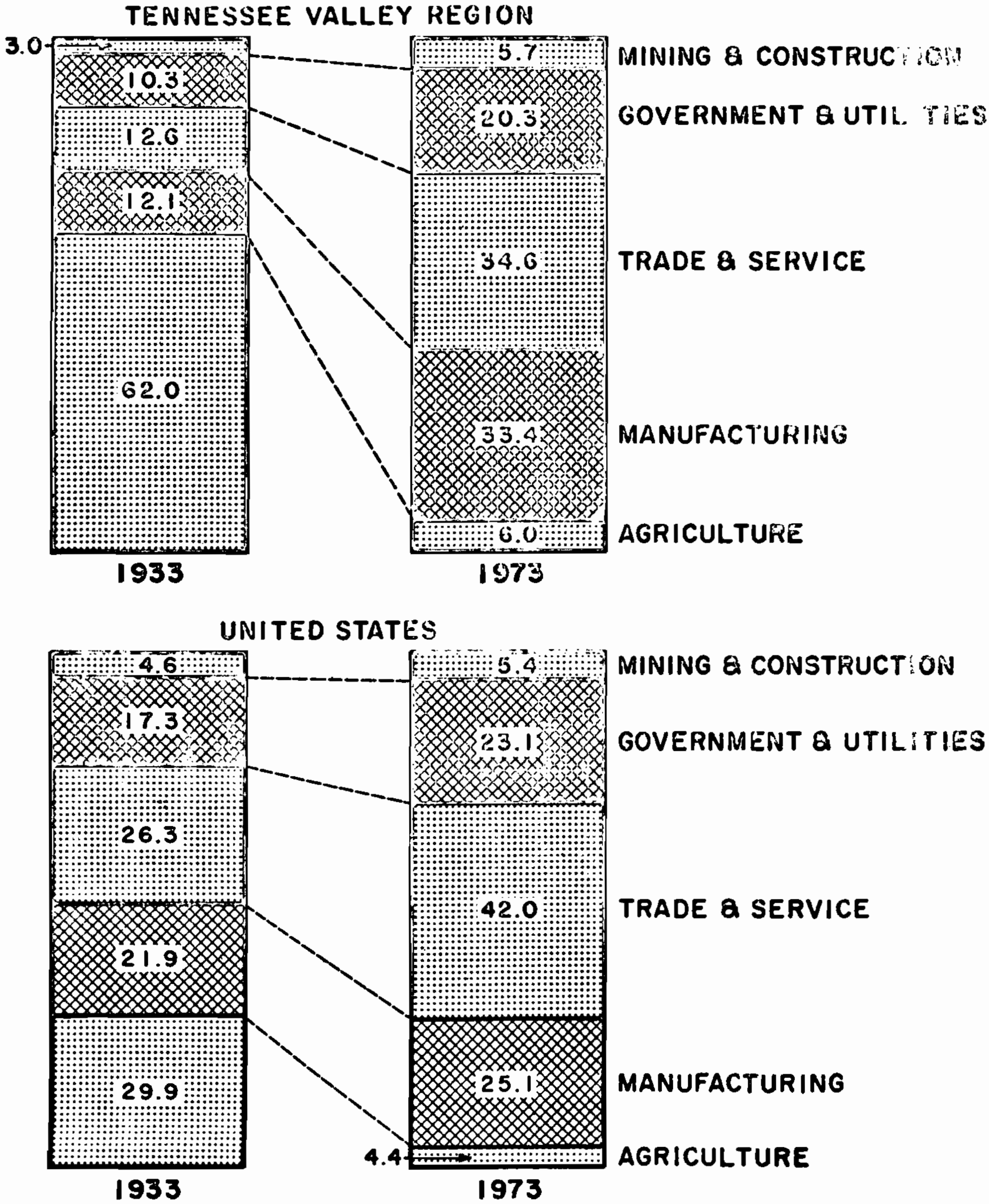


CHART 7

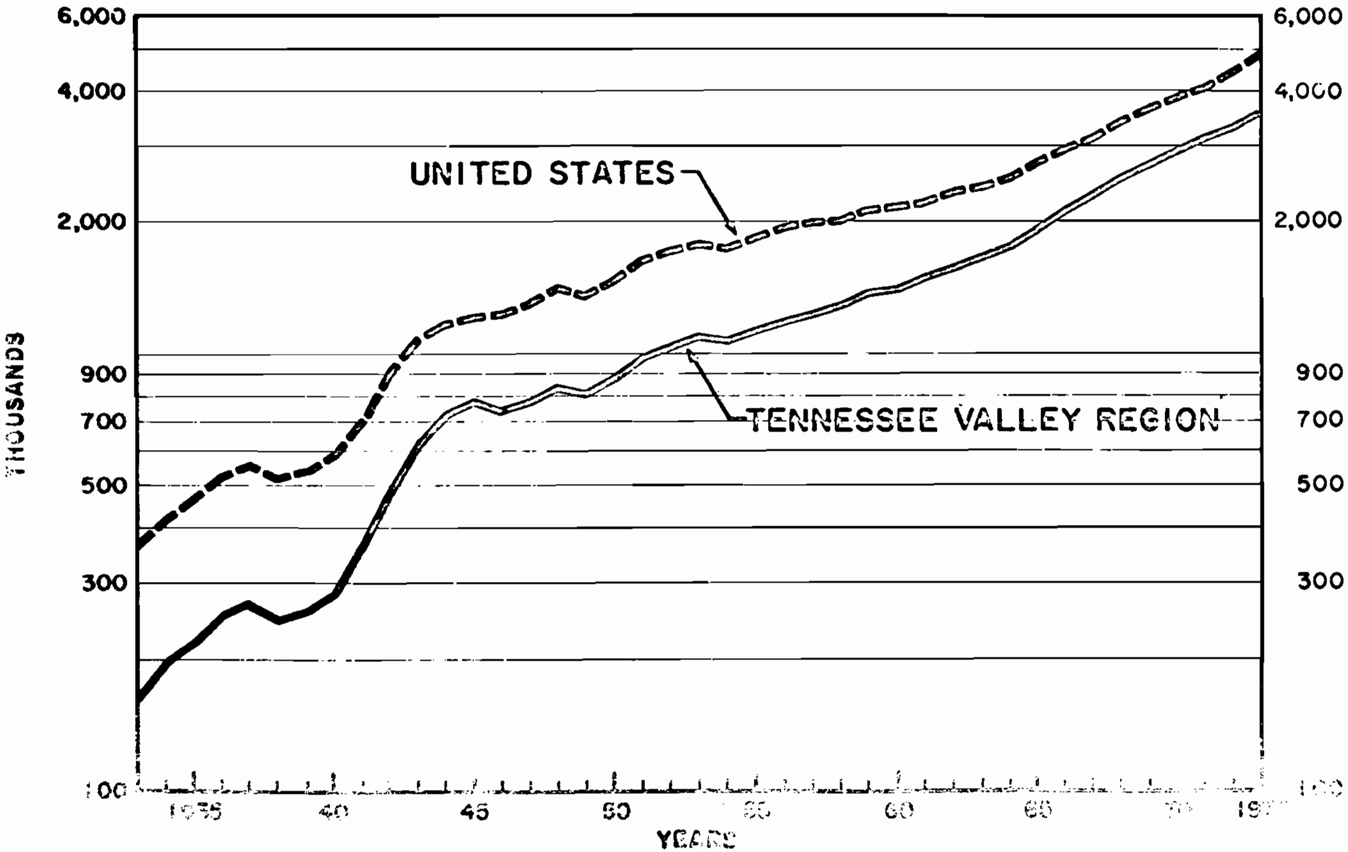
PERCENT DISTRIBUTION OF EMPLOYMENT TENNESSEE VALLEY REGION AND UNITED STATES



The impact of the region's shift from primary dependence upon agriculture to manufacturing and other nonfarm employment is mirrored in its per capita income gains relative to the Nation. Chart 8 shows that although the region's per capita income remains considerably below the Nation's, the gap is gradually being closed. Per capita income rose from $168 or 45 percent of the national average in 1933 to $3,666 or 75 percent in 1973. Greatest gains for the region relative to the Nation were made between 1940 and 1945 when its per capita income rose to 64 percent of the national average. During the period from 1945 to 1949 the region experienced a mixture of gains and losses relative to the Nation, but since 1949 the climb toward the national average has been uninterrupted.

Although most indicators show that the region has enjoyed a relatively higher level of economic growth than the Nation, its fortunes nonetheless depend heavily upon a viable and growing national economy. Observation and study of trends in the relationships to the national economy will help to plan strategies that will tend to ensure that the record of past achievement can be sustained in the future. However, strategies are also needed for changes in the intraregional relationships. For this reason we need to continue to improve our knowledge and understanding of how national events, trends, changes, and also the inner workings influence the economy of the Tennessee Valley region. What we are doing in this area will be presented when we discuss our experience in regional economic simulation modeling. In preparation for this it may be helpful to put the regional economic indicators and national relationships into equation form. The following equations give the current values of the coefficients which quantify the relationships

CHART 8
PER CAPITA PERSONAL INCOME
1933-1973
(CURRENT DOLLARS)



between the region and the Nation:

Population

(1) $POP_R = .033\ POP_N$

Income (total personal)

(2) $INC_R = \left(POP_R\right)\left(.75\ \frac{INC_N}{POP_N}\right)$

$= \left(.033POP_N\right)\left(.75\ \frac{INC_N}{POP_N}\right)$

$= .025INC_N$

Employment

(3) $EM_R = .045AGEM_N + .028MINEM_N$

$+ .043MANEM_N + .035CONEM_N$

$+ .026TRSEM_N + .031GOVEM_N$

Gross Product

(4) $GPO_R = \left(.045AGEM_N\right)\left(X_{AG}\right)\left(\frac{AGPRO_N}{AGEM_N}\right)$

$+ \left(.028MINEM_N\right)\left(X_{MIN}\right)\left(\frac{MINPRO_N}{MINEM_N}\right)$

$+ \left(.043MANEM_N\right)\left(X_{MAN}\right)\left(\frac{MANPRO_N}{MANEM_N}\right)$

$$+ \left(.035CONEM_N\right)\left(X_{CON}\right)\left(\frac{CONPRO_N}{CONEM_N}\right)$$

$$+ \left(.026TRSEM_N\right)\left(X_{TRS}\right)\left(\frac{TRSPRO_N}{TRSEM_N}\right)$$

$$+ \left(.031GOVEM_N\right)\left(X_{GOV}\right)\left(\frac{GOVPRO_N}{GOVEM_N}\right)$$

$$= .045X_{AG}AGPRO_N + .028X_{MIN}MINPRO_N$$

$$+ .043X_{MAN}MANPRO_N + .035X_{CON}CONPRO_N$$

$$+ .026X_{TRS}TRSPRO_N + .031X_{GOV}GOVPRO_N$$

$$= \$35.1 \text{ billion.}$$

Where:

POP_R = Population in the Tennessee Valley region

POP_N = Population in the United States

INC_R = Total personal income in the Tennessee Valley region

INC_N = Total personal income in the United States

EM_R = Total employment in the Tennessee Valley region

$AGEM_N$ = Agricultural employment in the United States

$MINEM_N$ = Mining employment in the United States

$MANEM_N$ = Manufacturing employment in the United States

$CONEM_N$ = Construction employment in the United States

$TRSEM_N$ = Trade and service employment in the United States

$GOVEM_N$ = Government employment in the United States

GPO_R = Gross product originating in the Tennessee Valley region

$AGPRO_N$ = Total product from agriculture in the United States

$MINPRO_N$ = Total product from mining in the United States

$MANPRO_N$ = Total product from manufacturing in the United States

$CONPRO_N$ = Total product from construction in the United States

$TRSPRO_N$ = Total product from trade and services in the United States

$GOVPRO_N$ = Total product from government in the United States

X_i = Index of worker productivity in the Tennessee Valley region relative to the Nation, for major employment category i

IIASA DISCUSSION PAPER

T. Koopmans

Mr. Foster has summarized a very informative paper. The word relationship in its title is used in the sense of ratios, proportions and trends in ratios and proportions of variables for the TVA regions and for the entire USA, and in this sense the paper neatly compresses the economic history of the region before and after the advent of the TVA. I would like to widen the meaning of the word "relationship" for my comments so as to include in it also the effects of the TVA on the rest of the country. That is, for the purposes of systems analysis, we want to study not only the effect of the TVA within its own region--which is the main concern of the papers before the conference--but also the effect of TVA's existence and operation on the rest of the country (on which there is much less in the papers).

On the first, the effects of TVA within its region, I want to make just one remark and then go on to the second. That one remark concerns the great importance of the demonstration effect of the TVA's operation, particularly on one point that is again pertinent today: that the demand for electric energy does respond to price decrease in the long run, and quite substantially. This does not necessarily answer the question whether there is a similar response to price increase, but the inference would go in that direction.

The rest of my remarks will be on the question of the effect of the TVA on the rest of the country. I will limit myself to the effects connected with the TVA's role in regard to power supply, which has now become the most important single function of the TVA. First, does one need a model of the entire US economy to evaluate these effects? In principle, yes, but in an economy that is preponderantly a market economy some important effects are trasmitted through price signals. This might also be so, or not be so, in a centrally planned economy, depending on the extent to which the planners choose to use a price mechanism. In a market economy in a period of close-to-full employment of its labor force and its capital stock, the price signals do have an important function of aiding the efficient allocation of resources.

I am thinking particularly of the effects of power rates on the distribution of industry and population within the United States. For these effects to be desirable nationally, it is important that the rates reflect cost of generation of electric power. This leads also to a proposed definition of a term used in the title of another paper. That paper speaks of an "ample supply of electric energy." What is an ample supply? I would like to propose for discussion an objective function of the TVA power supply that includes the price signal and includes a definition of what is an ample supply. The proposal is to produce at mimimal total cost, that amount and assortment of electric energy services that is demanded at rates reflecting long-run incremental cost. That requires another definition of "incremental cost." Consider a given growth of demand which can again be itemized according to day-time power, night-time power, interruptible power, or any of the categories that have different effects on cost. The incremental cost of, say, a unit increase in any one of these components would be defined as the increase in the minimum total cost incurred by efficiently meeting the extra unit of that particular demand.

One of the other documents before us, Economic and Simulation Model, gives on page 10, TVA industrial power rates as a percent of an average of those of seven private power companies in surrounding areas. The percentages are in 1960, 55%, in 1973, 72%. The same paper contains three alternative projections according to three alternative hypotheses that would hold from 1974 on. In one this percentage is the same as in 1972, in another alternative it is 83%. in the third one 109%. In any case, going back to the 1960 figure, the TVA industrial power rates were 55% of those of surrounding utilities. My questions are:

1) To what extent is or was the lower TVA rate owing to

   a) superior organization of TVA;

   b) locational advantages such as low-cost access to coal deposits, or to waste heat sinks;

   c) exploitation by other utility companies of a monopoly position (even if a regulated monopoly position)?

I would submit as my own conjecture that to the extent that for these reasons the TVA rates were lower that has been salutary for the nation as a whole.

Or, was the difference in rates also owing to

   d) advantages of taxation or of access to capital;

   e) use of average-cost rate calculation in which a lower cost of hydropower weighed more strongly than in an incremental cost calculation;

   f) failure to include social cost of environmental damage or reclamation in the cost of calcualtion?

To the extent that the latter three factors have been operative, I would think that the rates are or have been correspondingly too low. In other words, I advance the principle that it is not in itself a merit if rates are low, or if rates are high. They should be meaningful, reflecting cost. To illustrate this with Mr. Foster's pictures of industrial plants, I think that in his interpretation these were regarded as attracted by the lower rates. If the rates were right, then that was in the national interest, if the rates were too low, then more may have been attracted than was in the national interest, and fewer if the rates were too high. For a similar reason, I also do not agree with Mr. Foster's criterion for migration. He seemed to think it was a shame for the state of Tennessee to lose able-bodied and vigorous young people if there is no employment for them. Whether that is so or not is, I think, to be determined by proper pricing of the resources at levels that express the opportunities of that state. I suggest that Mr. Foster's criteria could not be applied to all states of the nation. Would you want South Dakota to be brought up to the average of the country in the growth of either employment or population? There are of necessity some states that are disadvantaged. Tennessee and other valley states are advantaged by the resources that were present and that the TVA has developed. Proper pricing will help in determining how far that development is nationally valuable.

My proposal of incremental cost would have a consequence on which Mr. Newland's question this morning has a bearing. He asked, "Were there profits and what was done with them." On the incremental cost calculation, there may well be profits, there may also be losses, depending on the particular cost structure. Actually, it seems to me that if there was to be high positive or negative profits and if the rates were to be charged at that level anyway, this would be less of a problem of social justice to the TVA because of its two-way relationship with the US Treasury, whereby funds in excess could be repaid and deficits could be covered by appropriations.

Mr. Seeber's comments on the switch in the TVA's persuasion effort from one directed to stimulating electric power demand to one of holding it back, may lead one to think that the price signal is unimportant. I think that both the price signal and the persuasion are important and have their own effects. Many people will follow the price signal rather than the persuasion if these pull in opposite directions. Others will just be confused by that, and I see no reason why one should not use both so as to pull in the same desirable direction.

One further remark on the environmental cost factor I have mentioned last. I am recommending that factor for consideration regardless of whether utility companies in other areas have been equally slow to respond or have had less of a problem, and also regardless of whether damage to the environment was done in the TVA area or outside of it. The sorest point in this category is the surface mining of coal for sale to the TVA. The paper, TVA and Surface Mining, candidly describes the problem created by surface mining and the various things the TVA did to counteract its effects. To me these look like just the right things to do except, if I am also allowed candor, too little and too late.

With the switch to coal having started in the early 1950's and with about one-half of that coal coming from strip mining, was it necessary to wait until 1965 before the first reclamation clauses (that still required later strengthening) were written into the contracts? Of all utilities was not the TVA in a strong position both morally and economically to give a timely example, by exacting full land restoration from its suppliers and charging full restoration costs in its rates? It would have made a difference to the present condition of the Appalachians.

TVA RESPONSE TO T. KOOPMAN'S AND THE CONFERENCE DISCUSSION

On the point of price elasticity of the demand for electric power on the negative side (price increases and demand increases) we are not prepared to provide a coefficient. Price increases have been too recent to provide a basis for time series or even cross-sectional analysis. However, there is evidence that the reaction is far less than unity in the short run. Even when mixed, as it is today, with an energy conservation program, the result is less than proportionate to the increases in price. The long-range result may be another matter but must wait for time to reveal the answer.

While we question the statement that power supply is the most important single function of TVA, we will address the definition of "ample power supply." To the TVA this means the electric energy needed to supply the homes and economic activities that will be located in the TVA region by the market system and the resources of the region. The question of incremental cost pricing certainly relates to the allocation of resources in the energy field and at more indirect levels to the allocation of other resources, but probably not to the geographic allocation of economic activity and income unless the TVA were the only system to use it and the pricing results were very different from the existing cost basis.

The reasons for the difference between the TVA's rates and those of surrounding electric systems include those cited except the last one. Since the subject is TVA rates in comparison with others, it is not likely that failure to include full social cost is one of the causes. The TVA's rates reflect the cost of strip mining reclamation. Those of surrounding utilities do not. On the other hand, the rates on both sides of the comparison reflect some water and air quality preservation costs, the TVA probably more than the others. Perhaps the best answer is to state the rate basis and philosophy of the TVA:

> While the TVA power system is not operated for profit, it is required by law to pay its own way. In the TVA Act, Congress has specified how total rates shall be set. In effect the Act sets both a ceiling and a floor on power rates. The ceiling is the statutory objective that TVA power is to be sold "at rates as low as are feasible." The floor is the requirement that TVA charge rates that will produce gross revenues sufficient to provide funds to cover specified costs, plus a margin determined by the Board of Directors. Within this floor and ceiling, the TVA Board has authority to establish the amount of the margin. The margin of revenues over costs serves two purposes. First, it provides a contingency allowance

to cover a variety of factors that can cause actual costs to vary substantially from the estimates on which rates are based. Second, the margin is used to help pay the cost of new power system facilities. This reduces the need for borrowed capital, and helps to hold down future interest costs and rate increases.

Last fiscal year, for example, the TVA power system earned net income of $106 million. Most of that amount ($83 million) was required to cover specified payments to the US Treasury as a repayment and return on investment, based on the Federal appropriations that were used in financing TVA power facilities before Congress enacted a self-financing program for the power system in 1959. The remaining $23 million was used to pay the cost of new power facilities.

The TVA now uses two methods for establishing the levels of power rates. One of these involves a quarterly rate review by the TVA Board, while the other involves variable adjustments computed each month from the actual costs of power plant fuel and purchased power. The purpose of this approach is to keep rates and revenues closely based on actual cost trends as they develop, so that increases in electric bills can be the minimum amounts necessary to meet these costs. Otherwise, rates might have to increase in much larger jumps--like those some other power systems have experienced--if it became necessary to make up past shortfalls in revenue.

The present basic wholesale and retail rate schedules for TVA power were adopted in 1970. At that time, TVA and its wholesale customers agreed on a procedure that permits the TVA Board to review fiscal year cost and revenue estimates every three months, and to adjust rates for the next quarter if that will be necessary to cover financial requirements. Under this procedure, general rate adjustments have resulted at one-year intervals beginning in 1973.

In the spring of 1974, coal prices were beginning to increase so rapidly that it was evident they would have a substantial and unpredictable impact on the cost of power production. Because of these unpredictable fuel cost trends, monthly fuel cost escalators already had become common additions to electric rates in most states. The TVA adopted a variable adjustment based on changes each month in the actual cost of fuel used in TVA power plants. The amount of this adjustment each month is computed from the monthly power accounts.

This approach is particularly effective in holding revenues reasonably close to costs. It also gives the customer an automatic reduction in rates for those months when fuel cost declines, where a fixed adjustment would lock the higher cost level into rates. The only disadvantage of a fuel adjustment clause would be if it should remove the incentive for power producers to buy fuel economically. In the TVA's case, that is not a problem because the TVA is dedicated to maintaining power rates as low as possible, as provided by the TVA Act. The TVA's actions last year in resisting exorbitant coal prices, even when our coal stockpiles dropped to very low levels, are evidence that the TVA will continue doing all it can to protect the consumer

In addition to the question of how much total revenue TVA must obtain from its power customers, there is further question of the rate structure--that is, how much of the needed revenue shall be obtained from each different kind of power user. This was not much of an issue when rates were low, but the rising cost of electricity has produced much more interest in rate structures. Residential customers tell us that more of the cost should be paid by industries. As industries see it, they are already paying more than their share and more should be paid by the residential customers. Some environmentalists tell us that we should discourage the use of electricity by increasing the price as the customers use greater amounts. But the people who are already paying the highest home electric bills, because they use electricity for heating and water heating, see that approach as a subsidy at their expense for other families using gas or oil, and so on.

Some people are under the impression that TVA rates are designed to promote the use of electricity. In earlier years they were, because greater use was needed to allow more economical distribution of electricity. Because the region's needs changed, the TVA removed that promotional feature in the late 1960's. In recent years the TVA and local power distributors have carried on an extensive program to encourage power conservation and avoid waste in the use of energy.

Present rate structures are based on the costs of providing service for different kinds and levels of power use (except that the savings on low-cost hydroelectric generation at dams are allocated to home consumers and not to business and industry in accordance with the TVA Act). This still means that the cost per kilowatt-hour varies. Supplying a home with electricity involves some fixed costs that must be covered whether use is high or low--the cost of the power line, reading the meter, sending out bills, etc. If the use is low, these fixed costs are spread over fewer kilowatt-hours and show up as a higher charge per kilowatt-hour. If the use is high, these fixed costs become only a small part of the overall bill.

There are four basic tests to determine how well an electric utility is carrying out its responsibilities to the public:

1) The first of these tests is whether electricity is supplied at rates the users of electricity can afford. The rates charged by the TVA and by the local electric systems distributing TVA power are the lowest in the country, except for a few areas served mainly with hydroelectric power. Average electric rates in the Tennessee Valley region continue to be 40% less than the national average, even though both are increasing because of similar problems with fuel and other costs. Most power consumers across the country would be happy if their rates could be <u>reduced</u> to the levels applying to TVA power.

2) The second test is how well the power supplier plans to meet future power needs of the area it serves. This country faces a potentially serious problem of power supply in the coming years because financial obstacles have forced many electric systems to defer or delay construction of new generating capacity. This is not true in the case of the TVA, however, because the TVA is proceeding with the construction and planning of power plants that will meet the expected growth in our region's power requirements through the mid-1980's.

3) A third measure is the financial strength and stability of the power system. The bond ratings of the two national rating agencies provide an exacting test of financial soundness, and the TVA is one of the few power suppliers in the country whose bonds have been given in the highest ratings (AAA) by both Moody's and Standard and Poor's. Only three other power systems, all subsidiaries of Texas Utilities Company, have AAA ratings from both agencies. Only two companies, Commonwealth Edison of Chicago and Louisville Gas & Electric, have split AAA and AA ratings from the two agencies.

4) A fourth test is whether the power supplier operates its power system in a manner which protects the health and welfare of the public and the environment. There is no need here to repeat all that has been covered in our sessions in Baden, except to point out that we believe the TVA had the largest and most comprehensive program of environmental activities of any power in the country--as it should have.

On the point of migration flows as a test for the effectiveness of regional economic development programs, the TVA does not have an objective of stopping out-migration. The objective is to provide economic opportunities that will make migration unnecessary for economic reasons. This is quite a different thing. It relates to the ultimate in personal freedon. The TVA could piously add to this objective the phrase "consistent with an optimum allocation of resources." While this is implied, it is also recognized that the market economy in conjunction with the public sector does not automatically produce such an allocation. It is a judgment with political and social as well as economic factors. We see no problem with other regions or states measuring the effectiveness of their developmental programs by looking at changes in migration patterns. We remember in the early days of TVA it was suggested that the best way to raise per capita personal income for the region was to move out half the people, the lower income half. This, of course, was rejected. Based on judgment, we believe the alternative has resulted in a better utilization of resources, closer to that unknown but desirable optimum allocation.

Since incremental cost pricing is related to several of the comments, it seems to merit additional attention. In order to make sure we have a common understanding we start with our definition. The long-run incremental cost pricing concept is one of the several alternative pricing concepts being strongly advocated for electric utilities at the present time. Included among its supporters are the Environmental Advisory Committee of the Federal Energy Office and National Economic Research Associates Inc.

Long-run incremental cost (LRIC) pricing is one of the concepts based on the theory that the most efficient use of resources will occur when prices are based on marginal costs. Long-run incremental cost refers to the total cost of supplying additional increments of power use through expansion of the electric system's generation, transmission, and distribution facilities. LRIC-based rates are rates which charge the different classes of consumers the incremental cost associated with the typical characteristics of that type of consumer.

Application: Successful application of the LRIC pricing is contingent in part on the development of an acceptable basis for forecasting long-run incremental cost components, including the cost of marginal units of capital. In determining such costs it is also important to consider a time span that reflects the proper mix of base-load and peak-load facilities to supply the projected aggregate load.

The pattern of current and projected costs has been assumed to be such that the long-run incremental costs of resources consumed in the production of incremental amounts of electricity will be higher than embedded costs. In order to avoid generation of economic profits by the presumably higher rates, it is sometimes suggested that rate blocks should be increased to incremental cost where power use has the greatest elasticity and, if necessary, other blocks reduced where there is little or no elasticity.

In the calender year 1973 the incremental rate for electricity purchased by the power distributors was 0.77¢/kWh, This is equivalent to the end block energy charge plus the unit demand charge at a 64% average monthly load factor. The incremental rate is only slightly different from the average rate of 0.78¢/kWh since the distributors all pay the same flat demand charge and over 88% of the energy purchases are billed in the final block.

Because of the higher load factors of industries and Federal agencies served directly by the TVA, the incremental rate for the total system sales is somewhat lower, about 0.74¢/kWh, even though the rate schedule charges to these customers are somewhat higher. Subsequent adjustments through January 2, 1975, providing primarily for higher fuel costs have increased this incremental rate to 1.20¢/kWh.

At the TVA's request the National Economic Research Associates, Inc., is making an independent estimate of the long-run imcremental costs of the generation and transmission system. National

Economic Research Associates' preliminary findings indicated that incremental unit costs range from 1.11 to 0.99¢/kWh for annual load factors of 60%-70%. This range of load factors compares favorably with the TVA system load factor and suggests that incremental rates adequately cover these incremental costs. However, LRIC pricing might require offsetting adjustments in future demand and energy charges, which could change relative prices among users.

The application of the LRIC pricing concept also requires that long-run incremental distribution costs be determined. This is under study, but the results are not yet available. However, it is anticipated that, even if long-run incremental distribution costs are found to be higher than current average cost levels, the difference will not alter distribution cost characteristics enough to eliminate the justification for declining rate block charges for retail rate structures.

Most advocates of the LRIC pricing concept generally conceive the end result as a flattening of existing rate schedules. However, in the distribution area, the cost characteristics are such that higher LRIC are likely to require relatively larger increases in the initial block charges. Thus, the end result could be a declining rate curve that is even steeper than it is at present.

Economic and Environmental Effects

If LRIC estimates suggest more than proportionate increases in the initial blocks, and if sales in these blocks are, as is generally assumed, less elastic than the later blocks, then the net result of LRIC based prices will be a smaller reduction in energy use and pollution than a flat across-the-board increase per kWh sold which would yield the same total revenue.

One of the major arguments for LRIC pricing is that it enables the consumer to make the correct economic choice by setting rate charges at the level of the current cost of an increment to the systems load. LRIC pricing, in comparison with every other pricing system, does not protect against further rate increases that may be required to offset the effects of inflation on the supplier's costs. Strictly speaking, the argument for incremental cost pricing is valid only if all economic choices are evaluated on the same basis. In other words, unless alternate fuels are also priced according to LRIC concepts, the consumer could still make the wrong choice.

TVA ECONOMIC SIMULATION MODEL

INTRODUCTION

As pointed out in the previous paper there are basic economic relationships that exist between the region and the Nation. TVA has always dealt with these relationships and has measured and compared them on a historical basis in terms of various economic indicators.

It is well known that economic development and change in a region depend on national forces as well as regional and local forces. It is also known that there are interactions of policies and programs within the region that can (1) change the set of national-regional relationships and/or (2) cause the total change in the region to be different for a given set of national-regional relationships. Consequently, an interrelated system for making long-range forecasts of economic factors (population, employment, etc.) is needed in order to take these interactions into account and to give some dimension to expected changes in results when key regional variables change. The economic simulation model was developed and is being broadened in order to (1) take account of the impact of both national and regional forces on the regional economy and (2) determine the potential effects of changes in policies and programs upon regional conditions. For example: it is known that changes in population and employment are sensitive to changes in national conditions as well as regional conditions; but, how sensitive are they? Where are present policies and conditions leading? What will be the impact of assumption A versus assumption B--e.g. an increase or decrease in family size? What can be expected to happen to the region if better highway linkage is provided to surrounding markets, relative power costs change, or relative wage costs change? In veiw of these needs, the intention has been to develop a model that would serve as a practical planning tool.

The TVA model is based on the experience gained in the earlier work of others.[1] At the present stage of development, the model consists of two principal sectors: (1) the population-labor force submodel and (2) the employment submodel. A third submodel--the county allocation and land-use submodel--has been conceptually formulated and is being incorporated into the model.

The model as presently formulated has been designed to run for the TVA region as a whole and for nine principal subregions within the region. The model computes for a 60-year projection period, 1960-2020. The 1960-1970 period has been retained in order to verify the ability to trace the experience of this period.

A general description of the two-sector model is presented below along with some illustrative results. Appendix I discusses each of the principal components of the population-labor force submodel, and Appendix II discusses each of the principal components of the employment submodel. Appendix III presents the present stage of development of the county allocation and land use submodel.

---

1. For example, see H. R. Hamilton, et al., A Dynamic Model of the Economy of the Susquehanna River Basin, (Columbus, Ohio: The Battelle Memorial Institute, 1966); Ira S. Lowry, A Model of Metropolis, Rand Corporation Memorandum RM-4035-RC, August 1964); Jobs, People and Land - Bay Area Simulation Study (BASS), (Berkley, California: Center for Real Estate and Urban Economics, 1968). In addition, modifications of the Battelle Model have been undertaken at the University of Alabama which have proved helpful. See The Modification and Testing of a Dynamic Economic Model, (Tuscaloosa, Alabama: Bureau of Business Research, 1969).

POPULATION-LABOR FORCE SUBMODEL

The purpose of the Population-Labor Force Submodel is to project regional population by age and race, and to provide an estimate of the regional labor force.[2] Population is determined by three components --births, deaths, and migration. Births are determined in the model as the product of a set of race and age specific birth rates and the number of people in each child-bearing age group. Birth rates are computed from a birth rate function. Deaths are determined as a function of exogenously determined death rates and population for each age and race group. A table of trends in death rates over time, based on historical and projected death rate series, are introduced to estimate death rates by age and race. Inmigration and outmigration are computed separately and depend on the structure of the population and endogenously computed migration rates.

The labor force calculation is straight forward. A set of age specific labor force participation rates are applied directly to the population. Participation rates are variables in the model and determined by the regional or subregional unemployment rate.

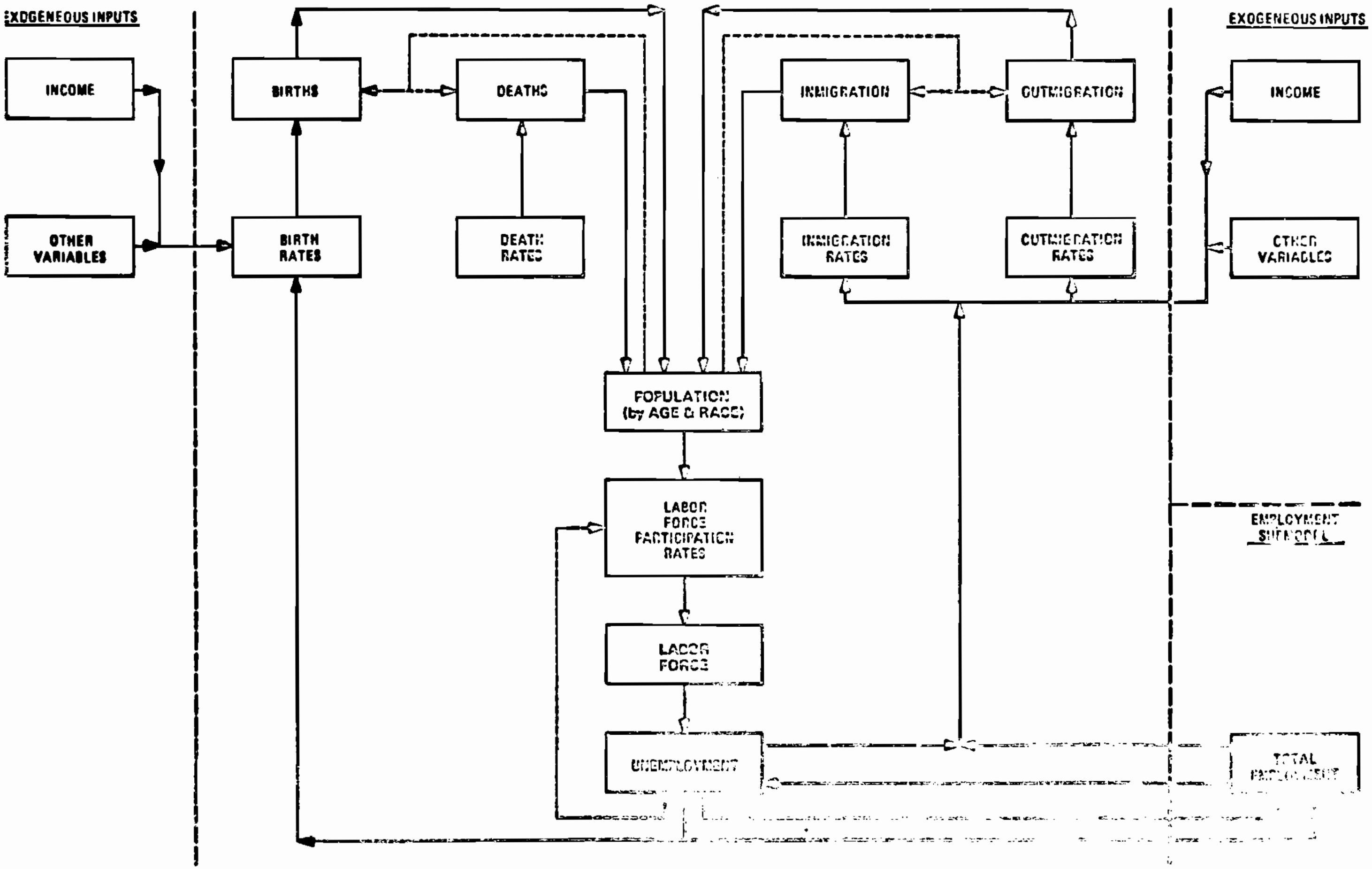
Figure 1 provides a schematic overview of the factors influencing population and the labor force. Solid arrows indicate the main flow of the submodel while dashed arrows show feedback relationships. Appendix I discusses each of the principal components of the Population-Labor Force Submodel in some detail.

---

2. Population is disaggregated into two racial categories and 12 age groups.

FIGURE 1

OVERVIEW OF POPULATION—LABOR FORCE SUBMODEL



EMPLOYMENT SUBMODEL

The purpose of the employment submodel is to project subregional employment by major industry sectors. The conceptual basis of the employment submodel is strongly rooted in export base concepts with the export sector identified as industries with prices determined in national markets. The export or basic sector consists of manufacturing, agriculture, mining, export recreation and export government; but manufacturing is the principle basic industry. Nonbasic industries are identified as those with prices primarily determined in local markets. The traditional trade and service industries form the bulk of the nonbasic sector.

Employment in all the basic industries except manufacturing is provided to the model by means of exogenous trends. A national share approach is used to project employment in manufacturing.[3] The national share approach is perhaps the simplest modeling strategy that can be adopted for a region such as the Tennessee Valley where it is imperative to incorporate the basically favorable location characteristics of the area into the model in order to accurately project manufacturing employment.

At the present time a simple aggregate technique is employed to project employment in the nonbasic (trade and service) sector. Recent work done by the Oak Ridge National Laboratory estimates separate relationships for 10 trade and service industries; this work is presently being incorporated into the submodel.

3. This technique is described in C. M. Tiebout, The Community Economic Base Study (New York: Committee for Economic Development, 1962) Supplementary Paper No. 16, p. 78.

Figure 2 provides a schematic overview of the factors influencing total employment. Appendix II discusses each of the principal components of the employment submodel in some detail.

MODEL RESULTS

Baseline Projections

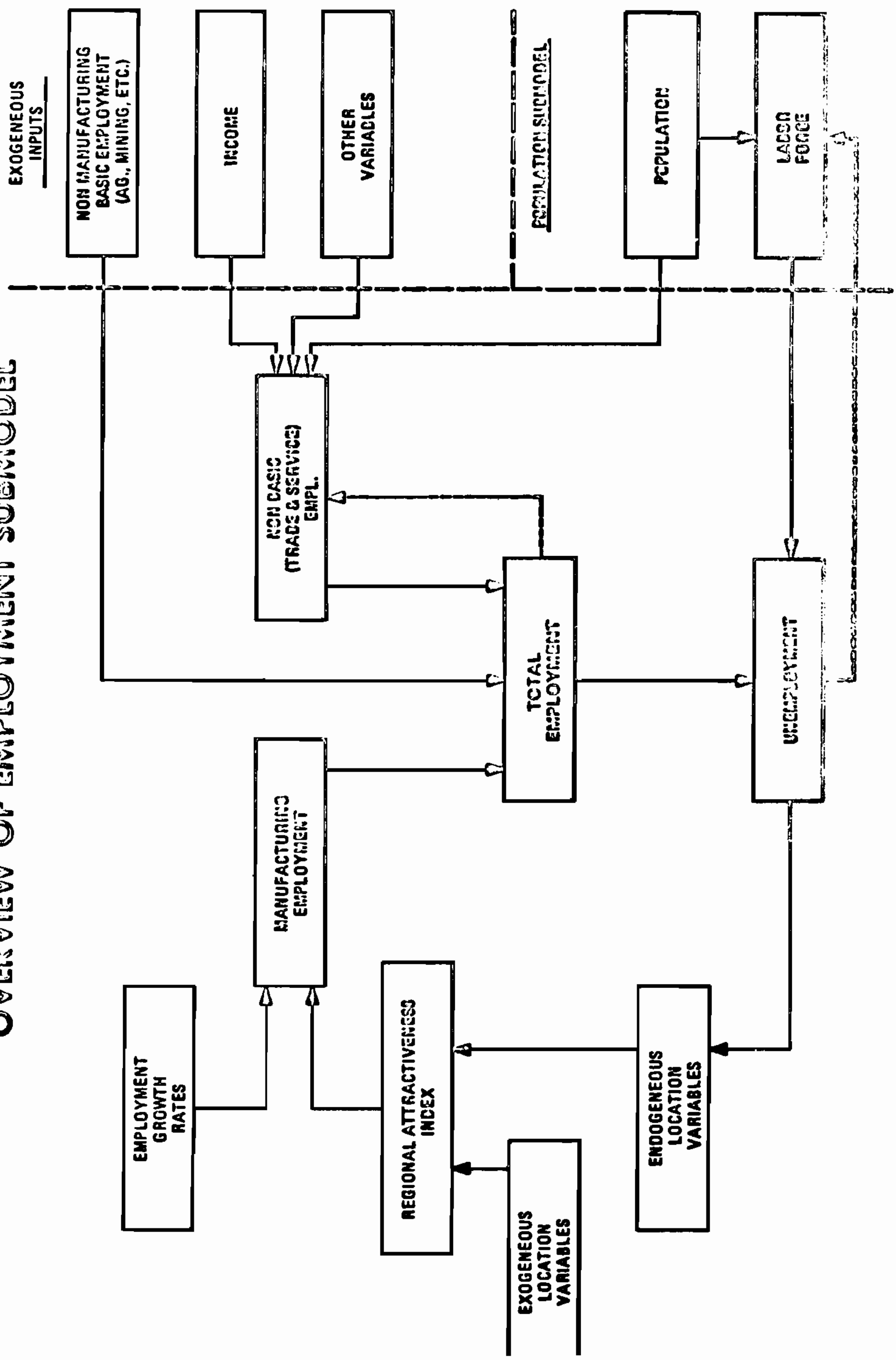
In cooperation with several other national and state agencies, TVA has made available population and employment projections for many areas in the Southeast. An important use of the simulation model is to provide alternative sets of projections which utilize different underlying assumptions. For example, table 1 compares a set of population and employment projections computed by traditional methods with those resulting from the model's "base" run for the 201-county TVA region.

As can be seen from table 1, the "traditional" projections and the model output are in fairly close agreement up to the year 1980. The actual 1970 population was 6,731.3 thousand. The model calculated a population of 6,740.0 thousand (a difference of 8,700) for an error of only 0.13 percent.

After 1980 the "traditional" and model projections begin to diverge rather substantially. The differences are largely due to the birthrate assumptions underlying the two sets of figures. The "traditional" projections are based on the U.S. Census Bureau's "Series C." The model incorporates a lower set of birthrates which approximate "Series D." It is quite evident from these results that long-range projections are very sensitive to alternative formulations

FIGURE 2

OVERVIEW OF EMPLOYMENT SUBMODEL



of the birthrate function. Deriving several alternative sets of projections by traditional methods, however, is an extremely time-consuming task.

Table 1

SIMULATED POPULATION AND EMPLOYMENT PROJECTIONS COMPARED WITH TRADITIONAL PROJECTIONS 1960-2020[1]

Year	Population		Employment	
	Traditional	Simulated	Traditional	Simulated
1960	6,178.9[2]	6,178.9[2]	2,089.7[2]	2,118.6[2]
1970	6,731.3[2]	6,740.0	2,481.1[2]	2,436.0
1980	7,561.7	7,223.0	2,926.0	2,824.1
1990	8,702.2	7,827.0	3,394.2	3,184.3
2000	9,867.5	8,500.2	3,940.3	3,890.0
2020	12,953.6	10,027.0	5,269.6	4,241.2

1. Source: Economic Research Staff, Tennessee Valley Authority.
2. Actual census data.

Table 2 contains simulated net migration data for selected years. These results suggest significant reversals of historical southern migration patterns. In particular, the net inmigration of 48,321 for the year 2000 implies a 10-year total net inmigration approaching one-half million.

Table 2

SIMULATED NET MIGRATION FOR THE TENNESSEE VALLEY

FOR SELECTED YEARS, 1960-2000

Year	Total Migration	White Migration	Black Migration
1960	-29,727	-13,002	-16,705
1965	-15,063	-1,745	-13,318
1970	326	10,239	-9,912
1975	12,323	19,479	-7,126
1980	21,820	26,709	-4,890
1985	29,610	32,779	-3,169
1990	36,401	38,135	-1,734
1995	42,563	43,010	-447
2000	48,321	47,542	779

Table 3 compares the model's migration estimate for the 1960-1970 decade with a recent estimate made by traditional methods.

Table 3

NET MIGRATION FROM THE TENNESSEE VALLEY, 1960-1970

	Model Calculations		
Total Net Migration 1960-1970*	Total Net Migration 1960-1970	White Net Migration 1960-1970	Black Net Migration 1960-1970
-143,000	-139,264	-8,359	-130,905

*Source: Economic Research Staff, Tennessee Valley Authority.

Sensitivity of Population and Employment to Changes in Relative Power Cost

An important parameter used to determine changes in manufacturing employment from one time period to another is change in the region's relative location cost advantage. Relative location cost is a composite index of traditional industrial location factors such as labor costs, material costs, and transportation costs, plus, in the case of the TVA model, the cost of electric power. Changes in the cost of electric power could, therefore, have a direct effect on the growth of manufacturing employment. Any alteration in the growth rate of manufacturing employment would generate secondary effects in other areas; for example, population growth and the level of migration.

In 1960 relative power cost in the TVA region was .546.[4] From 1960 to 1970, relative power cost increased to .753 indicating a decline in the TVA power cost advantage. After 1970 the trend in the RPC began to change. It was .716 in 1973. Figure 3 illustrates the recent trend and three alternative future projections of relative power cost. The three alternative future projections are defined as:

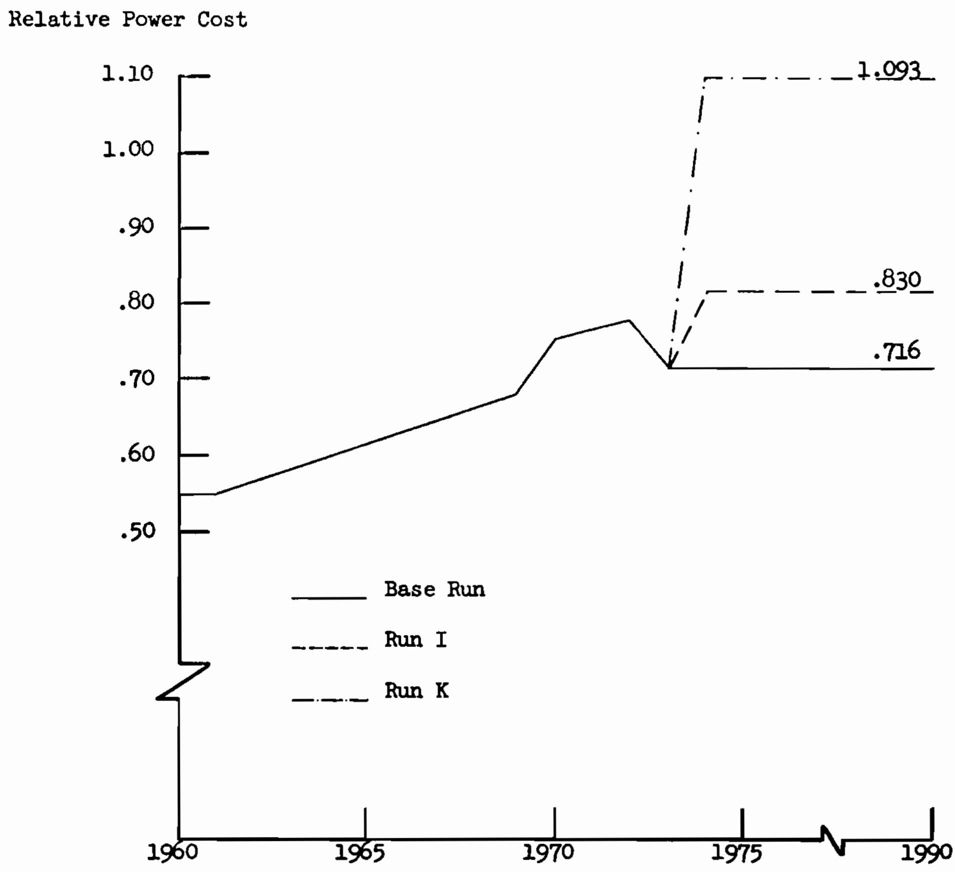
1. Base run--RPC advantage of 1973 will remain constant.
2. Run I--TVA will increase power rates by 20 percent in 1974, but no similar increase will be made by companies in competing areas. This will increase RPC to .830 in 1974 and this RPC will remain constant thereafter.
3. Run K will increase rates during 1974 such that RPC will be 1.093 and remain constant thereafter.

---

4. Relative power cost is computed as a ratio of TVA industrial power rates to that of seven private power companies surrounding the the TVA region.

Figure 3

Trends and Alternative Projections of Relative Power Cost to Industrial Users: 1960-1990



The impact of the three alternative projections of RPC on employment growth, population growth, and migration behavior was examined for the period 1970-1990 by comparing Run I and Run K with the Base Run.

The impact of increases in relative power cost on total manufacturing employment is relatively minor. This can be seen from figure 4 and table 4. By 1990 total manufacturing employment in Run I is 3,093 below the Base Run while Run K is 10,172 below the Base Run. The 1990 Run K difference represents a level of employment that is 1.0 percent below the Base Run. The relatively small impact of rising RPC on total manufacturing employment in the region is due to two major factors: (1) Electric power costs as a percent of total production costs are not large for the industries which encompass over 75 percent of the region's total manufacturing employment. (2) The industries in which electric power costs are relatively large are not growing rapidly in the region. Thus, these industries will represent a smaller percentage of total regional manufacturing employment in the future.

Heavy power using industries and major processing industries account for approximately one-half the total impact of rising RPC on manufacturing employment. Figures 5 and 6 show the simulated effect of the three alternative RPC's on these two groups of industries. In 1970 these two groups of industries accounted for 23.7 percent of total regional manufacturing employment. The disproportionate effect is largely due to the importance of electric power in the cost of production of these industries.

Figure 4

Simulated Effect of Increases in Relative Power Cost on
Manufacturing Employment in the TVA Region
1970-1990

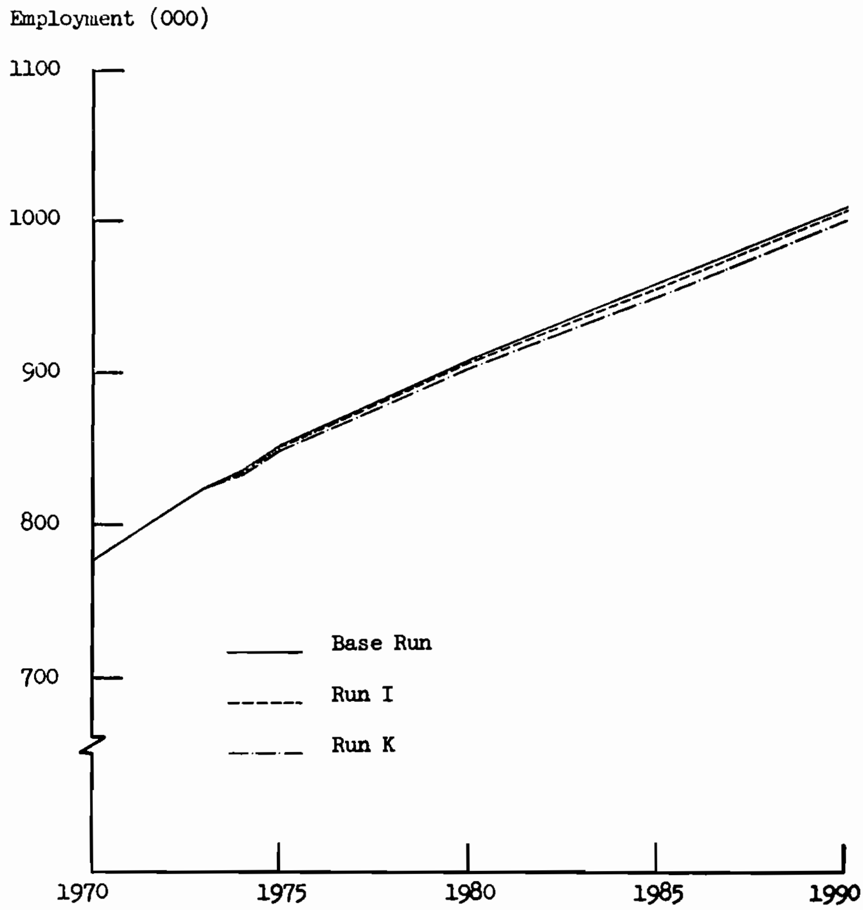


Table 4

SIMULATED EFFECT OF INCREASE IN RELATIVE POWER COST ON EMPLOYMENT

IN MANUFACTURING INDUSTRIES IN THE TVA REGION 1970-1990

	Projected Employment			Difference from Base Run		Difference as Percent of Base Run	
Year	Base Run	Run I	Run K	Run I	Run K	Run I	Run K
1970	778,264	778,264	778,264	0	0	0	0
1973	825,000	825,000	825,000	0	0	0	0
1974	838,806	838,747	838,603	-59	-203	*	*
1975	852,032	851,801	851,266	-231	-766	*	-0.1
1980	909,243	908,059	905,333	-1,184	-3,910	-0.1	-0.4
1985	960,648	958,527	953,576	-2,121	-7,072	-0.2	-0.7
1990	1,013,558	1,010,465	1,003,386	-3,093	-10,172	-0.3	-1.0

*Less than .05 percent.

Figure 5

Simulated Effect of Increases in Relative Power Cost on Employment in Heavy Power-Using Industries (SIC 28, 29, 33) in the TVA Region 1970-1990

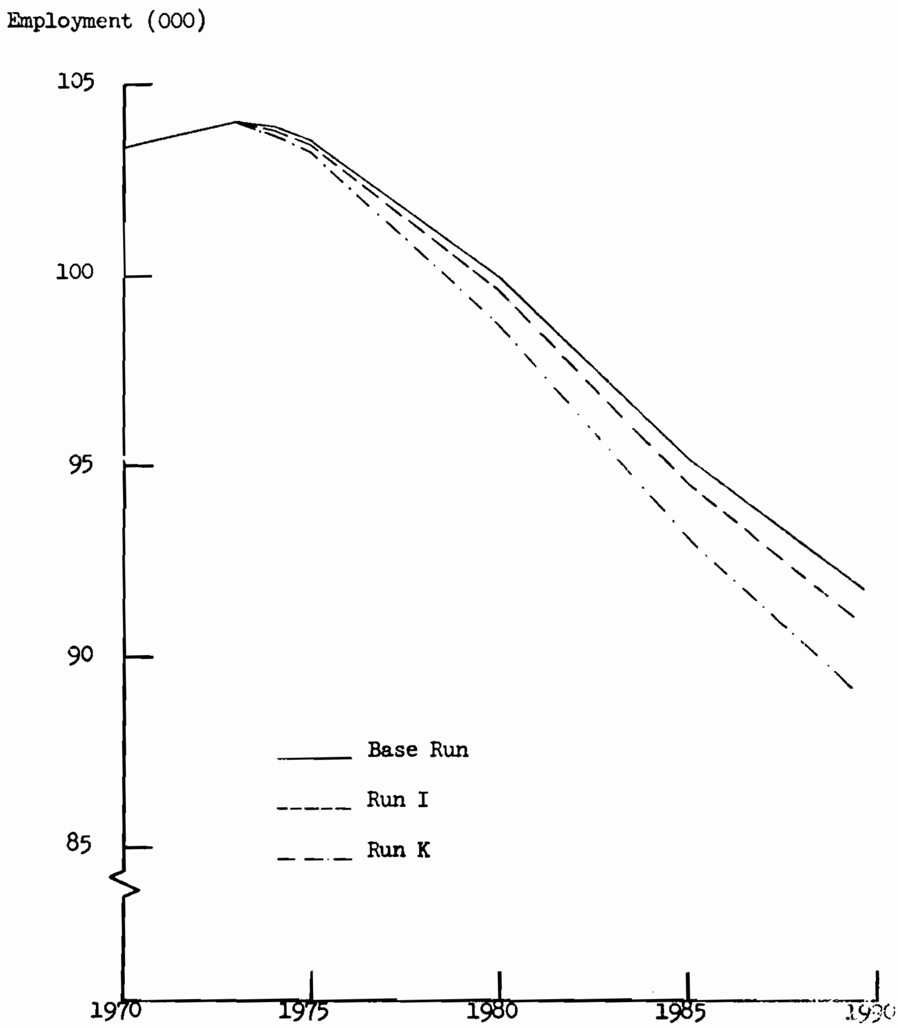
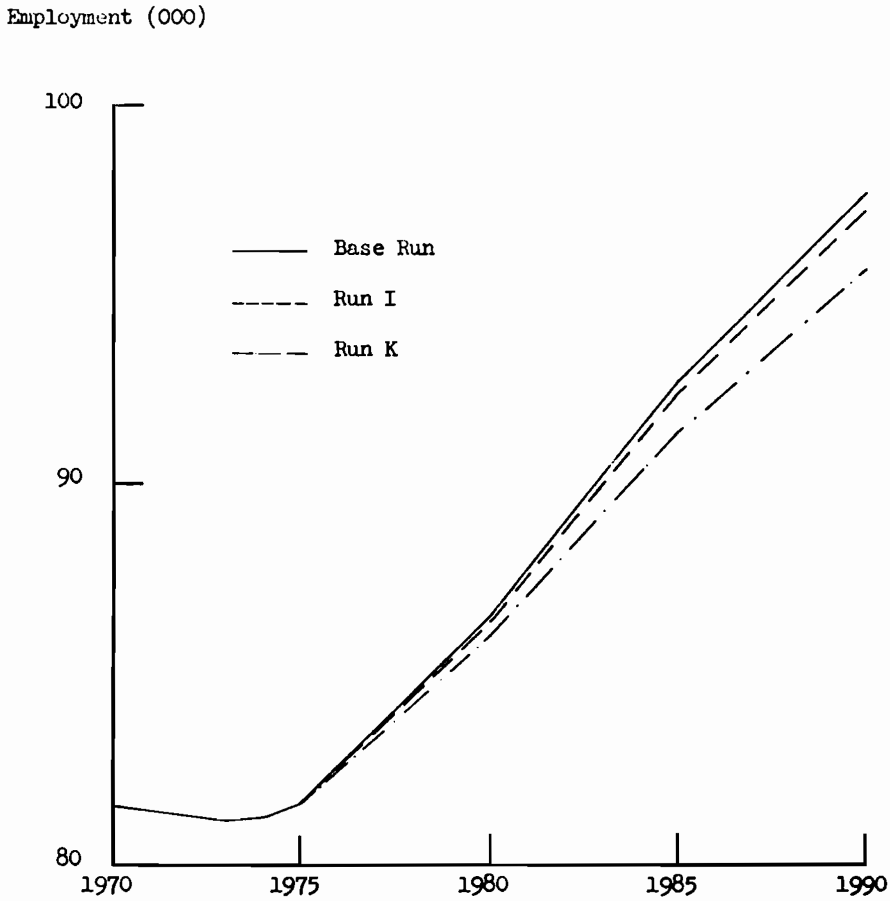


Figure 6

Simulated Effect of Increases in Relative Power Cost on Employment
in Major Processing Industries (SIC 24, 26, 32) in the TVA Region
1970-1990



The effect of rising RPC on projected population is negligible as can be seen from figure 7. For example, the 1990 Run K population projection is 2.6 thousand below the Base Run. This figure is less than .05 percent of the projected Base Run population of 7,825.6 thousand.

The Base Run projects net immigration of 23,423 in 1980 and 37,492 in 1990. The Run I and Run K projections of net migration are only slightly lower than the Base Run. These effects can be seen in figure 8.

The simulation results indicate that at aggregate levels of employment and population the deterioration of the region's RPC has only minor effects on future economic development. The results show relatively small total employment and population effects; however, it should be noted that more serious consequences could occur in specific industries at specific locations since aggregate declines in employment and population are not likely to be spread evenly over the entire region.

SUMMARY

A two-sector economic simulation model for the TVA region has been developed. A third submodel--the county allocation and land use submodel--has been conceptualized and is presently being incorporated into the overall model. The model provides output at an aggregate level which indicates how various regional activities would react to alternative assumptions.

Regional activities as determined by the model, however, are not likely to be evenly spread over the entire region nor are they

Figure 7

Simulated Effect of Increases in Relative Power Cost on
Population in the TVA Region
1970-1990

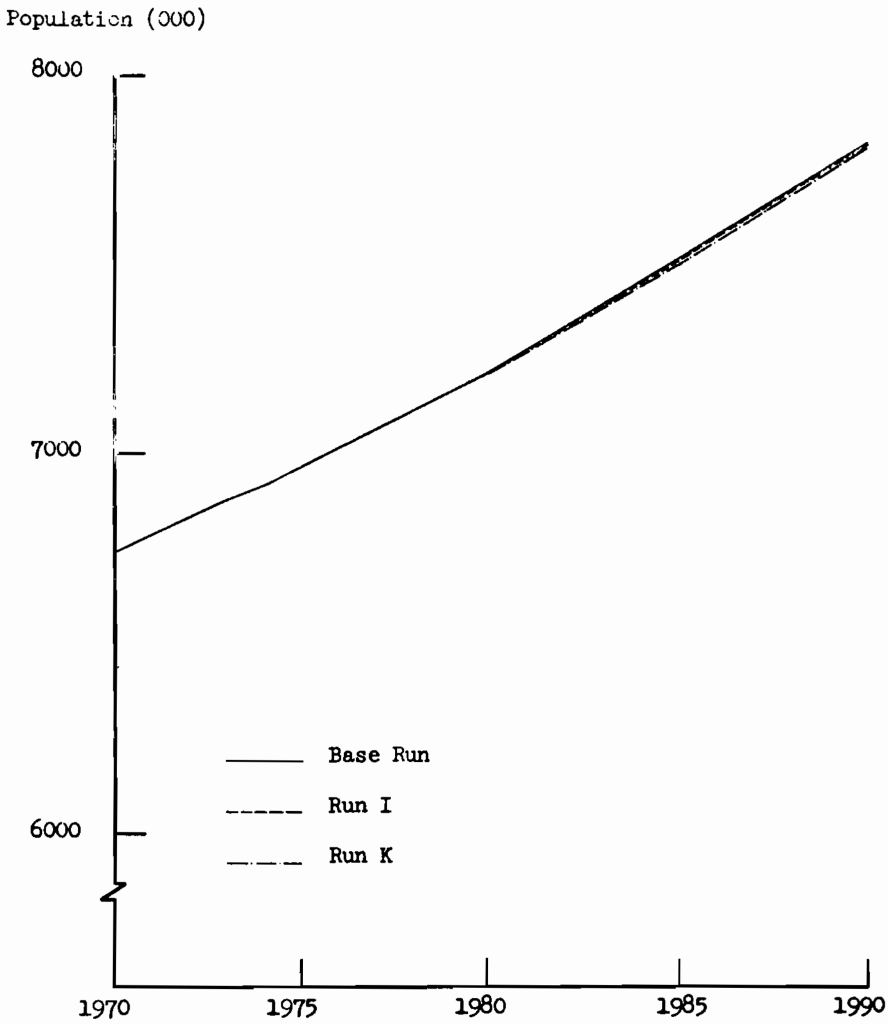
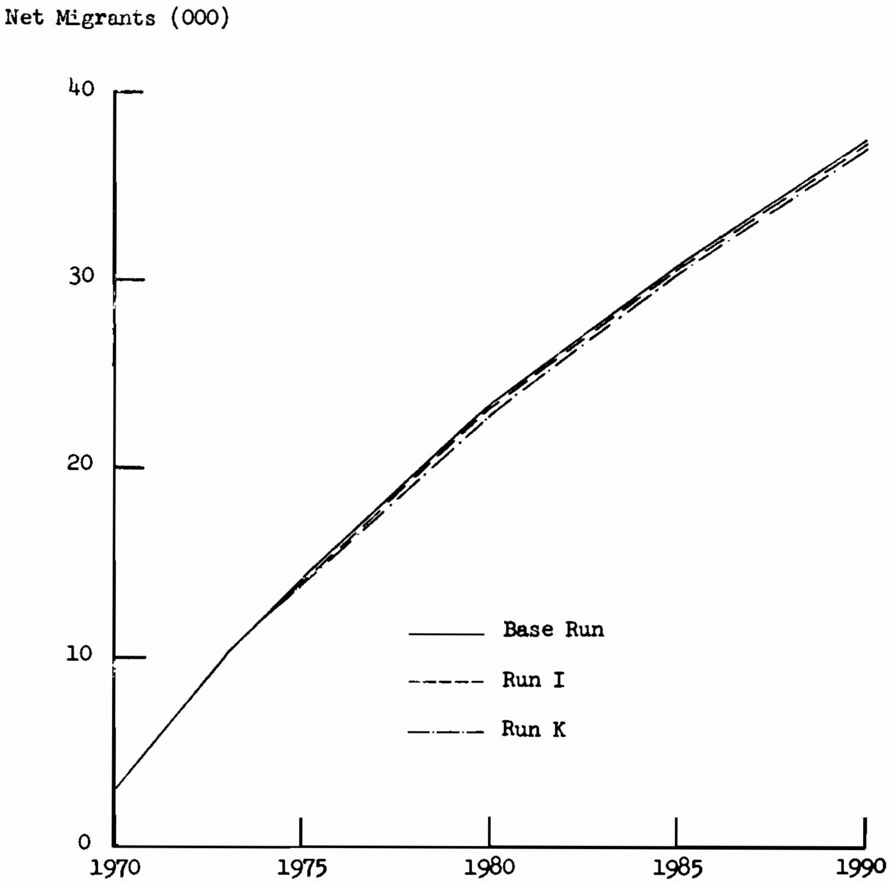


Figure 8

Simulated Effect of Increases in Relative Power Cost on
Net Migration in the TVA Region
1970-1990



likely to occur evenly within various industry groups. Consequently, it is necessary to develop and utilize other techniques and methods for system planning with respect to industrial promotion and planning as well as community development and related land use planning. The next two papers are devoted to the methodology and models used in industrial development and subregional and community development.

APPENDIXES

APPENDIX I

COMPONENTS OF THE POPULATION-LABOR FORCE SUBMODEL

BIRTHS AND THE BIRTH RATE FUNCTION

Birth rates in the South have been extremely volatile since 1945. Historically, they have been above national rates. However, since 1960 they have declined at a rate faster than the national average.

An anlaysis of the 16 Southern states and 11 contingent states has revealed that changes in regional birth rates can be accurately predicted by seven social and economic variables used in combination with national trend factors. The seven indicators which have been identified for their influence on births are the following: (1) level of educational attainment, (2) per capita income, (3) unemployment rate, (4) percent employed in manufacturing, (5) race, (6) age, and (7) potential female producers. The model provides output on all but two of these variables. Race and age are accounted for by dividing the population into its age and race components while unemployment is calculated as the difference between total labor force and employment. The percent employed in manufacturing also is provided by the employment submodel. The level of educational attainment and per capita income are provided exogenously.

The original development of this sector focused on using aggregate economic and social indicators to estimate the values of the behavioral coefficients of the birth rate function. This approach has proved conceptually unsatisfactory as it renders the variables statistically insignificant when estimated for the specific age and racial groups used in the model. This deficiency is being corrected for by incorporating into the estimating equations for birth rates the employment and educational attainment variables disaggregated by age and race. The variable potential female producers is another attempt to correct for the sexual bias in the estimates of birth rates which is due to the fact that the model is not structured with a sex component. This variable is a weighted difference between female population and females employed.

The modeling strategy is to compute an unadjusted subregional birth rate as a function of the seven variables previously identified; that is,

$$URBR_{ij}^{t} = \sum_{z=1}^{7} b_{ij}^{tz} \quad X_{ij}^{tz} \tag{1.1}$$

where

$URBR_{ij}^{t}$ = the unadjusted subregional birth rate for age-race cohort i in subregion j at time t.

X_{ij}^{tz} = the z^{th} factor determining the unadjusted subregional birth rate (e.g. unemployment rate, per capita income, etc.) for age-race cohort i in subregion j at time t.

b_{ij}^{tz} = the coefficient of the z^{th} factor determining the unadjusted subregional birth rate for age-race cohort i in subregion j at time t.

with the coefficients b_{ij}^{tz} being established by means of regression techniques. The unadjusted birth rate is then "adjusted" by means of a national trend factor as follows:

$$ARBR_{ij}^{t} = URBR_{ij}^{t} * BRTRN_{i}^{tn} \tag{1.2}$$

where

$ARBR_{ij}^{t}$ = the adjusted subregional birth rate for the i^{th} age-race cohort for subregion j at time t.

$BRTRN_{i}^{tn}$ = the n^{th} alternative national trend in birth rates for age-race cohort i in time t.

The national trend factors are derived from available Bureau of the Census birth rate projections (i.e. Series C, Series D, Series E, etc.). Following the computation of the adjusted subregional birth rate, births are computed according to equation (1.3).

$$BRTH_{ij}^{t} = POP_{ij}^{t} * ARBR_{ij}^{t} \tag{1.3}$$

where

$BRTH_{ij}^{t}$ = live births attributed to the i^{th} age-race cohort in subregion j at time t.

POP_{ij}^{t} = the population of the i^{th} age-race cohort in subregion j at time t.

By means of equations (1.2), both national and regional factors are brought to bear on birth rates. Equation (1.2) represents the same approach to incorporating both local and non-local influences on birth rates employed in the latter versions of the Battelle Model.[1] In the Battelle case, however, the equivalent of equation (1.1) which

---

1. Hamilton, H. R., et al., A Dynamic Model of the Economy of the Susquehanna River Basin (Columbus, Ohio: The Battelle Memorial Institute, 1966), pp. E 1-14.

feeds directly into equation (1.2) contained only a single explanatory factor (unemployment) whereas in the TVA model equation (1.1) contains seven.

DEATHS AND DEATH RATES

Extensive modeling of the death rate function has not been undertaken. Death rates are merely trended downward over time to reflect longer life expectancies in the future. Trends are based on analysis of historical data.

The decision to employ a simple trend projection for death rates is based on the assumption that model results are not particularly sensitive to alternative assumptions regarding death rates. The computational procedure for deaths is as follows:

$$DRTE^{t}_{ij} = IDRTE_{ij} * DTRN^{t}_{ij} \tag{1.4}$$

where

$DRTE^{t}_{ij}$ = the death rate for the i^{th} age-race cohort in subregion j at time t.

$IDRTE_{ij}$ = the death rate for the i^{th} age-race cohort in subregion j at time t = 0.

$DTRN^{t}_{ij}$ = the death rate trend factor for the i^{th} age-race cohort in subregion j at time t.

and

$$DTH^{t}_{ij} = DRTE^{t}_{ij} * POP^{t}_{ij} \tag{1.5}$$

where

DTH^t_{ij} = deaths attributed to the i^{th} age-race cohort in subregion j at time t.

THE MIGRATION FUNCTION

The model was initially programmed with a net migration function which computed net migration flows by age and race as a function of regional relative wage. The model is now being reformulated to employ separate inmigration and outmigration functions. The use of net migration rates was based on the assumption that in- and outmigration behaved symetrically. Recent investigations, however, have shown that this is not the case.[2] Specifically, outmigration rates have been found to vary on the basis of the demographic characteristics of the population such as age-race-sex composition as well as responding to economic conditions. On the other hand, inmigration has been found to be strongly influenced by economic factors alone.

The principal economic variables influencing both in- and outmigration are (1) relative income or wage levels, (2) the unemployment rate and (3) the rate of growth of employment. The demographic effect on outmigration is largely controlled for by disaggregating by age and race. Any residual demographic influence is accounted for by including a population density variable in the outmigration equations.

---

2. See Ira S. Lowry, Migration and Metropolitan Growth: Two Analytical Models (San Francisco: Chandler Publishing Co., 1966); C. E. Trott, "An Analysis of Outmigration," 1971 Proceedings, American Statistical Association, Washington, D.C., 1972; J. Eblen, A Study of Outmigration of Workers from Southeastern Metropolitan Areas, unpublished doctoral dissertation, The University of Tennessee, Knoxville, Tennessee, 1974.

Coefficients are based on the composite results of several recent studies (see footnote 2). In general form, therefore,

$$OMRT^{t}_{ij} = \sum_{w=1}^{3} a^{tw}_{ij} \; E^{tw}_{ij} + \sum_{r=1}^{3} c^{tr}_{tj} \; D^{tr}_{ij} \qquad (1.6)$$

where

$OMRT^{t}_{tj}$ = the outmigration rate for the i^{th} age-race cohort in subregion j at time t.

E^{tw}_{ij} = the w^{th} economic factor determining the outmigration rate of the i^{th} age-race cohort in subregion j at time t.

D^{tr}_{ij} = the r^{th} demographic factor determining the outmigration rate of the i^{th} age-race cohort in subregion j at time t.

a^{tw}_{ij} = the coefficient of the w^{th} economic factor determining the outmigration rate of the i^{th} age-race cohort in subregion j at time t.

c^{tr}_{ij} = the coefficient of the r^{th} demographic factor determining the outmigration rate of the i^{th} age-race cohort in subregion j at time t.

and

$$IMRT^{t}_{ij} = \sum_{g=1}^{3} s^{tg}_{ij} \; E^{tg}_{ij} \qquad (1.7)$$

where

$IMRT^{t}_{ij}$ = the inmigration rate for the i^{th} age-race cohort in subregion j at time t.

E^{tg}_{ij} = the g^{th} economic factor determining the inmigration rate for the i^{th} age-race cohort in subregion j at time t.

s_{ij}^{tg} = the coefficient of the g^{th} economic factor determining the inmigration rate of the i^{th} age-race cohort in subregion j at time t.

Outmigration, inmigration, and net migration are then computed by means of

$$OMIG_{ij}^{t,t+1} = OMRT_{ij}^{t} * POP_{ij}^{t} \tag{1.8}$$

$$IMIG_{ij}^{t,t+1} = IMRT_{ij}^{t} * POP_{ij}^{t} \tag{1.9}$$

$$NMIG_{ij}^{t,t+1} = IMIG_{ij}^{t,t+1} - OMIG_{ij}^{t,t+1} \tag{1.10}$$

where

$OMIG_{ij}^{t,t+1}$ = the number of outmigrants from age-race cohort i and subregion j during the period t,t+1.

$IMIG_{ij}^{t,t+1}$ = the number of inmigrants to age-race cohort i and subregion j in period t,t+1.

$NMIG_{ij}^{t,t+1}$ = the net number of migrants added to age-race cohort i in subregion j during period t,t+1.

LABOR FORCE CALCULATION

To obtain a labor force participation rate at time t for age-race cohort i, a target or long run function is employed. This function has been estimated by means of cross-section regression analysis for southern labor markets and states. The unemployment rate in period t-1 is used to evaluate the particpation rate function in time period t. The calculated rate becomes the target rate. The target rate is compared to the actual rate used to compute labor force in period t-1.

If the two rates are different, the actual rate is adjusted towards the target at a rate equal to k where $0 \leq k \leq 1$. The factor k accounts for markets not adjusting instantaneously to changing conditions. The computational routine may be described as follows:

$$TLFPR_{ij}^{t} = o_j + m_j \quad UNEMP_j^{t-1} \tag{1.11}$$

$$ALFPR_{ij}^{t} = ALFPR_{ij}^{t-1} + k \left(TLFPR_{ij}^{t} - ALFPR_{ij}^{t-1}\right) \tag{1.12}$$

where

$TLFPR_{ij}^{t}$ = the long-run equilibrium (target) labor force participation rate for the i^{th} age-race cohort in subregion j at time t.

$ALFPR_{ij}^{t}$ = the actual labor force participation rate for the i^{th} age-race cohort in subregion j at time t.

$UNEMP_j^{t-1}$ = the regional unemployment rate in subregion j at time t-1.

The labor force is then computed

$$LFRCE_{ij}^{t} = ALFPR_{ij}^{t} * POP_{ij}^{t} \tag{1.13}$$

where

$LFRCE_{ij}^{t}$ = the portion of the labor force in age-race cohort i in subregion j at time t.

while the regional unemployment rate is found by means of equation (1.14)

$$UNEMP_j^{t} = \left(TEMPLT_j^{t} - \sum_{i=1}^{n} LFRCE_{ij}^{t}\right) \div \sum_{i=1}^{n} LFRCE_{ij}^{t} \tag{1.14}$$

where

$TEMPLT_j^t$ = total employment in subregion j at time t.

APPENDIX II

COMPONENTS OF THE EMPLOYMENT SUBMODEL

GROWTH IN EMPLOYMENT IN MANUFACTURING INDUSTRIES

A two-digit SIC breakdown of manufacturing industries is employed in the model. For each industry an index of relative attractiveness is computed based on three traditional location variables; relative wage levels, market potential, and access to resources plus a fourth variable, relative power cost. The latter variable, of course, is of particular interest to TVA. Relative wage levels are provided endogenously. The other three factors are exogenous parameters that are trended over time. Attractiveness at time t of a typical subregion j for a typical industry i is computed as follows:

$$ATRCT^{t}_{ij} = CONST_{i} + W_{i}\left(RELWGE^{t}_{ij}\right) + W_{i}\left(MKTPOT^{t}_{ij}\right) + W_{i}\left(RCSRS^{t}_{ij}\right) + W_{i}\left(RPWCST_{ij}\right) \qquad (2.i)$$

where

$ATRCT^{t}_{ij}$ = 1 + index of relative locational attractiveness for industry i (e.g. SIC 20) in subregion j at time t.

$RELWGE^{t}_{ij}$ = the relative wage index for industry i in subregion j at time t.

$MKPOT^{t}_{ij}$ = the market potential facing industry i in subregion j at time t.

$RCSRS^t_{ij}$ = the accessibility of natural resources and other inputs to industry i located in subregion j at time t.

$RPWCST^t_{ij}$ = the relative cost of electric power facing industry i in subregion j at time t.

W_i = national industry cost weights (the percent of total cost represented by each locator variable).

$CONST_i$ = constant cost weight determined such that $CONST_i = 1 - \sum_{g=1}^{4} W_{ig}$ where the g are the locator variables employed in equation (3.1).

The index of relative attractiveness and national employment growth rates for each industry are then employed to compute regional employment growth in each industry. A typical equation in region j and industry i is

$$PCEMP^{t,t+1}_{ij} = NTGRW^{t,t+1}_{ij} + Z^t_j * RLTRCT^t_{ij} \tag{2.2}$$

where

$PCEMP^{t,t+1}_{ij}$ = percentage change in regional employment in industry i and subregion j during the next time period.

$NTGRW^{t,t+1}_{ij}$ = national growth rate in employment in industry i in the next time period.

$RLTRCT^t_{ij}$ = index of relative attractiveness for industry i in subregion j at time t.

Z^t_i = weight on regional location factors in industry i at time t.

Essentially, the technique described by equation (2.2) is to increment regional employment in each manufacturing industry at the national rate except in cases where the region is particularly attractive (or unattractive) to the industry. If the region is relatively attractive (unattractive) regional employment will grow at a rate faster (slower) than the national rate. The computational procedure is identical for each industry SIC 20-39 (SIC 19 has been combined with SIC 34).

National employment growth rates are derived from national projections of output and productivity for each industry. This technique has been incorporated into the model primarily due to the length of the projection period (60 years). Examination of historical data indicated that time series of output and productivity were much smoother than corresponding series on employment. Employment growth rates are computed as follows:

$$NEMPLT_i^t = NVAD_i^t \div NPRD_i^t \tag{2.3}$$

$$NTGRW_i^t = \left(NEMPLT_i^t \div NEMPLT_i^{t-1}\right) - 1 \tag{2.4}$$

where

$NEMPLT_i^t$ = projected national employment in industry i at time t.

$NVAD_i^t$ = projected national output in industry i at time t.

$NPRD_t^t$ = projected productivity of labor in industry i at time t.

THE RELATIVE WAGE MECHANISM

The parameter relative wage is the only endogenous location factor affecting the growth of manufacturing employment. Following the formulation of other models, an aggregate manufacturing relative wage is calculated as an inverse function of the regional unemployment rate.[1] The concept underlying this formulation is borrowed from Forrester. The system being modeled is defined as existing in an environment. Internal conditions, however, result in parameter values within the system differing from those in the environment.[2] This line of reasoning leads directly to the formulation of a parameter such as relative wage being solely a function of internal (regional) conditions.

In the model, the manufacturing relative wage is used as a predictor variable to obtain industry specific relative wages for each manufacturing, service, and exogenous industry. So as to not freeze the industry wage structure, the percent of employment in each industry enters the function as a moderator variable. In the manufacturing sector, it is the industry specific (i.e. SIC 20, SIC 30, etc.) relative wages that enters into the computation of the index of relative attractiveness.

---

1. Hamilton, et al., A Dynamic Model, op. cit., pp. H 1-4.
2. See J. W. Forrester, Urban Dynamics, (Cambridge, Massachusetts: The MIT Press, 1969.

RELATIVE MARKET POTENTIAL

This location parameter reflects the competitive advantage (or disadvantage) subregions within the TVA region enjoy when seeking to attract industries with a high degree of market orientation. The parameter is computed outside the formal model with model input consisting of several alternative trends. Each separate trend is based on a different set of assumptions with regard to the projected size of the market to be served and the projected ease in serving it.

Market potentials are computed for each manufacturing industry with the extent of the market based on existing sale distribution data. For example, products of manufacturers in the TVA region are shipped to most parts of the country with the exception of the far West and New England. The majority of products shipped, however, are destined for the South. Market areas differ for each SIC industry.

For a typical subregion j, market potential is computed as follows:

$$MKPOT_{ij}^{t} = a_{ij}^{t} \sum_{n=1}^{n} \frac{P^{tm}}{DT_j^{tm}} + b_{ij}^{t} \sum_{n=1}^{n} \frac{P^{tm}}{DR_j^{tm}} + c_{ij}^{t} \sum_{m=1}^{n} \frac{P^{tm}}{DW_j^{tm}} + d_{ij}^{t} \sum \frac{P^{tm}}{DO_j^{tm}} \qquad (2.5)$$

where

$MKPOT_{ij}^{t}$ is as defined previously and

P^{tm} = population of market (state or subregion) m at time t.

DT_j^{tm} = the time-distance between subregion j and m when traveling by truck at time t.

DR_j^{tm} = the time-distance between subregion j and m when traveling by rail at time t.

DW_j^{tm} = the time-distance between subregion j and m when traveling by water at time t.

DO_j^{tm} = the time distance between subregion j and m when traveling by any other mode of transportation in time t.

a_{ij}^{t} = the proportion of shipments from industry i in subregion j by truck at time t.

b_{ij}^{t} = the proportion of shipments from industry i in subregion j by rail at time t.

c_{ij}^{t} = the proportion of shipments from industry i in subregion j by water at time t.

d_{ij}^{t} = the proportion of shipments from industry i in subregion j by other means of transportation at time t.

Writing the market potential equation in this disaggregated fashion has several advantages. First, it makes explicit the possibility of trending the mass (population) and time-distance factors over time. Second, it allows improvements in transportation systems to be considered by mode and thus permits sensitivity tests for this factor. Finally, it relates changes in market size and time-distance to each industry individually.

RELATIVE ACCESS TO RESOURCES

This location parameter is intended to indicate the locational advantage of a subregion with respect to all major production requirements not just proximity to natural resources. Clearly, these may be agglomerative, industrial complex, or raw material in nature.

For each industry, the three most important intermediate inputs are identified at the two digit level. The gravity-potential concept is then employed to compute an index of access to resources as follows:

$$RCSRS_{ij}^{t} = e_i^t \sum_{m=1}^{n} \frac{M_i^{tm}}{D_j^{tm}} + g_i^t \sum_{m=1}^{n} \frac{S_i^{tm}}{D_j^{tm}} + k_i^t \sum_{m=1}^{n} \frac{T_i^{tm}}{D_j^{tm}} \qquad (2.6)$$

where

$RCSRS_{ij}^{t}$ is as defined previously and

M_i^{tm} = the output (production or sales) of the major intermediate input of industry i produced in subregion m at time t.

S_i^{tm} = the output of the second most important intermediate input of industry i produced in subregion m at time t.

T_i^{tm} = the output of the third most important intermediate input of industry i produced in subregion m at time t.

e_i^t = the proportion of total factor input cost represented by the most important intermediate input of industry i at time t.

g_i^t = the proportion of total factor input cost represented by the second most important intermediate input of industry i at time t.

k_i^t = the proportion of total factor input cost represented by the third most important intermediate input of industry i at time t.

The number of potential suppliers is restricted by considering only subregions located in the South.

OTHER BASIC INDUSTRY

Employment for several industries is not generated endogenously. Agriculture has been a declining industry (in terms of employment) in the Tennessee Valley for a number of years. Changes in employment in agriculture to 2020 are provided in a table based on forecasts of future employment in the industry compiled by TVA and the Department of Commerce. Mining is a relatively small sector in most of the Tennessee Valley. Changes in employment are derived in a manner similar to that employed for agriculture.

To project export employment in recreation and government, it is first necessary to break these two employment groups into export and non-basic components. Both location quotients and minimum requirement techniques have been employed in this regard. The only portion of export government employment that can be projected with great certainty (i.e. other than status-quo) are (1) large educational institutions with well established enrollment objectives and (2) newly established government installations with well defined production commitments that can be translated into manpower requirements. In the case of export recreation, growth or decline depends on the marketability of the region's export products. This is being established by employing the gravity-potential concept to estimate export recreation demand.

NONBASIC INDUSTRIES

At the present time a simple aggregate technique is employed in the model to project employment in the service (nonbasic) sector.[3] Two classes of service industries are identified: (1) consumer trades and services and (2) business services.

Consumer trades and services is composed of wholesale and retail trade and other consumer-oriented industries, SIC 60-90. At the present time, employment change in consumer trades and services is a function of regional population growth. Business services is composed of those industries that provide services to other industries (e.g. SIC 40-49). Growth in employment in business services is a function of the growth in total employment.

As noted earlier, recent work done at the Oak Ridge National Laboratory is being incorporated into the model. In that forumlation, both industry detail and the number of explanatory variables is greatly increased. The specific impact of population, income and other variables on individual industries will, therefore, be identified explicitly.

---

3. The actual computation of changes in employment in the two service industries is taken directly from the Battelle Model. See Hamilton, A Dynamic Model, op. cit., pp. C 33-36.

APPENDIX III

COUNTY ALLOCATION AND LAND REQUIREMENTS SUBMODEL

The objective of this submodel is twofold: (1) Assign the growth activity of a subregion to its constituent counties. (2) Project a set of implicit land use requirements based on changes in county activity.

The County Allocation and Land Requirements Submodel is designed to be run for each of nine subregions of the TVA region. Activity levels are projected for each time period by the Population and Employment Submodels and assigned to one of three broad sectors in the County Allocation and Land Requirements Submodel. The three sectors are industrial, household, and service. The industrial sector includes the subregions basic industries, i.e., manufacturing, agriculture, mining, export recreation, and export government. Two methods of allocation are employed in the industrial sector. (1) Subregional changes in employment in agriculture, mining, export recreation, and export government are allocated on the basis of their historical location pattern. (2) Manufacturing employment, however, is allocated to counties in a more sophisticated manner by means of a county manufacturing location algorithm. The algorithm assigns increases in manufacturing employment to counties on the basis of supply factors and site characteristics. It is assumed that export demand potential will not vary among the counties of a subregion.

In the household sector it is assumed that the primary determinant of residential site selection is the location of basic employment.

Changes in subregional population are distributed to counties on the basis of changes in industrial location patterns among counties. Other factors which are included as determinants of population distribution are accessibility to service activity and existing residential patterns. The service sector encompasses all the traditional trade and service industries with the exception of export recreation. This activity is assumed to serve local clients and is distributed in accord with the distribution of population.[1]

ALLOCATING INCREASES IN MANUFACTURING EMPLOYMENT

In this section a general description of the industrial allocation process employed for manufacturing industries will be given. For each of the counties in a subregion an index is calculated for each locator variable.

$$I^i_{tj} = \frac{X^i_{tj} - Min^i_t}{Max^i_t - Min^i_t} \tag{3.1}$$

where

I^i_{tj} = the index for the i^{th} factor for the j^{th} county for period t.

X^i_{tj} = the actual magnitude of the i^{th} factor for county j for period t.

Min^i_t = the minimum value of x^i for all j during period t.

1. The principal antecedents of this submodel are Ira S. Lowry, A Model of Metropolis, Rand Corporation Memorandum RM - 4035-RC, August 1964; and Jobs, People and Land - Bay Area Simulation Study (BASS). (Berkley, California: Center for Real Estate and Urban Economics, 1968).

Max^i_t = the maximum value of x^i for all j during period t.

i = 1,...,n is a locator variable index.

j = 1,...,m is a county index.

t = a time index.

Equation (3.1) reduces all variables to numbers between 0 and 1 (i.e., $0 \leq I^i_{tj} \leq 1$ for all i, j, and t). It allows the comparison of different kinds of variables such as wages, accessibility, etc.

Once these indexes are calculated they are combined by means of appropriate weighting to give scores for the counties. Thus, there are 20 different scores (measures of relative attractiveness) for each county corresponding to each of the 20 manufacturing industries on which the employment submodel provides input data. In this way each county's supply of the various factors important to the k^{th} industry will determine its relative attractiveness for the given industry. Scores are determined by

$$S^k_{tj} = \Sigma_i W^i_k I^i_{tj} \tag{3.2}$$

where

k = 1,...,20 is an industry group index.

t = 1960,...,2020 is a time index.

j = 1,...,m is a county index.

i = 1,...,n is an index of locator variables.

S^k_{tj} = the score for county j with regard to industry k for period t.

W^i_k = the appropriate weight of factor i in the location of industry k.

I^i_{tj} = previously derived indexes.

The algorithm then searches for the highest score among counties across all industries, and the "winning" county-industry combination (the score for the k^{th} industry in county j) is given a unit of new subregional employment equal to the number of employees per acre which is typical for the industry in question.

Twelve locator variables are employed by the submodel. These variables are of varying importance to each individual manufacturing industry, as indicated by the weights W^i_k in equation (3.2).[2] Values for each locator variable are determined for each county for each time period. Ten locator variables are forecast exogenously. Two, however, are generated endogenously. These are:

$LNDPRC_{tj}$ = the industrial land price factor for county j in time t.

and

$MANWGE_{tj}$ = the average manufacturing wage in county j at time t.

---

2. Locator variables and their respective weights are derived from W. Schriver, et al. An Explanation of Plant Location in Tennessee 1955-1965 (Memphis, Tennessee: Bureau of Business and Economic Research, Memphis State University, 1966).

Changes in LNDPRC result from converting increases in manufacturing employment into implicit land use demands. For any county j which "wins" an increment in employment in manufacturing industry k, updated land requirements are computed by means of equation (3.3).

$$LNDUSE_{tj} = LNDUSE_{t-1,j} + NEWEMP^{k}_{tj} * LAC^{k}_{t} \tag{3.3}$$

where k, t, and j are as defined previously (eq. 3.2)

$LNDUSE_{tj}$ = industrial (manufacturing) land use in county j at time t.

$NEWEMP^{k}_{tj}$ = new employment of type k locating in county j at time t.

LAC^{k}_{t} = the land absorption coefficient for industry k at time t.

The industrial land price factor in county j is then incremented as follows:

$$LNDPRC_{tj} = LNDPRC_{t-1,j} + \Delta LNDPRC_{tj} \tag{3.4}$$

$$\Delta LNDPRC_{tj} = 1 + \left[LNDUSE_{tj} \Big/ LNDAVL_{tj} \right] \tag{3.5}$$

where

$$1 \leq \Delta LNDPRC_{tj} \leq 2$$

and

$$LNDAVL_{tj} = LNDSTK_{t=0,j} - LNDUSE_{tj} + LNDCON_{tj} \tag{3.6}$$

where

$LNDAVL$ = unused industrial land available at the start of the t^{th} period for county j.

$LNDSTK_{t=0,j}$ = the initial stock of industrial land in county j at time zero.

$LNDCON_{tj}$ = land converted to industrial use during time t in county j.

The availability of industrial land is recomputed in each county after each unit of employment is assigned. By permitting land conversions to industrial uses, the elimination of a county from the list eligible for increases in subregional employment is in principle prohibited. It is unlikely, however, that significant land conversion will take place in much of the TVA region with the possible exception of central city counties. The rate of conversion is controlled by the relative price of industrial land in county j, i.e. by the index computed via equation (3.1) for the locator variable $LNDPRC_{tj}$. Let I^b_{tj} equal the index for the b^{th} locator variable $LNDPRC_{tj}$, then

$$I^b_{tj} = \frac{LNDPRC_{tj} - MINLNDPRC_t}{MAXLNDPRC_t - MINLNDPRC_t} \qquad (3.1a)$$

and

$$LNDCON_{tj} = \phi\left(I^b_{tj}\right) \qquad (3.7)$$

The procedure employed for updating the locator variable $MANWGE_{tj}$ is as follows:

Let

$$MANWGE_{tj} = MANWGE_{t-1,j} + \Delta MANWGE_{tj} \qquad (3.8)$$

and

$$\Delta MANWGE_{tj} = \theta \left[\frac{TEMPLT_{tj}}{TPOP_{tj}} \right] \qquad (3.9)$$

where

$TEMPLT_{tj}$ = total employment in county j at period t.

$TPOP_{tj}$ = total population in county j at period t.

As in the case of the land price locator variable $MANWGE_{tj}$ is updated following each increment to county manufacturing employment. Following the updating of $LNDPRC_{tj}$ and $MANWGE_{tj}$, the search process is repeated to find the next highest score among all counties across all industries. It may happen that the same county-industry combination will win again. In this manner the model deals somewhat simply with the ordering problem. The process continues until all of the manufacturing employment increases to be allocated are exhausted. Fractional units of employment (less than the typical employee/acre ratio in an industry) are stored and added to the allocation procedure during the next time period.

ALLOCATING DECREASES IN MANUFACTURING EMPLOYMENT

The method used to allocate increases in manufacturing employment is not used for allocating decreases. Neither the best counties nor the worst counties for growth <u>within a particular industry</u> are the most likely to decline. If an industry is a declining industry for a subregion it is assumed here that it will be declining industry in all counties in which it is located.

The following mechanism is used to treat declining employment: First, the percentage of total subregional decline which can be attributable to each county is calculated in equation (3.10).

$$PCDECL^k_{tj} = EMPLT^k_{ij} \Big/ EMPLT^k_t \tag{3.10}$$

where

k	=	1,...,20 is an industry index.
j	=	1,...,m is an index for the county.
t	=	1960,...,2020 is an index for the time period.
$EMPLT^k_{tj}$	=	employment in industry k in county j at time t.
$EMPLT^k_t$	=	total subregional employment in industry k at time t.
$PCDECL^k_{tj}$	=	percentage of the total decline in industry k at time t which is allocated to county j.

Once $PCDECL^k_{tj}$ is calculated, it is used to determine the amount of employment actually removed from county j using (3.11).

$$EMPLOS^k_{tj} = PCDECL^k_{tj} * \Delta EMPLT^k_t \tag{3.11}$$

where

PCDECL and the indexes k, t, and j are as defined above and

$EMPLOS^k_{tj}$ = total subregional decline in employment in county j and industry k at time t.

Lost employment is then converted to declines in land use by equation (3.3a).

$$LNDUSE_{tj} = LNDUSE_{t-1,j} - EMPLOS^k_{tj} * LAC^k_t \qquad (3.3a)$$

New land price and manufacturing wage factors are then calculated (via equations 3.4, 3.5, 3.6, and 3.8, 3.9) and the search process is recycled beginning with equation (3.1).

ALLOCATING CHANGES IN OTHER BASIC EMPLOYMENT

A symetrical procedure is employed for both increases and decreases in subregional employment in agriculture, mining, export recreation, and export government. The location of these activities among the several counties of a subregion is determined largely on the basis of geography, geology, history, and tradition. The procedure adopted is to allocate changes in subregional employment in these industries on the basis of continuously updated county relative shares. In the case of agriculture, for example, changes in subregional employment are allocated to counties as follows:

$$AGEMP_{tj} = AGEMP_{t-1,j} + \Delta AGEMP_t * \frac{AGEMP_{t-1,j}}{AGEMP_{t-1}} \qquad (3.12)$$

where

$AGEMP_{tj}$ = agricultural employment in county j at time t.

$AGEMP_{t}$ = total subregional agricultural employment at time t.

Similar equations are employed for the other three industries.

$$MXEMP_{tj} = MXEMP_{t-1,j} + \Delta MXEMP_{t} * \frac{MXEMP_{t-1,j}}{MXEMP_{t-1}} \quad (3.13)$$

$$ERCEMP_{tj} = ERCEMP_{t-1,j} + \Delta ERCEMP_{t} * \frac{ERCEMP_{t-1,j}}{ERCEM_{t-1}} \quad (3.14)$$

$$EXGEMP_{tj} = EXGEMP_{t-1,j} + \Delta EXGEMP_{t} * \frac{EXGEMP_{t-1,j}}{EXGEMP_{t-1}} \quad (3.15)$$

where

$MXEMP_{tj}$ = mining employment in county j at time t.

$ERCEMP_{tj}$ = export recreation employment in county j at time t.

$EXGEMP_{tj}$ = export government employment in county j at time t.

At the present time, the model does not compute implicit land use requirements for these activities.

ALLOCATING INCREASES IN POPULATION

Increases in population for a subregion are allocated among the counties of a subregion according to equation (3.16).

$$POP_{tj} = POP_{t} * \left[\frac{A_{tj}}{\sum_{j} A_{tj}}\right] \quad (3.16)$$

where

POP_{tj} = population increase for county j during t.

POP_t = population increase for the subregion.

A_{tj} = highway accessibility to basic employment, households, and service activity during t in county j.

In this equation highway accessibility relates a particular county in a particular subregion to all other counties in the subregion in terms of an index which is porportional to activity levels in all counties (i.e. basic employment, households, and services) and inversely proportional to the travel time among counties. The accessibility index may be written as follows:

$$A_h(t) = \left[\sum_{k=1}^{n} \Delta P_k(t-1) e^{-\psi D_{hk}(t)} + \Delta S_k(t-1) e^{-\Gamma D_{hk}(t)} + \Delta M_k(t)\, e^{-\alpha D_{hk}(t)} \right] \qquad (3.17)$$

where

$A_h(t)$ = the accessibility index of county h in time t.

$\Delta P_k(t-1)$ = the change in population in the k^{th} county during the previous period.

$\Delta S_k(t-1)$ = the change in service employment in the k^{th} county during the previous period.

$\Delta M_k(t)$ = the change in manufacturing employment in the k^{th} county during the current period.

$D_{hk}(t)$ = the travel time between county h and the k^{th} county at time t.

k = 1,...,n counties in the subregion.

The accessibility index reflects agglomeration gravity. The exponents ψ, Γ, and α indicate the impedance effect of travel time between counties for each type of activity.

Population is converted to land use requirements by employing a density coefficient. Decrements in subregional population are handled in a similar manner to increments as follows:

$$POP_{tj} = POP_t * \left[1 - \frac{A_{tj}}{\sum_j A_{tj}} \right] \qquad (3.16a)$$

Equation (3.16a) suggests a more rapid rate of population decline for the less accessible counties in the subregion.

ALLOCATING CHANGES IN SERVICE ACTIVITY

Total subregional increases in this sector are allocated among the counties on the basis of population change, i.e.:

$$HBEMP_{tj} = HBEMP_t * \frac{POP_{tj}}{\sum_j POP_{tj}} \qquad (3.18)$$

where

$HBEMP_{tj}$ = new services activity in county j during t.

$HBEMP_t$ = new service activity in the subregion during t.

Employment is then converted to land usage by a land absorption coefficient.

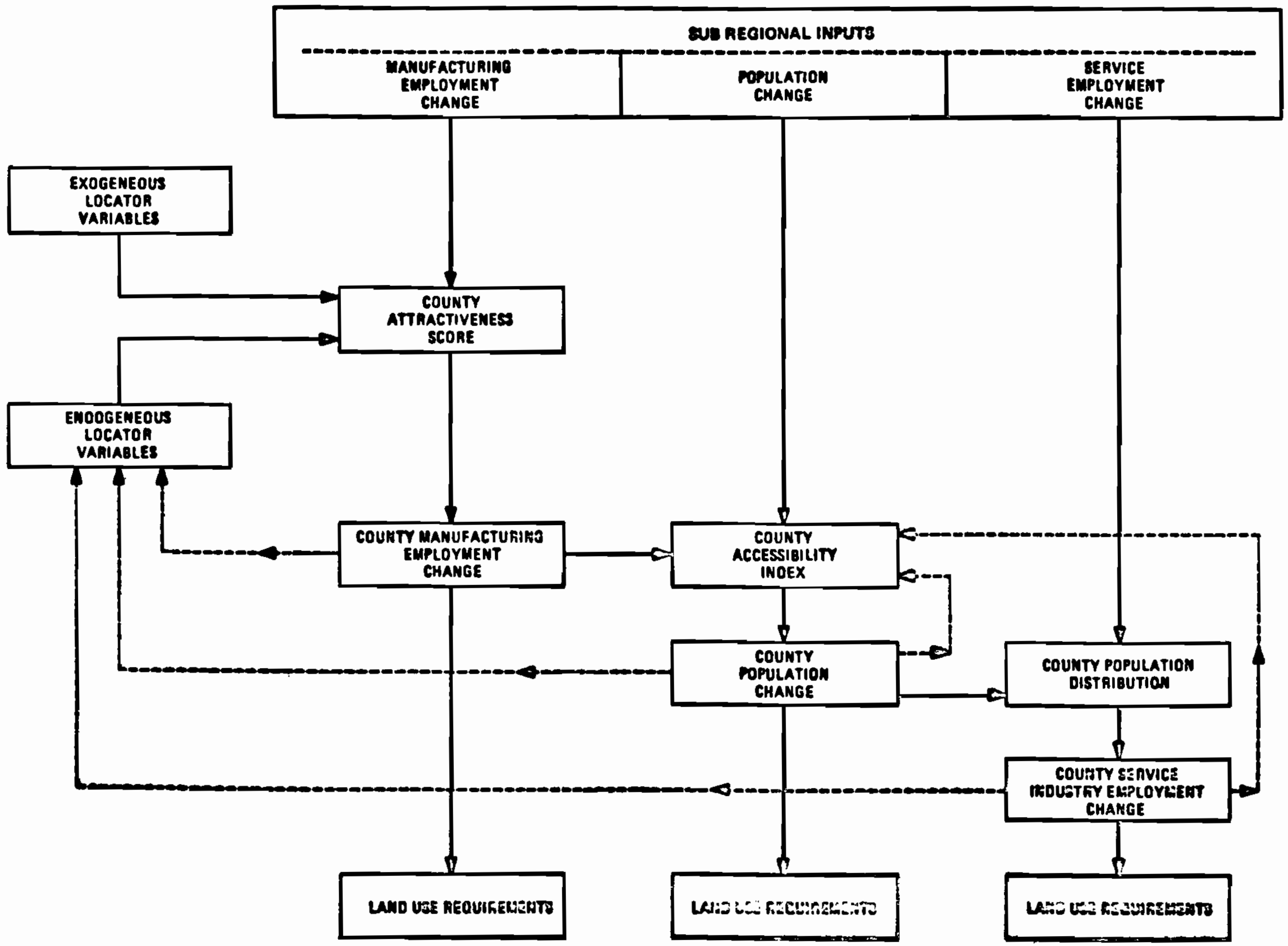
No constraint is placed on the amount of activity in this sector. The assumption is that population growth in a county will adequately limit service activity. Decrements to service employment are handled in exactly the same manner as increments [i.e. by means of equation (3.18) in reverse.]

A SUMMARY OVERVIEW

Figure 9 provides a visual presentation of the three major components of the County Allocation and Land Requirements Submodel. As the allocation of Other Basic Employment is not translated into land use requirements, it is omitted from the diagram. Other Basic Employment, however, does affect the distribution of population and service employment as indicated in the preceding text.

In figure 9, the heavy vertical arrows indicate the main flow in each component of the submodel. Horizontal solid arrows indicate the direct relationships that exist between components while the dashed arrows show feedback effects.

OVERVIEW OF THE COUNTY ALLOCATION AND LAND REQUIREMENTS SUBMODEL



IIASA DISCUSSION PAPER

R. Mackinnon

Large-scale simulation models can be important learning experiences as well as effective planning tools. In implementing such models the research team must come up with a system of numerically spcified relationships that can work with purely theoretical models or models which are operational only in principal. This is clearly a very difficult task, one in which perhaps many ad hoc decisions need to be made and the perfect surrogates have to be used and in vain the best of all possible worlds do not exist.

As an academic with some interest in regional policy I hope that I can make some comments that are relevant in this context. Some of my comments are essentially questions of clarification. Difficulties I have had were in interpreting the presentation where no substantial cirticism is necessarily implied. Other comments are clearly critical. They are my attempts to flag the apparent shortcomings of the model. Unfortunately, in such cases it is not always possible to provide a better operational solution. I realize that a theoretically competent model may not always be possible because of shortages of data, resources, or a good relevant theory. The construction of operational models can not always wait for an adequate theory, nor, however, can such models escape criticism because good theory does not yet exist.

My comments are of two major types. In my remarks now I will stress the most general conceptual problems that I see with this model. I have some more specific comments and questions about the details of the simulation model which I will pass on to Dr. Hinote and we can discuss them privately or perhaps in Tennessee proper.

The population-labor force model has a migration component which predicts in-migrants and out-migrants for the large regions and for each of the smaller subregions. As I understand the out-migrants for the nine regions are predicted and pooled with two of all the other regions. In-migrants are then allocated from this pool. That is, in-migrants are selected independently of their origin in much the same way as an interregional input-output model. This ignores strong interregional migration ties which can arise for a number of reasons. In general I would suggest that migration should be viewed as a unified origin-destination specific process rather than two independent leaving and arriving processes.

Still on migration several researchers--for example Morrison of Rand and Cordey-Hayes of IIASA--have shown that it is not realistic to view migration as a simple push-pull process. People do not always leave areas because economic conditions are poor. Out-migrations from such fast growing high wage areas as California are often very high because social and occupational mobility are high in such areas. My interpretation of the TVA migration model is that it is very much of the push-pull tradition. While certainly much migration has been of this type, the relatively foot-loose middle and upper income groups should not be ignored.

Now moving to the employment model, it is highly dependent on an economic base methodology where manufacturing activities pass a critical role and in fact essentially determine all future employment opportunity in the nation. Over the past 20 years economic base models have been severely criticized in the literature of national studies. Two examples span that period--Blumenfeld, 1955 and Richardson, 1973--and they have been criticized on several accounts: excessive preoccupation with external demand, no attention paid to the possibility of capacity constraints or autonomous investment nor to other causes relating to regional economic growth. As a nation or an economy matures there is ample evidence that manufacturing per se plays a lesser role in determining economic growth.

Service industries are proportionally more important and they themselves can be critical in providing an attractive environment for economic activities for all types. Service activities can play very important export roles in both direct and indirect ways. Moreover, industry may be of lesser importance as national economy matures. I would suggest that the view of economic location reflected in the TVA economic simulation model seems to be more relevant to the 19th and early 20th centuries than to the 1980's, 1990's, and beyond.

Far more important to modern industry than raw material collection and production costs are agglomerate economies in the broadest sense of that term. In only one place are these mentioned and it is not at all clear how or even whether they are incorporated within the model. These can be rather subtle and difficult to model interdependencies but they should be given some explicit attention in a serious modeling effort.

The philosophy behind this model seems to be that job opportunities will provide the stimulus for population growth. This one-way causation is almost certainly not realistic. There is a growing belief that jobs follow people as much as vice versa and people may move into an area for a variety of reasons, many of them nonmonetary.

Now the final broad comment I was going to make concerns the apparent deterministic nature of this model. This perhaps sounds funny to those of you who have not read the paper and have just heard the remarkds of Dr. Hinote, but, from my reading of the paper, it is a deterministic simulation model. There is no indication of probability distributions, variance, or co-variance structures, and I think that these are essential components of a stochastic model. So I will make the comments as prepared.

My final comment concerns the modeling approach rather than the substantive theory. There is virtually no mention made in the paper that we are dealing with a rather poorly understood system. We are not only uncertain about future values of exogenous variables, we are also not sure of the appropriate form of the relationship including the casual direction or even which are the relevant variables. For example, the market potential and accessability inputs to the employment submodel require exogenous predictions for every time period of population of every state, transportation time costs by four modes between the region and every state. This is how I interpret the paper and the outputs of those industries again by state, and the relative importance of the three most important inputs to every industry.

Now remembering that the projections are to be over the next 50 years, this model requires heroic exogenous predictive capabilities not only on the number of variables but on the implied form and constancy of production functions over time. Under such conitions it would seem appropriate to take cognizance of these uncertainties and deal with them in probabalistic ways. That a stochastic simulation model would be far more appropriate is particularly evident in the presentation of the county allocation submodel where counties obtain scores and a number of indices which are then collapsed to a single measure. A plant locates in the county having the highest score. The algorithm then procedes to the next plant location program. The weights attached to such indices and the indices themselves can certainly be justified only on very rough pragmatic grounds. I would say fuzzy grounds, but that has taken on another meaning these days.

Thus, there is no reason to think that the location process is known at a deterministic level or even that the process itself is a deterministic one. Many locations could for all practical purposes be indistinguishable under such circumstances. Extensive sensitivity analyses can be a partial substitute for a probabilistic approach but the simulation mode of analysis seemed to be quite amenable to an explicitly stochastic model.

Now again, I may have misread the paper. I do not think I did, and it may be that the paper just was not presented in the stochastic mode of analysis that I think all simulation models should have. Certainly the emperical results of such stochastic models should give some idea of the expected variance at least, covariance between different variables rather than presenting single, apparently deterministic trends. Now, these end the major comments I have on the model.

I have a fairly long list of smaller points, some of which I consider quite important, and the points mainly have to do with specific indexing problems. I will certainly make these comments available to Dr. Hinote. I am a newcomer to IIASA and so I am not sure of the projects doing work related to this model. I would think that the Urban Project would come closest with its interest in migration, urban growth, and related topics. With respect to migration, we are attempting to develop models which adequately reflect dynamic aspects of the job market, which has probabilistic formulation. Given these dynamics, we are attempting to determine what leverage national urban planners have to alter the distribution of people within a system of cities, either by direct control, job creation, direction of migrants, or incentives (amenities, wage subsidies, etc.).

In closing, I will say that the TVA economic simulation model represents a synthesis of pragmatism and theory. The shortcomings of the model are as much a reflection of the weakness of the available theory as they are of any lack of diligence on the part of the TVA research team.

TVA COMMENTS ON DISCUSSION BY R. MACKINNON

Dr. MacKinnon's discussion focused on three major issues in the paper: 1) the migration function, 2) the employment sector and 3) the general nature of the model.

1. The Migration Function

We do not currently have in the model the separate in- and out-migration functions suggested in the paper. The paper presents a conceptualization of the process which we were considering including in the model at the time the paper was written. This was in response to recent studies criticizing the net-migration approach much as Dr. MacKinnon does in the discussion paper. With regards to the suggestion that we incorporate a "unified origin-destination specific process," data are simply not available in the US to perform the analyses requires to adequately describe the necessary relationships.

Regarding the discussion on the "push-pull tradition," note that in equation 1.6 explicit recognition is given to noneconomic factors in the out-migration function. Note also references in the write-up preceding the equation which suggest immigration to vary primarily with economic factors.

The model currently relies on the net-migration concept. We had work under contract to determine the most appropriate approach to the migration sector. The results led to the conclusion that the net approach may have a great predictive power as the in- and out-approach. The main advantage of the latter appears to be not so much in forecasting ability, as in simply allowing more of the system's variables to be explicitly considered and manipulated.

2. The Employment Sector

The primary discussion point relative to the employment sector concerned the export base mathodology employed in the model. While export base theory has received its share of criticism, it has also received considerable support as a predictive tool. A number of studies supporting its use are discussed by Robert B. Williamson in "Predictive Power of the Export Base Theory" Growth & Change (January 1975). The studies showed that there are significant correlations between the size of a region's total economy and its export sector.

The TVA model is a weak version of export base theory. The export sector (namely, manufacturing) is projected by a pragmatic approach which relates subregional growth rates to national growth rates according to their relative strengths on certain location factors. Other employment sectors, except for business-serving and household-serving industries, are forecast exogenously. Household serving employment is calculated as a function of population, which is to some degree related to total employment and manufacturing employment. Business services are directly related to total employment. We agree with the statement that as an "economy matures. . . manufacturing per se plays a lesser role in determining economic growth". Several of the other papers presented at the Conference reflect the increasing importance of the trades and service sector in the TVA region. The approach taken in the model was a pragmatic one, and work is underway to expand this section of the model.

Another point brought out in the discussion paper was that agglomerate economies in the broadest sense are "far more important to modern industry than raw material collection and production costs". While locational theory and empirical studies have confirmed the importance of agglomerative economies in <u>some</u> particular types of industries, the experience in the TVA region does not indicate that it is accurate to say that agglomerative economies in the broadest sense are far more important than raw material collection and production costs. Empirical location studies indicate that there are a number of factors that industry considers when selecting a plant location and that these factors rank differently for certain groups of industry and in many cases individual firms within the groups. This point is fully recognized, but a pragmatic approach was taken, namely, to consider the most important factors first and then refine the model as theory, data, and resources become available. Agglomerative economies is certainly one of the factors that will be considered as the model is refined.

One of the local factors considered in plant location is the availability of labor at a particular wage level. Thus, the concept that jobs follow people is another point that Mr. Mackinnon discusses. The opposite of this concept is that people follow economic opportunities; this ceoncept was the experience of the TVA region. As pointed out in another paper, the region's proportion of the nation's total population fell from 4.1% in 1933 to 3.3% in 1973; however, during this period there was a 1.8 million increase in the total population of the region. During this period, job opportunities were increasing many fold. We agree that population growth is not solely dependent on job opportunities, but in fact is dependent on a great deal more, employment being one important factor. In the model, this concept is captured only in the migration function of the population-labor force submodel.

3. <u>The General Nature of the Model</u>

The model does indeed make extensive use of exogenous projections. For a long-range model, such as the TVA model, this is most appropriate. The TVA has considerable experience in time-series analysis of economic variables and projecting them. Although time-series analysis lacks expositional power, it often provides the most accurate forecasting technique. A simultaneous equation model of the Wharton Econometric Forecasting Associates genre would not seem appropriate for the purposes of our work. The TVA model aims at a series of outputs which are consistent with each other. A large number of exogenous projections is not frightening at this time, although as the model develops we hope to reduce the number.

It is correct to say that the model is deterministic, and it is also correct to say that we are dealing with a rather poorly understood system. A stochastic model would seem desirable for several reasons. Certainly all exogenous forecasts are subject to error, as well as mechanisms within the model which cannot be said to operate deterministically. However, it is not at all clear that introducing a probabilistic nature to this model would be useful to the decision-making process to which this model feeds. Furthermore, we are already dealing with a model in which playing with the underlying assumptions can rapidly blossom into a very large number of runs. Should we want to add to this burden by requiring a number of runs for each set of input in order to get an estimate of output variability? It seems likely that in a model of this nature, the only benefit to such an exercise might be to make more explicit what we already feel to be the case; that is forecast errors are quite large, increasing rapidly as time is extended into the future.

One point brought out in the discussion which is not clear in the paper is the integration of the regional simulation model with power demand forecasting. At the time the paper was written, the output of the simulation model was being used exogenously as input into power demand forecasting. Also at that time a design in concept was being developed for a Power System Integrated Planning Model. The design in concept envisioned the integration of these two models. As work progresses the simulation model will be an integral element in the process of power demand forecasting as well as in planning for new energy generating facilties. It is also being integrated into the other regional planning activities of TVA, e.g. environmental and recreational planning.

COMPUTERIZED PLANT LOCATION MODELS

INTRODUCTION

The amount of developmental planning currently going on puts great stress on the need for more insight into future industrial development. Hardly a sewage disposal or water system or a multi-million dollar dam project can be successfully proposed without some estimate of the number of new manufacturing jobs that can reasonably be expected as a result. The models to be described do not purport to do the complete job. Hopefully, they do provide useful information about the probability of an area attracting certain types of industry.

Presented here are three models. Each successive one provides greater detail in results and uses the output of the earlier model. The first provides identification and measurements of market advantages in a region. The second furnishes a list of the companies that will have the greatest advantage. The third model evaluates a potential plant location from the standpoint of raw material costs and transportation costs of inbound and outbound freight.

CHAPTER I

MARKET ANALYSIS MODEL

The market analysis technique is used to determine the market potential for an industry at state and regional levels. The technique estimates the supply and demand for a given product in each state. By taking the difference, an estimate of the production deficit or production surplus is derived. For products which are market oriented, a region or a state experiencing a production deficit is a realistic area to consider for the location of a new or expanded plant.

The market analysis technique is used to analyze industrial and consumer products, or a combination of the two. For an industrially consumed product, the state market estimates are based on consuming industry input ratios at a national level. The national ratios of consumption per employee in each consuming industry are multiplied by the employment for each consuming industry in a given state, and the results summed to yield an estimate of the state market.

Computation of State Market for an Industrially Consumed Product

$$M_i = \sum_{j=1}^{N} (R_j \times E_{ij}), \quad (i = 1, 2, \ldots 49)$$

where

M_i = market in state i

R_j = ratio of consumption per employee in industry j

E_{ij} = employment in state i in industry j

N = number of consuming industries

The analysis can also be applied to industries which manufacture products which are supplied directly to the consumer. For example, the market for toilet preparations can be estimated based on an index of consumer buying power which weights income, 5; retail sales, 3; and population, 2. The acceptable level of explained variation sets the limits for independent variables which should be considered. The net regression coefficients of the regression equation are the weights for the independent variables to estimate the market at a state level for the product.[1]

Computation of State Market for Product Purchased by Ultimate Consumer

$$M_i = V \times C_i$$

where

V = total U.S. output for domestic use

C_i = consumer purchasing index in state i and

$$\sum_{i=1}^{49} C_i = 1.00$$

The market for a product which is used by both industrial and ultimate consumers, such as automobile tires which are sold to automobile manufacturers and directly to consumers for tire replacement, is computed by applying a combination of the two methods.

Production is estimated based on the output per employee in the industry under consideration.

---

1. Mordecai Ezekiel and Karl A. Fox, Methods of Correlation and Regression Analysis (New York, 1959), pp. 153-154.

Computation of State Production

$$P_i = KL_i, \quad (i = 1, 2, \ldots 49)$$

where

P_i = production for domestic use in state i

K = ratio of output per employee in the producing industry

L_i = employment in state i in the producing industry

A production deficit exists when the state market exceeds the state production.

Computation of Production Deficit

$$D_i = M_i - P_i, \quad (i = 1, 2, \ldots 49)$$

where

D_i = production deficit in state i

For the analysis, an underlying assumption is:

$$\sum_{i=1}^{49} P_i = \sum_{i=1}^{49} M_i$$

Also for $D_i > 0$ the number of additional manufacturing facilities of an industry needed in a given region is:

$$PF_t = \sum_{i=1}^{T} D_i \div \left(\frac{\sum_{i=1}^{49} P_i}{\sum_{i=1}^{49} F_i} \right)$$

where

PF_t = number of potential production facilities in region t

T = number of states in region

F_i = number of manufacturing facilities in state i

A more dynamic approach to analyzing the market is to examine the expected market distribution pattern in 1980. By forecasting the market for a product to 1980 and analyzing the market shifts, the area offering the best future market potential can be identified. Market projections were made by determining the 1980 consumption pattern and applying the procedure previously described using projected employment.

The 1980 projected manufacturing employment at a 4-digit SIC[2] level for each state was a result of curve-fitting and extensive investigation for reasonableness. For each industry in each state historical employment data were fitted to seven curves[3] to determine which yielded the least unexplained variation. This curve was then examined for reasonableness to arrive at the 1980 forecast. Using these projections, a planner can look at the future market for a product, determine markets and production shifts, and identify areas which will probably be lacking in adequate facilities to supply the area's needs in 1980.

---

2. Standard Industrial Classification.

3. Exponential $Y = ab^X$

   Modified exponential $Y = c+ab^X$

   Gompertz $Y = ca^{b^X}$

   Logistic $Y = 1 \div (c+ab^X)$

   Logarithmic parabola $Y = ab^Xc^{X^2}$

   Second degree $Y = a+bX+cX^2$

   Straight line $Y = a+bX$

CHAPTER II

BRANCH PLANT MARKET ANALYSIS MODEL

There is little need to lay a theoretical foundation for the idea of market orientation as a location factor. Simple illustrations using one market and one source of inputs are quite familiar. More sophisticated illustrations appear in more advanced writings.[4] On the other hand, the gravity model is probably a much more direct ancestor of the methodology to be presented. It will be apparent that the concept of gravitational pull was utilized with a different method of using the concept of mass.[5]

There are those who seem to doubt the significance of market orientation relative to the total number of manufacturing plant location decisions made in a given period of time. The reasons usually given are the amount of cross-hauling in our transportation system and the answers that firms furnish in response to survey questionnaires.[6] There are other explanations for cross-hauling such as competition between firms not yet large enough to cover the entire market but striving to increase their shares, or temporary over-capacity in newly located plants seeking to operate at minimum unit cost. Also there is reason to suspect that company officials do not always reveal all of the company's affairs when answering a questionnaire for a survey in which they have no real interest.

The decision was made that market orientation is important enough as a plant location factor to warrant the development of a model. Some evidence will be presented as to the ability of the model to predict locations.

Since such a model would only be useful to developmental planning if large numbers of companies could be analyzed and the probability of a

---

4. For example, see Walter Isard, Methods of Regional Analysis: An Introduction to Regional Science, Chapter 7.

5. As developed by J. Q. Stewart.

6. Robert G. Spiegelman, "A Method for Analyzing the Location Characteristics of Footloose Industries: A Case Study of the Precision Instrument Industry," Land Economics, February 1964, pp. 79-86.

certain type of industry being attracted to a certain area computed, the most important requirement was that only publicly available information, obtainable in large masses and conducive to electronic processing could be used.

A basic assumption was made that inputs per production worker in a 4-digit SIC group on a national basis are representative of all the production workers in that group in any given state and the same was assumed to hold true for output per worker. Since the marketing strategy of each firm in an industry cannot be ascertained, it was necessary to assume that each firm is trying to serve its proportionate share of the market in each state. While this does not hold true for many firms, it seems probable that firms deciding to build branch plants will locate them as though serving the entire market were the ultimate goal. If this is true or approximately true, the model should come fairly close to the firm's market-oriented motivations.

To summarize the objective of the model, it was designed to allow the developmental planner who has determined the growth industries, perhaps on the basis of investment plans, overtime hours, new hirings of production workers, increases in profits or production, or other similar symptoms to compare the market for the products of that industry with the production in the area and then analyze the position of each of the firms in the industry from the standpoint of where their plants are currently located. If a certain percentage of the firms could improve their position most with respect to the total market by locating their next branch plant in the area, it seems reasonable that the area should plan for the proportion of that industry's expected growth that is represented by these firms.

The branch plant analysis model determines the optimum location for a given manufacturing firm to locate its next branch plant for the production of a specific product, considering the following variables:

1. Distribution of the national market by states.
2. Location of the firm's branch plants which manufacture the product.
3. Relative capacity of each plant.
4. Distances from plants to the markets in each state.

The model can be used to analyze three types of products--industrial, consumer, or a combination of the two.

The objective function of the model is to select the optimum location from a list of potential locations for a company's next branch plant to produce a specific product. In order to measure the effect of a new plant on a firm's "well-being" and compare it to the existing situation, an abstract index called market potential index (MPI) is used. This index measures the intensity of possible contact with the market. The market in each state is divided by the distance in miles from the plant to each state market served by that plant.[7] State markets are assigned to individual plants according to plant capacity and MPI, using the transportation method of linear programming.[8] The MPI for a plant is the sum of the market distance ratios and MPI for a firm is the sum of MPI for the firm's plants. The objective is to maximize the MPI for the firm by placing an additional branch plant in the most strategic location to serve the entire market.

Computation of the Market Potential Index for a Branch Plant

$$MPI_k = \sum_{i=1}^{L} (M_i/D_{ki})$$

where

MPI_k = market potential index for branch plant k

M_i = market in state i

D_{ki} = distance from plant k to state i

L = number of states served by branch plant k

---

7. Chauncy D. Harris, "The Market as a Factor in the Localizations of Industry in the United States," Annals of the Association of American Geographers, Volume 44 (December 1954), p. 321.

8. M. L. Balinski and R. E. Gomory, "A Primal Method for the Assignment and Transportation Problems," Management Science, Volume 10 (April 1964), pp. 578-594.

Computation of the Market Potential Index for the Firm

$$MPI_f = \sum_{k=1}^{Q} MPI_k$$

where

MPI_f = market potential index for firm f

Q = number of branch plants of firm f producing the product being analyzed

Distance is measured by a coordinate system. A map of the United States was overlaid with a grid scale and coordinates for each county were read. Each state was assigned a geographic market center which was determined by the concentration of manufacturing and population. Using the county coordinates to locate market centers and branch plants, the distance is calculated.

The MPI is calculated for the company's present plant locations. The model evaluates a potential location by measuring the increase in MPI which would occur if a plant were built. The optimum location is the one which maximizes MPI. The potential locations are selected in areas where a production deficit exists.

Input data for the individualized firm analysis are coordinates for each alternative and existing plant location and capacity estimates for each plant. Plant capacity determines the share of the total market potential assigned to each branch plant, and the total market potential equals the total U.S. market. When an estimate of the capacity of the new branch plant is not available, the model assumes it will have a capacity equal to the average of the company's present plants.

The model first assigns state markets to existing branch plants within each plant's capacity limits such that MPI is optimized. Then for each potential location, the model reassigns the state markets to existing plants and the one additional plant and sums the MPI for all plants. This process is repeated for each potential location. The solution is optimum when it maximizes the MPI. The locations are then ranked according to the estimated contribution each will make to the market potential of the firm.

Results of the Empirical Testing of the Branch Plant Analysis Model

Nine hundred and seventy-nine firms were analyzed, using a 1963-1964 directory of plant locations.[9] A comparison of this directory with the 1966 edition showed that 81 of these firms had added new branch plants as shown in table 1. These 81 companies established a total of 108 plants in the two to three year interval.

Thirty-one of the 108 branch locations were identified as test locations, using the excess demand approach, prior to the announcement of the new establishments as shown in table 2. Without any specific firm information, almost one-third of the new plant locations was selected, using the excess demand method of identifying potential locations. The potential locations were selected on an industry basis; therefore, all the companies within a given 4-digit SIC group were analyzed using the same potential locations. The smallest number of potential locations considered was 8 and the largest, 13. The region predicted for the new plant was selected for 71 of the 108 new branch plants. If each company had been analyzed with respect to its actual market, the percentage would have been higher.

Twenty-five of the actual locations of the new branch plants were chosen by the model as the best locations. Over half of the new plant locations ranked in the top five based on increase in MPI, as shown in table 3.

Again, it must be emphasized that this model is used only to measure one variable in plant location. The twenty-five in which the predicted locations were actually selected are probably companies in which access to markets is of primary importance when possible locations for new branch plants are being considered.

---

9. Fortune 1963-1964, Plant and Product Directory of the 1000 Largest U.S. Industrial Corporations.

TABLE 1

NUMBER OF FIRMS IN SELECTED INDUSTRIES
WHICH ADDED ONE OR MORE BRANCH PLANTS
BETWEEN 1963 AND 1966

SIC	Industry	Number of Firms Analyzed 1964	Number of Firms With New Branches
2034	Dried and dehydrated fruits and vegetables	12	2
2295	Coated fabrics, not rubberized	17	5
2641	Paper coating and glazing	25	4
2645	Die cut paper and board	18	1
2731	Books: publishing and printing	21	-
2813	Industrial gases	20	4
2815	Dyes, dye intermediates and organic pigments	38	4
2818	Industrial organic chemicals, n.e.c.	95	-
2821	Plastics materials and resins	41	8
2823	Cellulosic man-made fibers	4	-
2824	Organic fibers, noncellulosic	3	2
2844	Toilet preparations	33	3
3079	Plastics products, n.e.c.	144	-
3221	Glass containers	4	1
3312	Blast furnaces and steel mills	54	8
3316	Cold finishing of steel shapes	13	-
3361	Aluminum castings	32	-
3392	Nonferrous forgings	15	1
3519	Internal combustion engines	30	2
3541	Metal-cutting machine tools	24	2
3542	Metal-forming machine tools	25	2
3553	Woodworking machinery	12	1
3554	Paper industries machinery	19	-
3555	Printing trades machinery	15	1
3562	Ball and roller bearings	14	-
3599	Miscellaneous machinery	58	5
3679	Electronic components, n.e.c.	95	13
3831	Optical instruments and lenses	22	1
3841	Surgical and medical instruments	14	2
3842	Surgical appliances and supplies	30	2
3861	Photographic equipment	25	4
3942	Dolls	2	-
3955	Carbon paper and inked ribbon	5	3
	TOTAL	979	81

Source: Fortune: Plant and Product Directory of the 1000 Largest U.S. Industrial Corporations.

TABLE 2

ACTUAL LOCATIONS SELECTED AS TEST LOCATIONS

BY THE MODEL

SIC	Industry	State Selected	Region Selected	Number of Plants
2034	Dried and dehydrated fruits and vegetables	-	-	2
2295	Coated fabrics, not rubberized	2	3	5
2641	Paper coating and glazing	4	4	6
2645	Die cut paper and board	-	-	1
2813	Industrial gases	-	4	5
2815	Dyes, dye intermediates and organic pigments	1	3	5
2821	Plastics materials and resins	7	13	14
2824	Organic fibers, noncellulosic	-	3	3
2844	Toilet preparations	1	4	6
3221	Glass containers	-	-	2
3312	Blast furnaces and steel mills	2	7	10
3392	Nonferrous forgings	-	1	1
3519	Internal combustion engines	-	1	2
3541	Metal-cutting machine tools	1	1	2
3542	Metal-forming machine tools	-	2	2
3553	Woodworking machinery	-	1	1
3555	Printing trades machinery	1	1	5
3599	Miscellaneous machinery	1	1	6
3679	Electronic components, n.e.c.	9	16	17
3831	Optical instruments and lenses	-	-	1
3841	Surgical and medical instruments	-	-	2
3842	Surgical appliances and supplies	-	1	2
3861	Photographic equipment	2	4	5
3955	Carbon paper and inked ribbon	-	1	3
	TOTAL	31	71	108

TABLE 3

RANK OF ACTUAL LOCATION WHEN CONSIDERED AS A POTENTIAL LOCATION

SIC	Industry	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
2034	Dried and dehydrated fruits and vegetables	2													2
2295	Coated fabrics, not rubberized					1				2	2				5
2641	Paper coating and glazing	2	1	1	1					1					6
2645	Die cut paper and board	1													1
2813	Industrial gases	1	1					1	1		1				5
2815	Dyes, dye intermediates, and organic pigments	2						1		1		1			5
2821	Plastics materials and resins	1	2		2	2	1			1	3	1		1	14
2824	Organic fibers, noncellulosic	2	1												3
2844	Toilet preparations	2	1									2	1		6
3221	Glass containers	1	1												2
3312	Blast furnaces and steel mills	1				2		2	1		3	1			10
3392	Nonferrous forgings								1						1
3519	Internal combustion engines							1	1						2
3541	Metal-cutting machine tools							1				1			2
3542	Metal-forming machine tools		1					1							2
3553	Woodworking machinery								1						1
3555	Printing trades machinery	1	1			1			1	1					5
3599	Miscellaneous machinery	2		2	1				1						6
3679	Electronic components, n.e.c.	3	1	2	2	2			1	2	3	1			17
3831	Optical instruments and lenses									1					1
3841	Surgical and medical instruments									2					2
3842	Surgical appliances and supplies		1					1							2
3861	Photographic equipment	2			1				1	1					5
3955	Carbon paper and inked ribbon	2						1							3
	TOTAL	25	11	5	7	8	1	9	9	12	12	7	1	1	108

CHAPTER III

BRANCH PLANT RAW MATERIAL AND TRANSPORTATION COST ANALYSIS MODEL

A decision-maker must consider many factors other than market in selecting the location for a new branch plant. Factors such as transportation, raw materials, electric power, fuel, and labor are tangible and lend themselves to a mathematical analysis. A model which could analyze all quantitative factors, while desirable, would be extremely expensive and time consuming.

A systematic procedure for analyzing three quantitative location factors--cost of raw materials at points of origin, cost of transporting raw materials to plants, and cost of transporting the finished product to markets including both wholesalers and retailers has been developed within TVA. The objective of this model is to determine from a list of potential locations, the location which would minimize cost of raw materials and the transportation costs of inbound and outbound freight.[10]

Data used in the analysis include cost of each raw material at each source, cost of shipping each raw material from each source to the existing and potential facilities, and the cost of shipping the finished product from each manufacturing facility to wholesalers, then to retailers. Since the accuracy of the model is dependent on the data, it is essential to use the company's raw material suppliers, present markets, and additional markets the company wishes to serve. The transportation data used are typically ICC published rates. The amount of each raw material required and the markets to be served are determined by the production capacity of the existing and potential facilities. The assignment of raw material sources to plants and plants to markets is sensitive to changes in capacity. Also, a modification in the market area will affect the assignment.

A location problem of this magnitude requires a computerized method for handling a volume of data--in this case all possible combinations of raw materials to plants and plants to markets and their respective costs.

---

10. Any of the three factors may be excluded from the analysis.

The simplex method of linear programming[11] was incorporated in this model where the objective function in the existing situation was:

Find

$$A_{ijk} \geq 0, \ (i = 1, 2, \ldots N1; \ j = 1, 2, \ldots N2_{(i)}; \ k = 1, 2, \ldots N3)$$

$$B_{kl} \geq 0, \ (k = 1, 2, \ldots N3; \ l = 1, 2, \ldots N4)$$

$$B_{km} \geq 0, \ (k = 1, 2, \ldots N3; \ m = 1, 2, \ldots N5)$$

$$B_{mn} \geq 0, \ (m = 1, 2, \ldots N5; \ n = 1, 2, \ldots N6)$$

in order to minimize

$$Z = \sum_{i=1}^{N1} \sum_{j=1}^{N2_{(i)}} \sum_{k=1}^{N3} (C_{ij}+S_{ijk})A_{ijk} + \sum_{k=1}^{N3} \sum_{l=1}^{N4} B_{kl}T_{kl} + \sum_{k=1}^{N3} \sum_{m=1}^{N5} B_{km}T_{km} + \sum_{m=1}^{N5} \sum_{n=1}^{N6} B_{mn}T_{mn}$$

subject to the constraints,

$$\sum_{j=1}^{N2_{(i)}} \sum_{k=1}^{N3} A_{ijk} = a_i \qquad \text{for } i = 1, 2, \ldots N1$$

$$\sum_{k=1}^{N3} \sum_{l=1}^{N4} B_{kl} = b_1$$

$$\sum_{k=1}^{N3} \sum_{m=1}^{N5} B_{km} = b_2$$

$$\sum_{k=1}^{N3} \sum_{l=1}^{N4} B_{kl} + \sum_{k=1}^{N3} \sum_{m=1}^{N5} B_{km} = b_3$$

$$\sum_{m=1}^{N5} \sum_{n=1}^{N6} B_{mn} = b_2$$

---

11. IBM, Mathematical Programming System - Extended, program number 5734-XM4.

where

C_{ij} = unit cost of raw material i at source j

A_{ijk} = amount of raw material i shipped from source j to manufacturer at location k

S_{ijk} = unit cost of shipping raw material i from source j to manufacturer at location k

B_{kl} = amount of the finished product shipped from manufacturer at location k to wholesaler/retailer at location l

T_{kl} = unit cost of shipping the finished product from manufacturer at location k to wholesaler/retailer at location l

B_{km} = amount of the finished product shipped from manufacturer at location k to wholesaler at location m

T_{km} = unit cost of shipping the finished product from manufacturer at location k to wholesaler at location m

B_{mn} = amount of the finished product shipped from wholesaler at location m to retailer at location n

T_{mn} = unit cost of shipping the finished product from wholesaler at location m to retailer at location n

N1 = number of raw materials

N2(i) = number of sources for each raw material i

N3 = number of manufacturing locations

N4 = number of wholesaler/retailer locations

N5 = number of wholesaler locations

N6 = number of retailer locations

a_i = total fixed amount of raw material i available

b_1 = fixed amount of the finished product to be shipped from manufacturer to wholesaler/retailer

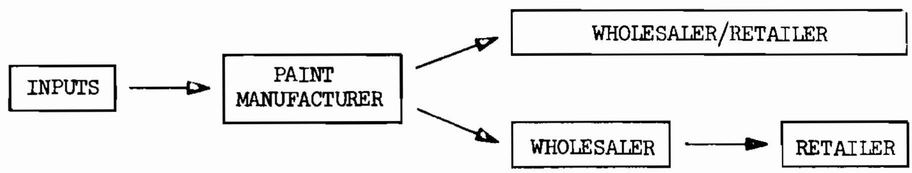
b_2 = fixed amount of the finished product to be shipped from manufacturer to wholesaler and from wholesaler to retailer

b_3 = total amount of the finished product produced by manufacturer

Raw material costs and transportation costs are analyzed simultaneously by the model first for the existing situation. This provides a basis for evaluating the efficiency of increasing production facilities. Each potential location is then analyzed independently with the existing locations to determine the minimum costs. The location having the least cost is the best.

An Analysis of the Bold Color Paint Company

In 1972 the Bold Color Paint Company had sales of $54 million. The company distributed through two types of outlets--wholesaler/retailers and to wholesalers who sold directly to retailers. In 1972, $37 million was distributed to wholesaler/retailers and the remaining $17 million went to wholesalers. The Bold Color Paint Company is an integrated operation, producing not only paint but also producing the inputs for paint. A simplified diagram of the company's operational flow is:



Currently Bold Color Paint Company has 13 manufacturing facilities which serve its wholesale and wholesale/retail markets. Demand in these markets has increased sufficiently to justify increased production capacity--either by the expansion of an existing facility or by the addition of a new manufacturing plant. The objective is to locate the new plant such that the costs[12] of transporting raw materials and paint will be minimized. In 1972 the Bold Color Paint Company had manufacturing facilities in the following locations:

Oakland, California	Winston-Salem, North Carolina
Los Angeles, California	Cleveland, Ohio
Anaheim, California	Wooster, Ohio
Morrow, Georgia	Dayton, Ohio
Forest Park, Illinois	Memphis, Tennessee
Gibbsboro, New Jersey	Garland, Texas
Newark, New Jersey	

12. The cost of like inputs does not vary from location to location for the Bold Color Paint Company.

Each manufacturing location receives its inputs from the following locations:

Commodity	Source
Vegetable oils	Cleveland, Ohio
Labels	North Olmsted, Ohio
Inorganic pigments	Chicago, Illinois Coffeyville, Kansas
Organic chemicals	Cincinnati, Ohio
Resins	Bound Brook, New Jersey Ashtabula, Ohio
Ground minerals	Rochester, Michigan
Metal cans	San Leandro, California Elgin, Illinois Hubbard, Ohio

The manufacturer may use one or more sources of multiple source commodities. The existing optimum pattern for the Bold Color Paint Company to secure its inputs and distribute its finished product is given in table 4. This distribution pattern will minimize total transportation costs. The Bold Color Paint Company is considering locating a manufacturing plant in one of five locations. These locations, Detroit, Michigan; Charlotte, North Carolina; Philadelphia, Pennsylvania; Memphis, Tennessee;[13] and Richmond, Virginia, were in areas with greatest sales potential. With the additional capacity, Bold Color Paint Company sales should reach $58 million, an increase of 8 percent over the present production. The new facility is expected to contribute the additional $4 million in sales. Each potential location was analyzed independently with the thirteen existing locations to determine which would minimize transportation cost for the company. From the standpoint of transportation costs Charlotte, North Carolina was the best location of the five shown below:

Potential Locations	Percent Increase Transportation Costs
Charlotte, North Carolina	3.2
Detroit, Michigan	3.5
Richmond, Virginia	3.9
Memphis, Tennessee	4.1
Philadelphia, Pennsylvania	4.5

13. An expansion of the Memphis, Tennessee manufacturing facility.

The optimum distribution pattern for the Bold Color Paint Company with an expansion of the Memphis, Tennessee facility is given in table 5. Similar patterns were determined for all potential locations.

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	115	OAKLAND, CA
Labels	North Olmsted, OH	73	
Pigments	Chicago, IL	502	
Org. chems.	Cincinnati, OH	316	
Resins	Ashtabula, OH	413	
Minerals	Rochester, MI	14	
Metal cans	San Leandro, CA	175	
GRAND TOTAL		1,608	

Distribution of Paint to Markets

Markets Wholesale	Amount ($1000)	Retail Markets	Amount ($1000)
Fresno, CA SMSA	251	California	251
Oregon-Washington	586	Arizona	65
		California	101
		Idaho	28
		Montana	47
		Oregon	129
		Utah	216
		Total	586
Mountains	335	Colorado	157
		Nebraska	135
		Utah	43
		Total	335
Plains	335	Iowa	166
		Kansas	8
		Nebraska	41
		North Dakota	92
		South Dakota	28
Wholesale Total	1,507	Total	335

Table 4

[illegible]

OPTIMUM PATTERN FOR [illegible]

[illegible]

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($[illegible])	Manufacturer	Markets	Amount ($[illegible])	Retail Markets	Amount ($1000)
				Wholesale/Retail			
			OAKLAND, C[illegible] (continued)	California	648		
				Colorado	354		
				Idaho	89		
				Iowa	89		
				Kansas	110		
				Minnesota	6[illegible]		
				Montana	149		
				Nebraska	5[illegible]		
				North Dakota	2[illegible]		
				Oregon	354		
				[illegible]	[illegible]		
				Wholesale/Retail Total	3,[illegible]		
				GRAND TOTAL	4,[illegible]		

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale			
Oils	Cleveland, OH	69	LOS ANGELES, CA	Southeast Texas	804	Texas	804
Labels	North Olmsted, OH	43					
Pigments	Chicago, IL	299		Wholesale/Retail			
Org. chems.	Cincinnati, OH	188		Kansas	184		
Resins	Ashtabula, OH	246		New Mexico	235		
Minerals	Rochester, MI	9		Oklahoma	89		
Metal cans	San Leandro, CA	104		Texas	1,55[illegible]		
				Wholesale/Retail Total	2,059		
GRAND TOTAL		958		GRAND TOTAL	2,8[illegible]2		

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	36					
Labels	North Olmsted, OH	23					
Pigments	Chicago, IL	158					
Org. chems.	Cincinnati, OH	100	ANAHEIM, CA	Texas	1,512		
Resins	Ashtabula, OH	130					
Minerals	Rochester, MI	5					
Metal cans	San Leandro, CA	55					
GRAND TOTAL		507					

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	119	MORROW, GA				
Labels	North Olmsted, OH	75					
Pigments	Chicago, IL	11					
	Coffeyville, KS	508		Florida	3,522		
Org. chems.	Cincinnati, OH	327		Georgia	1,446		
Resins	Bound Brook, NJ	181		Wholesale/Retail Total	4,968		
	Ashtabula, OH	246					
Minerals	Rochester, MI	15					
Metal cans	San Leandro, CA	91					
	Elgin, IL	90					
GRAND TOTAL		1,663					

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale/Retail			
Oils	Cleveland, OH	6					
Labels	North Olmsted, OH	4					
Pigments	Chicago, IL	28					
Org. chems.	Cincinnati, OH	18	FOREST PARK, IL	Wisconsin	270		
Resins	Ashtabula, OH	23					
Minerals	Rochester, MI	1					
Metal cans	Elgin, IL	10					
GRAND TOTAL		90					

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	1					
Labels	North Olmsted, OH	1					
Pigments	Chicago, IL	6					
Org. chems.	Cincinnati, OH	4	GIBBSBORO, NJ	Richmond, VA SMSA*	54		
Resins	Bound Brook, NJ	5					
Minerals	Rochester, MI	—					
Metal cans	Hubbard, OH	2					
GRAND TOTAL		19					

— Less than $1000

*Served by more than one manufacturing location.

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	178	NEWARK, NJ
Labels	North Olmsted, OH	113	
Pigments	Chicago, IL	778	
Org. chems.	Cincinnati, OH	491	
Resins	Bound Brook, NJ	641	
Minerals	Rochester, MI	22	
Metal cans	Hubbard, OH	272	
GRAND TOTAL		2,495	

Distribution of Paint to Markets

Markets Wholesale	Amount ($1000)	Retail Markets	Amount ($1000)
Baltimore-Wash.D.C.	201	Virginia	201
Newark, NJ SMSA	837	New Jersey	139
		Pennsylvania	84
		Virginia	567
		West Virginia	47
		Total	837
Paterson, NJ SMSA	268	New York	268
New York, NY SMSA	737	New Mexico	92
		New York	124
		Ohio	521
		Total	737
Philadelphia, PA SMSA	753	Tennessee	561
		Virginia	192
		Total	753
Lancaster, PA SMSA	385	Ohio	71
		Pennsylvania	314
		Total	385

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale			
						Connecticut	204
						Maine	268
				New England	670	Massachusetts	55
						New Hampshire	55
						New York	88
						Total	670
				Richmond, VA SMSA*	411		
				Wholesale Total	4,262		
			NEWARK, NJ (continued)				
				Wholesale/Retail			
				Connecticut	583		
				Maine	857		
				Massachusetts	89		
				New Hampshire	6[illegible]		
				New Jersey	17[illegible]		
				New York	1,416		
				Wholesale/Retail Total	3,190		
				GRAND TOTAL	7,452		

*Served by more than one manufacturing location.

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	3					
Labels	North Olmsted, OH	2					
Pigments	Chicago, IL	11					
Org. chems.	Cincinnati, OH	7	WINSTON-SALEM, NC	North Carolina	108		
Resins	Bound Brook, NJ	9					
Minerals	Rochester, MI	—					
Metal cans	Elgin, IL	4					
GRAND TOTAL		36					

— Less than $1000

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SYSTEM

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	489	CLEVELAND, OH
Labels	North Olmsted, OH	309	
Pigments	Chicago, IL	2,131	
Org. chems.	Cincinnati, OH	1,344	
Resins	Ashtabula, OH	1,754	
Minerals	Rochester, MI	61	
Metal cans	Elgin, IL	270	
	Hubbard, OH	475	
GRAND TOTAL		6,833	

Distribution of Paint to Markets

Wholesale Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Buffalo-Albany, NY	352	North Carolina	352
Pittsburgh, PA SMSA	352	Ohio	352
Detroit-Toledo	2,727	Illinois	370
		Indiana	[illegible]
		Kansas	37[illegible]
		Michigan	1,44[illegible]
		Minnesota	1[illegible]
		Missouri	74
		Wisconsin	33[illegible]
		Total	2,727
Miami, FL SMSA*	1,181		
Georgia	603	Alabama	461
		Georgia	142
		Total	603
Carolinas	1,256	Florida	501
		Georgia	330
		South Carolina	425
		Total	1,256

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale			
				Richmond, VI SMSA*	221	Florida	240
						North Carolina	18
						Virginia	428
				Wholesale Total	6,692	Total	686
				Wholesale/Retail			
			CLEVELAND, OH (continued)	Florida	1,737		
				Illinois	149		
				Indiana	43		
				Kentucky	533		
				Michigan	4,016		
				North Carolina	395		
				Ohio	2,213		
				Pennsylvania	768		
				South Carolina	503		
				Virginia	3,100		
				West Virginia	149		
				Wisconsin	114		
				Wholesale/Retail Total	13,720		
				GRAND TOTAL	20,412		

*Served by more than one manufacturing location.

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	1					
Labels	North Olmsted, OH	1					
Pigments	Chicago, IL	6					
Org. chems.	Cincinnati, OH	4	WOOSTER, OH	Florida	54		
Resins	Ashtabula, OH	5					
Minerals	Rochester, MI	—					
Metal cans	Elgin, IL	2					
GRAND TOTAL		19					

— Less than $1000

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	128	DAYTON, OH
Labels	North Olmsted, OH	81	
Pigments	Chicago, IL	558	
Org. chems.	Cincinnati, OH	352	
Resins	Ashtabula, OH	459	
Minerals	Rochester, MI	16	
Metal cans	Elgin, IL	195	
GRAND TOTAL		1,789	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Wholesale			
Dayton-Cincinnati	1,171	Indiana	216
		Kentucky	296
		Tennessee	659
		Total	1,171
Wholesale Retail			
Indiana	2[illegible]1		
Tennessee	3.8[illegible]		
Wholesale/Retail Total	4,1[illegible]		
GRAND TOTAL	5,3[illegible]		

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	3	MEMPHIS, TN	Memphis, TN SMSA*	108		
Labels	North Olmsted, OH	2					
Pigments	Chicago, IL	11					
Org. chems.	Cincinnati, OH	7					
Resins	Ashtabula, OH	9					
Minerals	Rochester, MI	—					
Metal cans	San Leandro, CA	4					
GRAND TOTAL		36					

— Less than $1000

*Served by more than one manufacturing location.

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE EXISTING SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	145	GARLAND, TX
Labels	North Olmsted, OH	92	
Pigments	Chicago, IL	631	
Org. chems.	Cincinnati, OH	398	
Resins	Ashtabula, OH	520	
Minerals	Rochester, MI	18	
Metal cans	San Leandro, CA	221	
GRAND TOTAL		2,025	

Distribution of Paint to Markets

Markets (Wholesale)	Amount ($1000)	Retail Markets	Amount ($1000)
Dallas-Ft. Worth-El Paso	335	Texas	335
Southwest	167	Oklahoma	167
Miami, FL SMSA*	157	Florida	1,338
Mississippi-Alabama	536	Alabama	29
		Louisiana	129
		Mississippi	323
		Texas	55
		Total	536
Memphis, TN SMSA*	947	Arkansas	84
		Oklahoma	416
		Texas	555
Wholesale Total	2,142	Total	1,055

*Served by more than one manufacturing location.

Table 4

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE [illegible]

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale Retail			
			GARLAND, TX (continued)	Alabama	1,446		
				Arkansas	6[illegible]		
				Louisiana	414		
				Mississippi	946		
				Texas	1,[illegible]40		
				Wholesale Retail Total	3,[illegible]		
				GRAND TOTAL	6,[illegible]		

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	115	OAKLAND, CA
Labels	North Olmsted, OH	73	
Pigments	Chicago, IL	502	
Org. chems.	Cincinnati, OH	316	
Resins	Ashtabula, OH	413	
Minerals	Rochester, MI	14	
Metal cans	San Leandro, CA	175	
GRAND TOTAL		1,608	

Distribution of Paint to Markets

Markets Wholesale	Amount ($1000)	Retail Markets	Amount ($1000)
Fresno, CA SMSA	270	California	270
Oregon-Washington	631	Arizona	70
		California	109
		Idaho	30
		Montana	51
		Oregon	139
		Utah	232
		Total	631
Mountains	367	Colorado	169
		Nebraska	151
		Utah	47
		Total	367
Plains*	103	Iowa	179
		Kansas	14
		Nebraska	39
		North Dakota	99
		South Dakota	30
Wholesale Total	1,371	Total	361

*Served by more than one manufacturing location.

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale/Retail			
			OAKLAND, CA (continued)	California	698		
				Colorado	414		
				Idaho	96		
				Iowa	96		
				Minnesota	65		
				Montana	160		
				Nebraska	542		
				North Dakota	221		
				Oregon	381		
				Utah	762		
				Wholesale/Retail Total	3,435		
				GRAND TOTAL	4,806		

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	69	LOS ANGELES, CA
Labels	North Olmsted, OH	43	
Pigments	Chicago, IL	299	
Org. chems.	Cincinnati, OH	183	
Resins	Ashtabula, OH	246	
Minerals	Rochester, MI	9	
Metal cans	San Leandro, CA	104	
GRAND TOTAL		953	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Wholesale			
Plains*	258		
Southeast Texas	866	Texas	866
Wholesale Total	1,124		
Wholesale/Retail			
Kansas	317		
New Mexico	253		
Oklahoma	96		
Texas	1,072		
Wholesale/Retail Total	1,738		
GRAND TOTAL	2,862		

*Served by more than one manufacturing location.

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	36					
Labels	North Olmsted, OH	23					
Pigments	Chicago, IL	158					
Org. chems.	Cincinnati, OH	100	ANAHEIM, CA	Texas	1,512		
Resins	Ashtabula, OH	130					
Minerals	Rochester, MI	5					
Metal cans	San Leandro, CA	55					
GRAND TOTAL		507					

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale/Retail			
Oils	Cleveland, OH	119	MORROW, GA				
Labels	North Olmsted, OH	75					
Pigments	Coffeyville, KS	519					
Org. chems.	Cincinnati, OH	327		Florida	3,411		
				Georgia	1,557		
Resins	Bound Brook, NJ	245		Wholesale/Retail Total	4,968		
	Ashtabula, OH	182					
Minerals	Rochester, MI	15					
Metal cans	Elgin, IL	181					
GRAND TOTAL		1,663					

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	6					
Labels	North Olmsted, OH	4					
Pigments	Chicago, IL	28					
Org. chems.	Cincinnati, OH	18	FOREST PARK, IL	Wisconsin	270		
Resins	Ashtabula, OH	23					
Minerals	Rochester, MI	1					
Metal cans	Elgin, IL	10					
GRAND TOTAL		90					

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale			
Oils	Cleveland, OH	1					
Labels	North Olmsted, OH	1					
Pigments	Chicago, IL	6					
Org. chems.	Cincinnati, OH	4	GIBBSBORO, NJ	Baltimore-Washington, DC*	54	Virginia	216
Resins	Bound Brook, NJ	5					
Minerals	Rochester, MI	—					
Metal cans	Hubbard, OH	2					
GRAND TOTAL		19					

— Less than $1000

*Served by more than one manufacturing location.

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	178	NEWARK, NJ
Labels	North Olmsted, OH	113	
Pigments	Chicago, IL	778	
Org. chems.	Cincinnati, OH	491	
Resins	Bound Brook, NJ	641	
Minerals	Rochester, MI	22	
Metal cans	Hubbard, OH	272	
GRAND TOTAL		2,495	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Wholesale			
Baltimore-Washington, DC*	84		
Newark, NJ SMSA	901	New Jersey	150
		Pennsylvania	90
		Virginia	610
		West Virginia	51
		Total	901
Patterson, NJ SMSA	282	New York	282
New York, NY SMSA	794	New Mexico	99
		New York	133
		Ohio	562
		Total	794
Philadelphia, PA SMSA	811	Tennessee	603
		Virginia	208
		Total	811
Lancaster, PA SMSA	415	Ohio	76
		Pennsylvania	339
		Total	415

*Served by more than one manufacturing location.

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale			
						Connecticut	220
						Maine	289
				New England	722	Massachusetts	59
						New Hampshire	59
						New York	95
				Wholesale Total	4,016	Total	722
				Wholesale Retail			
			NEWARK, NJ (continued)	Connecticut	634		
				Maine	923		
				Massachusetts	96		
				New Hampshire	6[illegible]		
				New Jersey	193		
				New York	1,525		
				Wholesale/Retail Total	3,436		
				GRAND TOTAL	7,45[illegible]		

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale/Retail	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	3	WINSTON-SALEM, NC	North Carolina	108		
Labels	North Olmsted, OH	2					
Pigments	Chicago, IL	11					
Org. chems.	Cincinnati, OH	7					
Resins	Bound Brook, NJ	9					
Minerals	Rochester, MI	—					
Metal cans	Elgin, IL	4					
GRAND TOTAL		36					

— Less than $1000

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	489	CLEVELAND, OH
Labels	North Olmsted, OH	309	
Pigments	Chicago, IL	2,131	
Org. chems.	Cincinnati, OH	1,344	
Resins	Ashtabula, OH	1,754	
Minerals	Rochester, MI	61	
Metal cans	Elgin, IL	212	
	Hubbard, OH	533	
GRAND TOTAL		6,833	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Wholesale			
Baltimore-Washington, DC*	78		
Buffalo-Albany, NY	379	North Carolina	379
Pittsburgh, PA SMSA	379	Ohio	379
Detroit-Toledo	2,934	Illinois	398
		Indiana	129
		Kansas	39[illegible]
		Michigan	1,55[illegible]
		Minnesota	1[illegible]
		Missouri	8
		Wisconsin	35[illegible]
		Total	2,934
Georgia	649	Alabama	497
		Georgia	15[illegible]
		Total	649

*Served by more than one manufacturing location.

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale			
				Carolinas	1,352	Florida	538
						Georgia	356
						South Carolina	458
						Total	1,352
				Richmond, VA SMSA	739	Florida	259
						North Carolina	19
						Virginia	461
				Wholesale Total	6,510	Total	739
			CLEVELAND, OH (continued)				
				Wholesale/Retail			
				Florida	1,552		
				Illinois	160		
				Kentucky	37		
				Michigan	4,325		
				North Carolina	434		
				Ohio	2,383		
				Pennsylvania	827		
				South Carolina	542		

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets	Amount ($1000)	Retail Markets	Amount ($1000)
				Wholesale/Retail			
			CLEVELAND, OH (continued)	Virginia	3,338		
				West Virginia	160		
				Wisconsin	144		
				Wholesale/Retail Total	13,902		
				GRAND TOTAL	20,412		
				Wholesale/Retail			
Oils	Cleveland, OH	1	WOOSTER, OH	Florida	54		
Labels	North Olmsted, OH	1					
Pigments	Chicago, IL	6					
Org. chems.	Cincinnati, OH	4					
Resins	Ashtabula, OH	5					
Minerals	Rochester, MI	—					
Metal cans	Elgin, IL	2					
GRAND TOTAL		19					

— Less than $1000

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	128	DAYTON, OH
Labels	North Olmsted, OH	81	
Pigments	Chicago, IL	558	
Org. chems.	Cincinnati, OH	352	
Resins	Ashtabula, OH	459	
Minerals	Rochester, MI	16	
Metal cans	Elgin, IL	195	
GRAND TOTAL		1,789	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Wholesale			
Dayton-Cincinnati	1,260	Indiana	230
		Kentucky	319
		Tennessee	711
		Total	1,260
Wholesale Retail			
Indiana	349		
Kentucky	537		
Tennessee	3,200		
Wholesale/Retail Total	4,086		
GRAND TOTAL	5,346		

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers				Distribution of Paint to Markets			
Input	Source	Amount ($1000)	Manufacturer	Markets Wholesale	Amount ($1000)	Retail Markets	Amount ($1000)
Oils	Cleveland, OH	3	MEMPHIS, TN	Memphis, TN SMSA*	108	Arkansas	90
Labels	North Olmsted, OH	2				Oklahoma	448
Pigments	Chicago, IL	11				Texas	597
Org. chems.	Cincinnati, OH	7				Total	1,135
Resins	Ashtabula, OH	9					
Minerals	Rochester, MI	—					
Metal cans	Elgin, IL	4					
GRAND TOTAL		36					

— Less than $1000

*Served by more than one manufacturing location.

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	145	GARLAND, TX
Labels	North Olmsted, OH	92	
Pigments	Chicago, IL	603	
	Coffeyville, KS	28	
Org. chems.	Cincinnati, OH	398	
Resins	Ashtabula, OH	520	
Minerals	Rochester, MI	18	
Metal cans	San Leandro, CA	221	
GRAND TOTAL		2,025	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Market	Amount ($1000)
Wholesale			
Dallas-Ft. Worth-El Paso	361	Texas	361
Southwest	180	Oklahoma	180
Miami, FL SMSA	1,440	Florida	1,440
Wholesale Total	1,981		
Wholesale/Retail			
Arkansas	65		
Florida	705		
Louisiana	445		
Mississippi	1,019		
Texas	1,833		
Wholesale/Retail Total	4,067		
GRAND TOTAL	6,048		

Table 5

BOLD COLOR PAINT COMPANY

OPTIMUM PATTERN FOR PURCHASING INPUTS AND DISTRIBUTING PAINT

FOR THE POTENTIAL SITUATION

Distribution of Inputs to Manufacturers

Input	Source	Amount ($1000)	Manufacturer
Oils	Cleveland, OH	99	MEMPHIS, TN**
Labels	North Olmsted, OH	63	
Pigments	Chicago, IL	434	
Org. chems.	Cincinnati, OH	274	
Resins	Ashtabula, OH	357	
Minerals	Rochester, MI	12	
Metal cans	San Leandro, CA	144	
	Elgin, IL	7	
GRAND TOTAL		1,390	

Distribution of Paint to Markets

Markets	Amount ($1000)	Retail Markets	Amount ($1000)
Wholesale			
Mississippi-Alabama	577	Alabama	31
		Louisiana	139
		Mississippi	348
		Texas	59
		Total	577
Memphis, TN SMSA*	1,027		
Wholesale Total	1,604		
Wholesale/Retail			
Alabama	1,557		
Tennessee	993		
Wholesale/Retail Total	2,550		
GRAND TOTAL	4,154		

*Served by more than one manufacturing location.

**Distribution for the expansion only.

IIASA DISCUSSION PAPER

O. Bernardini

What I am going to say may be partly influenced by an incomplete knowledge on my part of what the particular application is all about. The paper is very short and the problem very large. If I make any undue criticisms on this account I trust Mr. Foster will correct me later.

The problem of forecasting the location of industries is a very complicated one and to the best of my knowledge none has yet found a solution to it. Probably none ever will.

The main factors of location are shown in Figure 1.

- market: obviously important, not much to say.
- transportation costs: becoming less and less important because of improvement in transportation and because of increasing value/weight ratio of products. They are also very sensitive to the pricing policy adopted by the company for product distribution and of the companies providing the main materials inputs. If both of these are cif. then transportation cost is not a location variable.
- materials supply: generally speaking no longer very important since the cost of raw materials is tending to spatial uniformity.
- labor: cost, specialization and productivity is becoming less important as a location variable but is still to be taken into consideration.
- cost of utilities: generally not very important except for some industries e.g. fertilizers, aluminum, etc.
- land and building costs: generally not an important locational variable.
- capital costs: rarely locationally variable.
- state and local taxes: sometimes need to be taken into account.
- public policy and planning: must be taken into account. This includes zoning laws, tax penalties, financial inducements, etc.

RELATIVELY EASY TO QUANTIFY	MARKET TRANSPORTATION COSTS MATERIALS SUPPLY LABOR COST OF UTILITIES LAND AND BUILDING COSTS CAPITAL COSTS STATE AND LOCAL TAXES PUBLIC POLICY AND PLANNING
NOT EASY TO QUANTIFY BUT EXTREMELY IMPORTANT	SUBJECTIVE PERSONAL PREFERENCE AGGLOMERATION AND EXTERNAL ECONOMIES DEVELOPING TECHNOLOGY ECONOMIES OF SCALE
	SOCIAL COSTS

FIGURE 1. LOCATION VARIABLES

These are all relatively easy to quantify. There are, however, a number that are not easy to quantify but are nevertheless extremely important.

- subjective personal preference: a random element.

- agglomeration and external economies: that is fundamental. It includes industrial complex economies, localization economies and urbanization economies. It takes into account inter-industry relations, facility of communication, well-developed infra-structure of highways, railway lines and terminals, airports, special facilities such as technical colleges and research centers, educational institutions and services which a single industry would not be able to afford, quality of the labor pool and other intangibles.

- developing technology: connected with technological forecasting. These become especially important if we try to forecast ten years into the future as the models seem to be attempting.

- economies of scale: the size of the new facility has immense importance which cannot always be quantified with a simple production function.

These last four factors are generally very difficult to quantify and therefore to consider in a computerized location model. It would have been impossible to forecast location of new sulphuric acid plants in Italy on the basis of simple location models as can be seen from Figure 2.

- social cost: this is not important now but will become very much so in the future. These include pollution, noise, dirt, ugly sights, traffic congestion, etc. Up to recently they were generally speaking, considered as externalities to the industrial location phenomenon. Montedison, for example, already plans to use air and water pollution models beginning next year for relocation of industrial activity in the Porto Marghera region where the social cost has manifested itself in worker strikes with a well defined cost to the company.

The tendency through time has been, very roughly, for industrial location models to move in emphasis in the direction of the arrow of Figure 1.

The basic structure of the TVA location model is shown in Figure 3.

Model I Market Analysis Model

- I am a little worried by the averaging involved in determining the production deficit in each state because it becomes very hazy when projections are made to 1980.

SULPHURIC ACID PRODUCTION IN ITALY

$$\frac{7}{2}O_2 + 2\,FeS \rightarrow Fe_2O_3 + 2SO_2$$

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

DISPERSED PLANT CONFIGURATION

MARKET AND LABOR ORIENTED LOCATION

- ~10 PRODUCTION PLANTS
- TRANSPORTATION COSTS OF RAW MATERIALS TO PLANTS
- TOTAL RECUPERABLE HEAT WASTED ~500 MW
- FERRIC OXIDE CALCINE SOLD VERY CHEAPLY TO IRON AND STEEL PLANTS

CONCENTRATED PLANT CONFIGURATION

SUPPLY ORIENTED LOCATION

- 4 PRODUCTION PLANTS
- TRANSPORTATION COSTS OF PRODUCT TO MARKETS
- ~500 MW RECOVERED AS MEDIUM PRESSURE STEAM
- FERRIC OXIDE UPGRADED BY REDUCTION, MAGNETIZATION AND PELLETIZATION, SOLD WITH GOOD PROFIT TO IRON AND STEEL PLANTS
- ECONOMIES OF SCALE

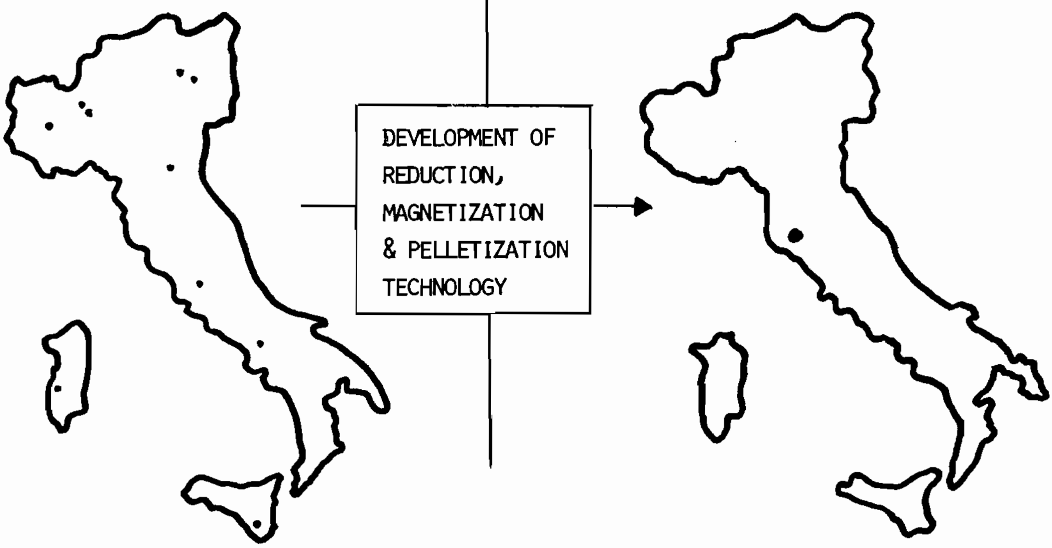


FIG. 2

- The thing which really bothers me, however, is the level of resolution of the analysis. Why should a state become a location just because there is a production deficit? The potential location regions are very sensitive to the regions for which the production deficit was calculated. With this type of analysis every block in an urban region would require a baker or a shoe repair shop, for example.

- How are the multistate regions for potential location defined?

- The level of resolution has always been a big problem in this type of analysis. In 1967, Klaassen, in Methods of Selecting Industries for Depressed Areas, OECD, Paris 1967, developed a very interesting procedure for determining these "relevant regions".

- The partition of the nation into relevant regions was made on the basis of interindustry input output relations and implicity takes into account all sorts of transportation and communication costs. Each industry is associated with a partition of the nation. Examples of partitions according to Klaassen are shown in Figure 4, 5 and 6.

- I doubt very much that the regions used in the TVA model were the same as the relevant regions. We shall see the effect this can have on predicting industrial location later.

Model II Branch Plant Market Analysis Model

- Both Models II and III contain examples of the location--allocation problem. The methods used here are somewhat outdated. The optimum location allocation structure calculated with the criteria given here has probably very little to do with the actual structure.

- The type of inconsistency they lead to is illustrated by the Harris-Dunn Dilemma (C.D. Harris, "The Market as a Factor in the Localization of Industry in the United States," Annals of the Association of American Geographers, Vol. 44, December 1954). Maximizing the gravitational market index generally gives a widely different optimal location from minimizing transportation costs. In the example shown in Figure 7, the optimal locations according to these two criteria are 2,000 miles apart.

- Any errors in the selection of potential regions for locations inherent in the first model carry over to the second model. Much of the disagreement between actual location chosen and rankings for predicted location is probably due to an incorrect partition of the nation into regions. Almost 50% of the predicted locations ranked between 6 and 13. How were the regions chosen? Could any improvement be obtained by using the relevant regions? The relevant region for the optimal instruments and lenses industry Figure 6 is the whole United States. The probability of

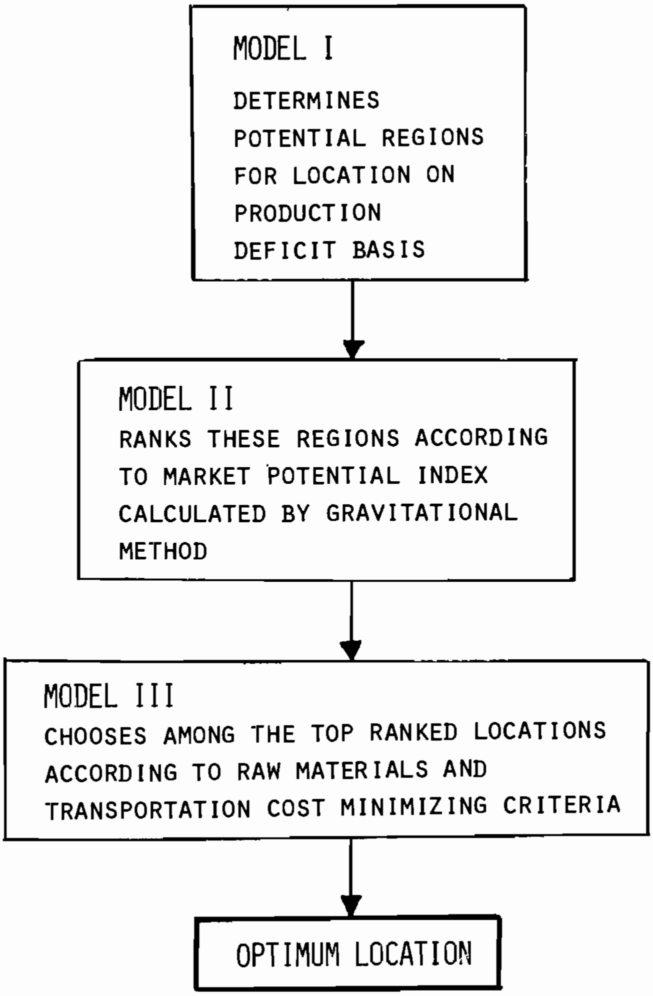

MODEL I
DETERMINES POTENTIAL REGIONS FOR LOCATION ON PRODUCTION DEFICIT BASIS
MODEL II
RANKS THESE REGIONS ACCORDING TO MARKET POTENTIAL INDEX CALCULATED BY GRAVITATIONAL METHOD
MODEL III
CHOOSES AMONG THE TOP RANKED LOCATIONS ACCORDING TO RAW MATERIALS AND TRANSPORTATION COST MINIMIZING CRITERIA
OPTIMUM LOCATION

FIGURE 3

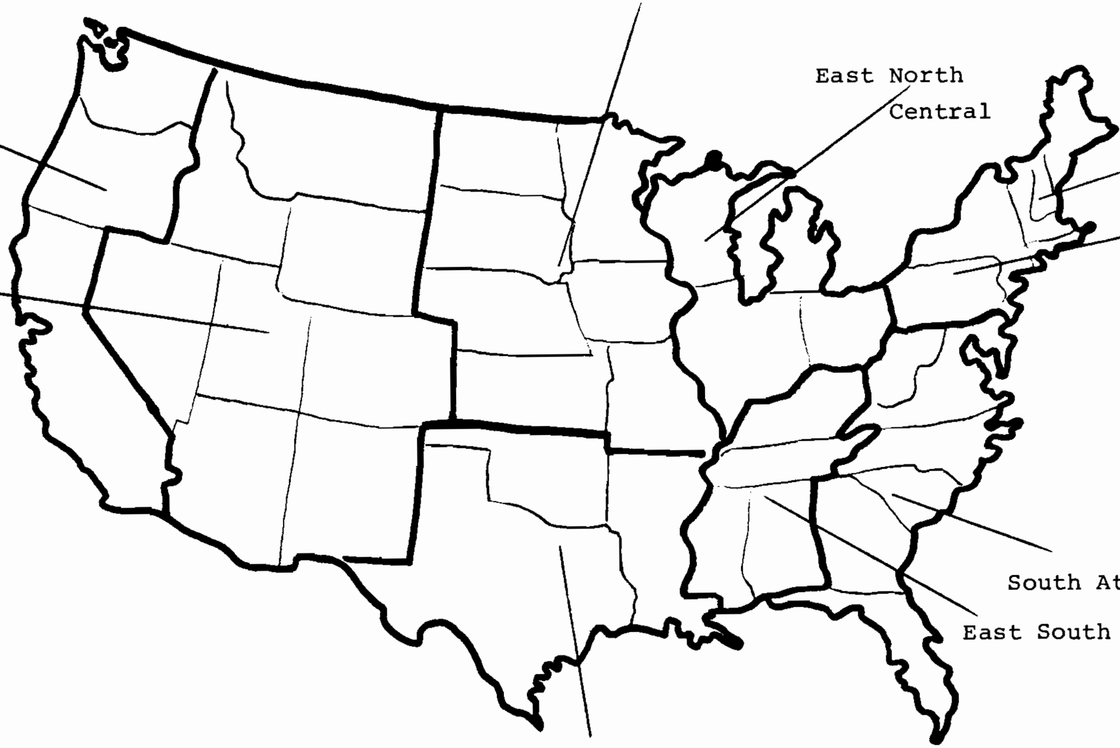


Figure 4. Partition of the United States into Relevant Regions for the Electronic Components Industry

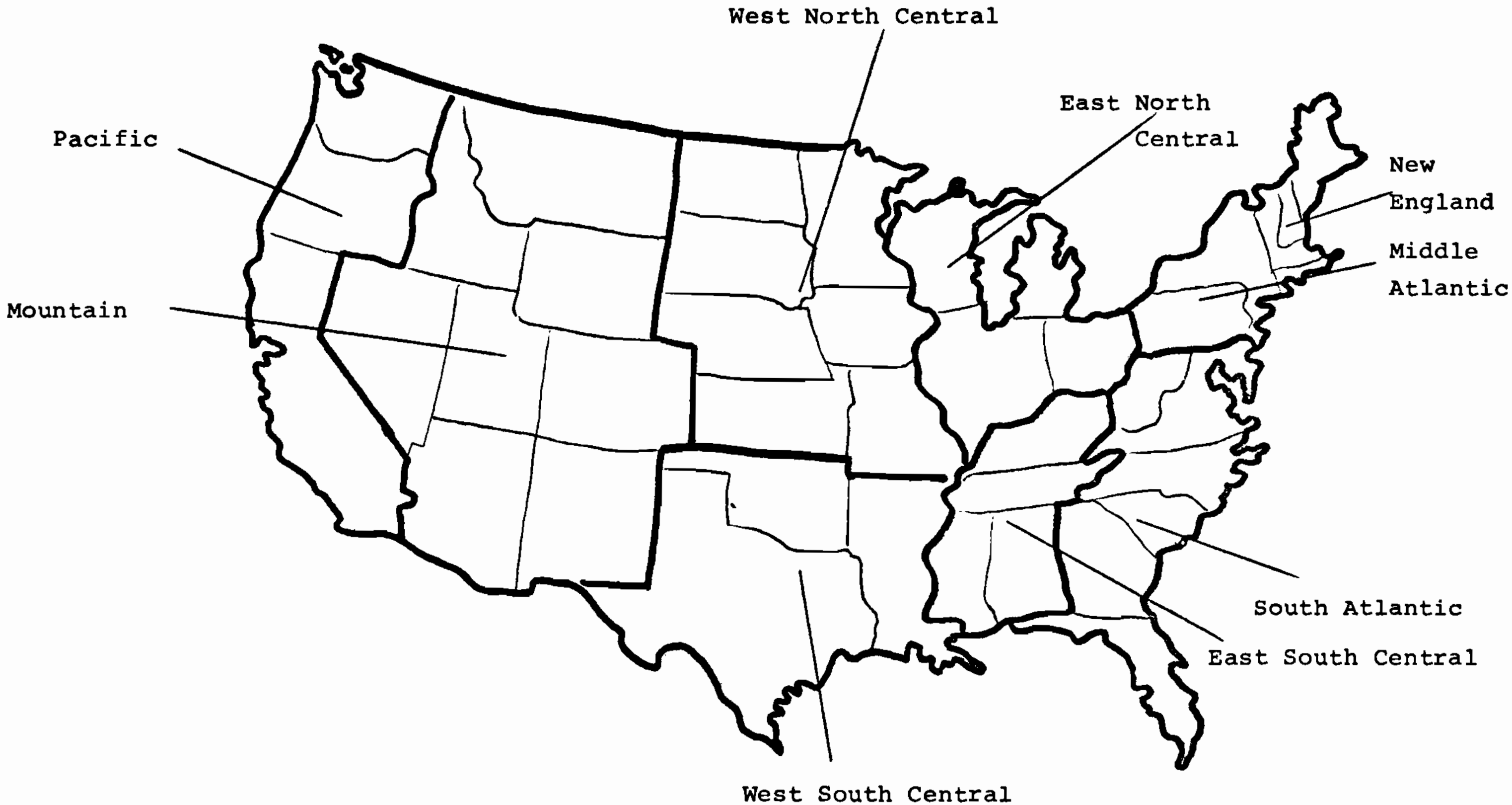


Figure 5. Partition of the United States into Relevant Regions for the Glass Products Industry

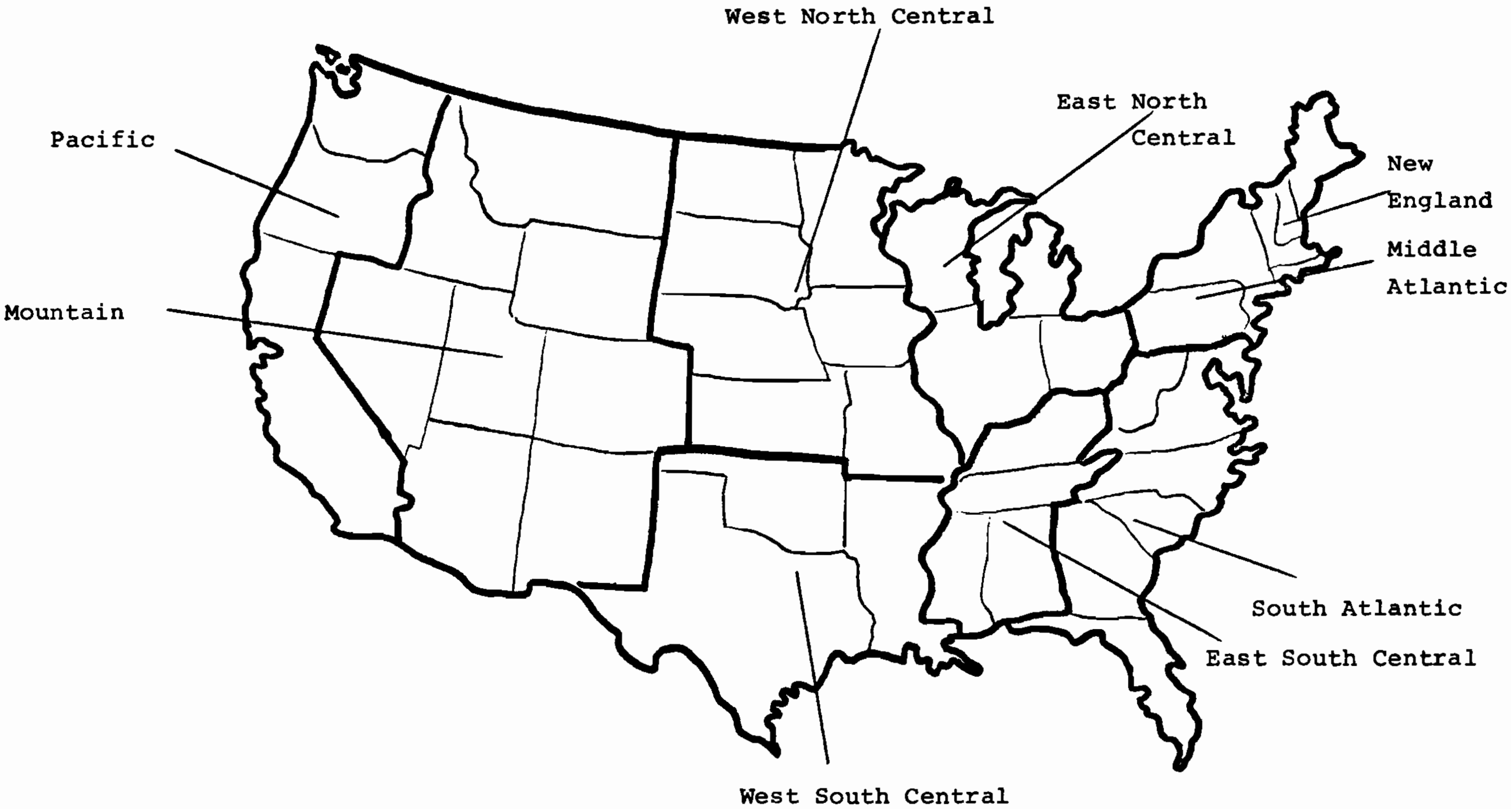


Figure 6. Partition of the United States into Relevant Regions for the Optical Industry

guessing the correct location for this industry in view of this is less than 10%. The same can be said for the surgical instruments industry. Neither of these industries not surprisingly, were located where the model predicted as can be seen from Figure 8.

Model III Branch Plant Raw Materials and Transportation Cost Analysis Model

- The example of the Bold Color Paint Company shows that at least in this case transportation and raw materials cost are not important for lcoation. There is only a 1.3% differential upon which to base a choice Figure 9. Surely other locating criteria are much more important in this case. If the company wishes to minimize investment costs, it will surely just expand the Memphis facility.

- My general feeling is that the model is heavily dated--say 1959/1960. Things have changed considerably since then with regard to prevalent locating criteria. Models should take these chances into account.

Questions for Mr. Foster

1. What criteria were used for lumping states into one region in Model 1? Contiguous production deficit states or what ?.

2. What is the size of the regions in Model II? The goodness of the results is dependent on the size of these regions.

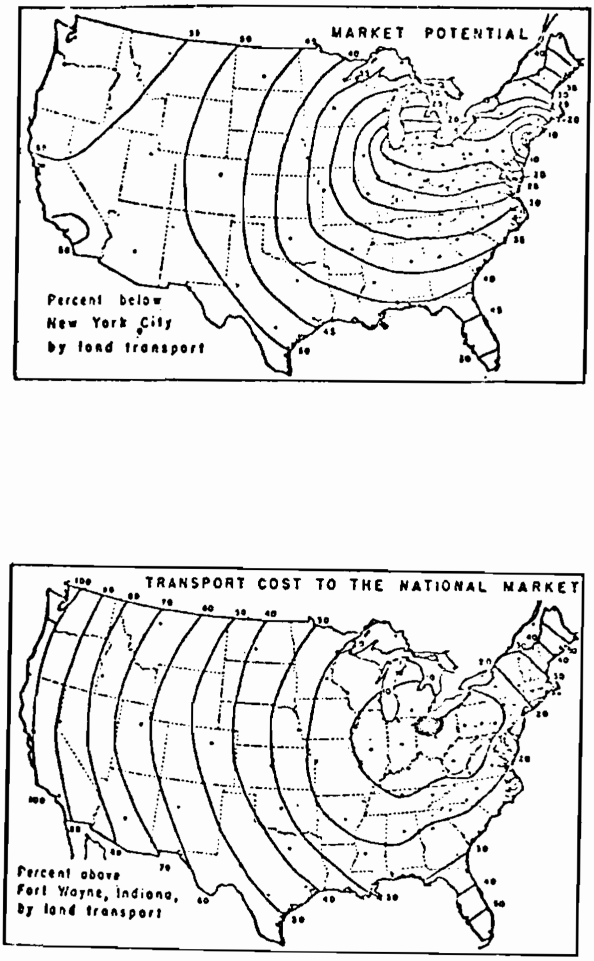
3. To what type of indutry is the model applicable and to which have you applied it?

4. To what extent have you used the models? Have you applied them nationwide or only to limited areas?

5. Am I correct in inferring that the models were developed in the early 1960's? Say 1959-62?

6. If yes, are you currently developing more sophisticated models to keep abreast of changing emphasis in locational factors?

7. If these models have the desired persuasive effect on local and state authorities, that is to provide attraction for certain types of industry and not others, presumably these industries will tend to be attracted. If the model provides uncertain, possibily incorrect or arbitrary forecasts, do you not think this might result in a distortion of the regional and national economy?



Source: C.D. Harris, "The Market as a Factor in the Localization of Industry in the United States", Annals of the Association of American Geographers, Vol. 44, December 1954.

Figure 7.

RANK OF ACTUAL LOCATION WHEN CONSIDERED AS A POTENTIAL LOCATION

SIC	Industry	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
2034	Dried and dehydrated fruits and vegetables	2													2
2295	Coated fabrics, not rubberized					1				2	2				5
2641	Paper coating and glazing	2	1	1	1					1					6
2645	Die cut paper and board	1													1
2813	Industrial gases	1	1					1	1		1				5
2815	Dyes, dye intermediates, and organic pigments	2						1		1					5
2821	Plastic materials and resins	1	2		2	2	1			1	3	1		1	14
2824	Organic fibers, noncellulosic	2	1												3
2844	Toilet preparations	2	1									2	1		6
3221	Glass containers	1	1												2
3312	Blast furnaces and steel mills	1				2		2	1		3	1			10
3392	Nonferrous forgings								1						1
3519	Internal combustion engines							1	1						2
3541	Metal-cutting machine tools							1							2
3542	Metal-forming machine tools		1					1							2
3553	Woodworking machinery								1						1
3555	Printing trades machinery	1	1			1			1	1					5
3599	Miscellaneous machinery	2		2	1				1						6
3679	Electronic components, n.e.c.	3	1	2	2	2			1	2	3	1			17
3831	Optical instruments and lenses									1					1
3841	Surgical and medical intrumetns									2					2
3842	Surgical appliances and supplies		1					1							2
3861	Photographic equipment	2			1				1	1					5
3955	Carbon paper and inked ribbon	2						1							3
	TOTAL	25	11	5	7	8	1	9	9	12	12	7	1	1	108

POTENTIAL LOCATIONS		PERCENT INCREASE IN TRANSPORT COSTS
CHARLOTTE	NORTH CAROLINA	3.2
DETROIT	MICHIGAN	3.5
RICHMOND	VIRGINIA	3.9
MEMPHIS	TENNESSEE	4.1
PHILADELPHIA	PENNSYLVANIA	4.5

TVA COMMENTS ON DISCUSSION BY O. BERNADINI

The point that there are many factors governing plant location decisions is well taken. The optimum solution would be a technique to evaluate all location factors, both quantitative and nonquantitative, and to have current data available for each factor. Since such a utopia in applications research does not exist, it was felt that a method for estimating markets by geographic regions would be a useful first step. The Tennessee Valley Authority's role is, in part, a supportive one in that the TVA provides the research for the local development agencies to use in implementing their programs. In order to provide this type of assistance it is necessary to develop analytical processes for which data are available and which will provide practical solutions for use in a local program.

The success of industrial development efforts at the local level depends on the ability to identify those industries which would have a locational advantage in a given area. Knowledge of industry location determinants is essential to guide area industrial developers in a rational search for industries for their area.

In a survey completed by the US Department of Commerce,[1] over 2,600 firms in industries with good growth prospects were canvased. Each firm selected had 100 or more employees. Nine factors associated with plant location were analyzed. Respondents selected a maximum of the three most important locational factors for their companies. The results are shown in Table 1 in decreasing order of importance.

The results of this survey indicate that firms in the US consider access to markets as the primary locational determinant; thus, the function of Model I in estimating the market and production of manufactured products by geographic regions seems to square with the practicalities of decision making in the firm.

The regions used in Model I were modifications of regions defined in Mobility for States and State Economic Areas.[2] The regions could be redefined since the building blocks are state boundaries. At this writing states are being replaced by 171

---

[1] "Industrial Location Determinants 1971-1975," US Department of Commerce, Economic Administration (February 1973).

[2] "United States Census of Population, 1960, Mobility for States and State Economic Areas," US Department of Commerce, Bureau of the Census.

Table 1

Locational Factor	Percent of Firms Selecting Factor
Market: Access to markets	58.8
Proximity to distributors and customers	48.6
Transportation economics	45.6
Labor force	33.3
Access to raw materials	30.8
Large site size	24.4
Proximity to company plants	11.0
Special requirements (energy, etc.)	10.2
Proximity to competitors	2.9

trade areas[3] as the basic geographical unit. In Model I regions are held constant for simplicity of presentation.

In the development of Model I the option of regional consumption ratios was incorporated; however, on a practical level these data are rarely, if ever, available.

Model II was developed to identify the location for additional productive capacity at which a company could improve its access to markets within the framework of the company's existing locations and the national market. This model, thus, focuses on an individual company's relation to the market and this information would be used in conjunction with the other locational considerations which are of importance to the company. The regions are defined internally by the model in order to maximize access to markets for the company. Obviously, the industrial developer uses this model only with companies for which market accessibility is a prime consideration.

The testing of Model II was done using industries and companies for which published data were available. The industries were not selected as being market oriented but as a cross section of the manufacturing sector of the economy. The results may be viewed as rough indicators of the importance of this market as a locational factor. As Mr. Bernardini observes, industries such as the optical industry are just not sensitive to regional markets in their location decisions.

---

[3]These are BEA regions, excluding Alaska and Hawaii. See OBE Economic Areas of the United States. Regional Economics Division, Office of Business Economic, US Department of Commerce.

Model III was expanded to analyze access to markets and raw materials in terms of minimizing transportation costs. Model III relies heavily on a company's actual data and expectations, whereas Model II was designed to analyze large numbers of companies using publicity available information. Model II is an abstract index of market accessibility, whereas, Model III minimizes actual transportation costs. The Models were developed between 1965 and 1972.

SUBREGIONAL OVERVIEW STUDIES: A TOOL FOR RELATING ECONOMIC TRENDS IN THE INDUSTRIAL AND NONBASIC SECTORS TO COMMUNITY DEVELOPMENT AND LAND NEEDS

Introduction

Planning for development in the basic sector (manufacturing, agriculture, mining, etc.) gives an idea of the job generating potential of a local area; however planning for development in the nonbasic sector must also be done.[1] Growth and change in the nonbasic sector is directly related to developments occurring in the basic sector.

It is the nonbasic sector that provides the distribution system for goods and services to the point of final consumption. While the regional level of activity in this sector has grown steadily over the past several decades, the distribution of activity among the local areas (cities and counties) in the TVA region has undergone considerable change due to the shifting distribution of employment in the major industrial groups and the rural to urban shift in population. In 1930 only 25.2 percent of the population in the 201-county Tennessee Valley region lived in ubran places. In 1970 this proportion had increased to 49.4 percent. During the same period, employment in agriculture declined from 56.2 percent of total employment to less than 10 percent in 1970.

The impact of the shifts in employment and population has generally been different in each community in the region. In the larger urban centers (cities with population of 25,000 and over), an explosion of commercial activity has occurred which resulted in unsightly and unplanned development along existing streets and highways with concomitant incompatible and inconsistent land uses. In these areas, the expansion and growth of commercial activities generally followed the suburban spread of population occurring at the fringe of the cities where no local zoning authority existed. In the more rural communities (population of less than 10,000),

1. The nonbasic sector is essentially defined as the traditional trade and service sector which includes retail trade, wholesale trade, and the service industry.

this phenomenon was characterized by a decline in commercial activity due to outmigration of population. Communities in the middle size class (population between 10,000 and 25,000) seem to be more susceptible to outside forces in that some experienced growth equivalent to that in the larger urban centers while others remained stagnant.

Changing tastes and preferences of the consumer resulting from rapidly increasing per capita income compounds the problems created by population shifts. The new-found affluence of migrants to the urban areas accelerated the expansion of the commercial sector in those places while the changing tastes and preference of those who remained in rural communities resulted in an outleakage of commercial activity to the larger urban centers due to (1) an improved highway system and (2) to the desire of the small town resident for a greater choice and variety of goods and services.

The key to long-term area development is understanding the aforementioned significant economic and social trends on a regional scale and their impact on a subregional and community scale. Since the impacts of the economic and social forces are not evenly distributed throughout a region, it is necessary to transform the potential impacts into a spatial context. Such an approach facilitates interpretation of the demand for land and the geographic growth patterns evolving from that demand. For example, industrialization has been identified as a significant process occurring in the Tennessee Valley, and each factory unit seeks a location in a subregion and, subsequently, a community which provides optimum access to raw materials, markets, labor, and other services. Trade and service activities are related to the manufacturing employment and population that is projected to increase in the general proximity of the specific industrial location. However, the retail and service establishments are likely to select locations with maximum access to consumers. In both instances, the economic activities occur in subregions having a complementary set of location factors for a successful operation and they occur at specific points where land is available.

Subregional Overview Process

Functions and Description

TVA conducts land use analyses studies called subregional overviews (SRO's) for monitoring development trends in terms of urban-industrial growth and recent population and employment trends in the Valley as these impact subregional land-use patterns. Combined with population, retail-service and industrial projections, the SRO's identify the subareas of the Tennessee Valley where growth is likely to occur, and determine the compatibility of future land use with existing human and physical environments. The SRO's are a tool to assist in planning for regional and community land-use requirements for a growing subregion as well as providing a broad regional framework for coordinating planning efforts with various interested groups (e.g., state and local planning agencies). The overviews help accomplish the basic regional development planning functions of monitoring and information gathering, as well as analysis and evaluation of systems performance.

The subregional overview studies focus on the multi-county subregions of the Tennessee Valley region and are based on readily available information from existing reports, ongoing research, and knowledgeable staffs working in the study areas. The studies consist of maps and overlays, a matrix, and a written report. These materials analyze the physical resource base, land use, and economic trends to determine likely future growth dimensions.

SRO's begin with a regional level analysis of the physical resource base and existing land-use patterns. This is primarily a mapping exercise using a base map (1:250,000 scale) and a series of overlays.[2] Table 1 lists the

2. A larger scale (1:125,000) has been employed in one instance to analyze land use for a smaller area. This map is an experimental project to interpret land cover from hyper-altitude aerial infrared photography according to Anderson's level II classification. From this map, it is possible to recognize the significant land cover features of forest, agriculture, water and urban areas in some detail. The Anderson classification system is discussed in "A Land-Use Classification System for Use with Remote Sensor Data," by James R. Anderson, Ernest E. Hardy, and John T. Roach, Geological Survey Circular 671, U.S. Geological Survey, Washington, D.C., 1972.

overlays, lithos, and small maps used in conjunction with the base map to portray (1) physical characteristics that are adequate for urban-industrial development, e.g., slope and soil permeability; (2) significant social and economic trends, such as changes in population concentrations and proposed roads, parks, and other improvements; and (3) the impact that growth might have upon the physical environment. As the maps and overlays are examined, existing interrelationships become apparent.

To this analysis of existing conditions is added a series of projected land and space needs for the subregion derived from projected population and economic trends. These include determining future industrial land needs from manufacturing employment projections, future urban land needs from population projections, and retail-service space needs as a portion of future urban land needs from projected retail-service sales.

Analysis of Land Requirements in the Industrial Sector

Future land requirements are first calculated for industrial needs based upon manufacturing employment projections for the subregion. The procedure is:

$$I_r = \frac{e_r}{w_r}$$

where e_r = manufacturing employment increases for a subregion;

w_r = estimated workers per industrial site acre;

and I_r = additional industrial acreage required to support manufacturing employment increases at the estimated worker per acre level.

In addition to calculating future industrial land requirements, industrial site location studies are conducted in each county in the subregion to identify lands that are suitable for potential industrial use. These identifications are based primarily on physical site attributes such as level and buildable land; accessibility to rail, highway, water, and air transportaion; availability of water, sewer, and other utilities. In most cases, a number of potential sites are identified in each county

TABLE 1

Overlays, Lithos, and Small Scale Maps in Subregional Overviews

Overlays	Subject
1. Land Use	Highways, jurisdictions, TVA & other public lands
2. Critical Environmental Areas and Human Impact	Critical/sensitive environmental areas & proposed developments of regional impacts
3. Future Development	Urban growth impact areas, industrial expansion, etc.
Lithos	
1. Physical Features	Agricultural soils, prime forest, soils, soils for urban-industrial use
2. Recreation	Recreation capability, waterfowl resource areas, fisheries resource areas, upland game resource areas
Small Maps	
1. Population	County Census District Population trends
2. Physical Features	Geological features
3. Hydrologic Features	Ground water potential, observed minimal runoff
4. Industry	Distribution of manufacturing establishments

to form an industrial site inventory. Normally, the number of acres in the site inventory exceeds the calculated future subregional industrial land requirements. However, the excess provides a selection of potential sites for locating industries and it provides for industrial growth options beyond the current projection period.

After inventorying potential industrial sites and after calculating future industrial land requirements, potential industrial acres, consistent with the projected land requirements, are selected from the industrial site inventory as likely to be developed within the projection period, e.g., 1980 and 2000. At this point, the selected sites are presented on a future development overlay.

Analysis of Land Requirements for Urban Needs

Land requirements for urban needs, less industrial needs, are similarly calculated based upon population projections for the subregion. This procedure is:

$$L_r = \frac{p_r}{d_r}$$

where p_r = population increases for a subregion;

d_r = existing densities per gross urban acre for a subregion;

and L_r = additional urban acreage required to support population increases at existing density levels.

After calculating future subregional urban land requirements (L_r), these are also plotted on the future development overlay showing the expected spatial location of this growth. In allocating projected urban land, the following assumptions are made:

1. The existing urbanized areas in the subregion will continue to grow.
2. Major growth areas will occur along existing and proposed transportation routes.

3. The projected development will be encouraged to avoid areas with severe soil limitations for urban uses; however, it is recognized that some growth can occur in these areas in the pockets of more suitable soils.

4. Parks and recreation areas, particularly Federally owned land, will not become urbanized.

5. Growth will tend to continue in census districts that have grown rapidly in the last decade if these districts are not approaching saturation in terms of area densities.

While not reflected on the overlay, the future urban land projection is refined to indicate what portion of urban space needs will be required for trade and service functions.

Analysis of the Trade and Service Function

The trade and service analysis model fits a community into its subregional context and determines its existing and future commercial potential. It indicates alternative actions for realizing the full potential for developing this sector as well as providing projections for land requirements in a specific community.

The method of analysis employed for assessing a community's role in the subregion is based upon answering three key questions:

1. What is the present level of activity in this sector?

2. What is the present potential of this sector?

3. What is the future potential for development of this sector?

In answering each of these questions, the sector is initially divided into three major categories--retail trade, selected services, and wholesale trade. In a number of cases these major categories are further subdivided into types of business group.

The present level of trade and service activity is location specific and is determined for each area being analyzed. Actual trade and service volume for the area under consideration is computed from actual tax collections. The following equations conceptualize the computation:

$$S_t^i = \frac{100}{r}\left(T_t^i\right) + A_t^i \qquad (1)$$

where: S_t^i = sales in category i in year t

r = tax rate

T_t^i = tax collection in category i in year t

A_t^i = adjustment to account for nontaxable sales in category i in year t

and:

$$TS_t = \sum_{i=1}^{n} S_t^i \qquad (2)$$

where: TS_t = total sales in the trade and service section in year t

S_t^i = sales in category i in year t

In specific community analysis, additional indicators are compiled in order to present a more detailed description of what the community is actually doing. These indicators consist of such factors as number of establishments in each type of business group in each category, existing floor space by type of business, sales/establishment by type of business, employment/establishment by type of business, etc.

Clearly much of the information necessary to make this analysis is considered confidential. In order to obtain it the merchants and the citizens of the community must appreciate and support the idea of determining what is happening. Thus, one of the integral parts of this method of analysis is citizen involvement. While such trust and support takes time to develop, it has the advantage of helping to attain rapid implementation once the types of action required are determined.

After the actual level of activity in this sector has been established, the specific locality being analyzed is compared with regional, and in some cases national, averages for areas of comparable size and characteristics for each category or type of business group. The comparison gives an estimate of present potential for the community and allows an estimate to be made between what the locality is actually doing as compared to what other localities of similar characteristics are doing. The difference between the actual level of activity and the estimated potential level is trade leakage to other trade areas.[1] The comparison with regional or national averages of the number of establishments and volume per establishment by the various types, gives an indication of whether there will be space requirement implications if certain percentages of the leakage are recaptured by the local area. The recapture percentage that is reasonable to expect after remedial action on the part of the community is estimated by analyzing a number of determinants.[2] The determination of the impact of leakage recapture on physical requirements (square feet of space, etc.) is conceptualized by the following:

$$\Delta ST_t^i = \frac{P_t^i}{S_{t-1}^i} - A_{t-1}^i$$

where: ΔST_t^i = change in space required in category i in time t

P_t^i = potential sales recapture in category i in time t

S_{t-1}^i = average sales per unit of space in category i in a base time period

A_{t-1}^i = actual space in category i in a base time period

This analysis will give an estimate by kind of business activity of the space required, as well as providing guidance concerning where the space is needed, e.g., in the central business district or in the suburbs.

---

1. Trade leakage usually occurs because of the ease of mobility in most areas, coupled with the desire of the consumer for a greater variety of goods and services.

2. The assumed remedial action is analyzed for changes that will be brought about in one or more of the following determinants: distribution of income among various income classes, age distribution of the population, distance to cities in larger and smaller size classes, type of highway system, extent of commuting into other trade areas for employment, aesthetic quality of local shopping facilities, availability of adequate parking facilities, traffic flow in the local shopping areas, merchandising techniques used by local merchants, and buying habits of local consumers.

After it is determined what the community is actually doing in this sector and its present potential, consideration is given to the future development of this sector.

The method used to estimate the development potential is first determined for the region. The regional potential is then applied to a subregion or trade area within the region and allocated to smaller geographic areas based on past shares of total trade area volume. Adjustments based on other factors which affect local growth (such as the location of an industrial plant, improvement in transportation network, etc.) are then made to the allocated shares for the local area.

The potential level of retail trade and selected services at the regional level is conceptualized by the following regression equation:

$$L_t^i = a + b\,Y_{t-1} + cT \qquad (3)$$

where:

L_t^i = level of activity in category i in year t

Y_{t-1} = estimate of total personal income in year t-1

T = time from the year 1954

Current values of the coefficients in equation (3) for the southeastern U.S. have been estimated to be as follows:

	Retail Trade	Selected Services
a	128,152	190,319
b	.5885	.1036
c	361.884	4875

Using the assumption that economic areas[3] in the region will react similarly in total retail sales and services as the southeastern states, equation (3),

3. The U.S. Bureau of Economic Analysis has divided the U.S. into a number of homogenous economic areas and have made personal income projections for these areas. These economic areas are used as a proxy for trade areas at the subregional level.

using current coefficients, is applied to subregions to obtain the projected level of activity in the subregion. The subregional activity is then allocated to the county level and adjustments made to reflect any known changes (interstate highways, water resource projects, etc.). The projected level of activity is then converted to space requirements as follows:

$$TS_t = \sum_{i=1}^{n} \frac{A_t^i}{S_o^i}$$

where:

TS_t = total space (sq. ft.) required in all categories of trade and services in year t

A_t^i = projected sales in category i in year t

S_o^i = sales per unit of space in category i in base time period
Note: This is a difficult statistic to obtain for modern establishments. The chief source is the National Retail Merchants Association.

At the regional level, analysis indicates that the determinants of wholesale trade are quite different from the other two components making up this sector primarily due to the effect of large, multi-state trade centers in and/or surrounding the region. The projected change in space required for wholesaling is presently determined by trending the relationship between the volume of retail and wholesale trade and then adjusting the volume to reflect expected changes in transportation patterns with respect to the local area and surrounding wholesale centers.

The method of analysis in the trade and service sector allows for the determination of (1) what the local area is actually doing in this sector by kind of activity, (2) the present potential level of activity if the area takes certain necessary actions, and (3) the relationship of the area to the region and subregion and its potential for development. The analysis, therefore, provides the necessary information to estimate the potential urban land and space needs of this sector.

Integration of the Basic and Nonbasic Sector

With the refinement of the total urban land needs provided by the analysis of the trade and service function, the impact of urban and industrial growth in the communities of the subregion is better understood, particularly in terms of the impetus for local commercial development. This is important in terms of understanding pressures for commercial land use change and development in central business districts, suburban shopping centers, and highway locations.

Accompanying the base map and overlays on which the above inventories and future land requirements are shown is a matrix used to (1) briefly describe the significant trends in a subregion, (2) summarize the interrelationships between human and physical components as part of a subregional system, and (3) state significant problems and opportunities in the subregion as related to the land use components (Figure 4). The matrix serves as a transition between the maps and overlays and the overview report by summarizing major environmental problems and growth opportunities.

Interpretation of the data from the map, overlays, matrix, and other sources and identification of growth opportunities and problems is the final step in the SRO process. TVA regional planners working in conjunction with contributing staffs and agencies are responsible for this step. Their work results in a study report which has six parts: (1) a discussion of growth factors, (2) development of themes of regional growth, (3) estimation of the impact of growth upon a subregion, (4) projection of future development, (5) presentation of conclusions, and (6) a bibliography. The report discusses physical growth factors (e.g., highways, soils, water), and how they interrelate with processes of regional growth, such as urbanization, industrialization, and recreation. It also attempts to evaluate the effects of certain regional growth processes on the physical and human environment. Also, discussion of the opportunities for TVA projects and programs is included.

Summary

The subregional overview (SRO) and the trade and service analysis model make up a consortium of maps, overlays, matrix, and interpreting report that combines information on existing natural and manmade conditions with data on existing and projected economic trends to project and help monitor economic and urban development at the local level in the Tennessee Valley. The SRO is not a regional plan in the sense that alternative futures have been constructed, analyzed, and chosen between. Rather it is a projection of trends and forces that are operating in the Valley subregions and an interpretation of the development pattern and environmental conditions that these trends are likely to produce in the future. The SRO is a practical tool for private sector decision makers and public program managers. Its purpose is to aid them in conducting their activities with a greater awareness of the total system of which they are a part and in understanding the likely results of their collective actions.

Human / Physical	Urbanization	Industrialization	Transportation	Recreation Activities	Mineral Extraction	Agricultural Activity	Summary
Land form	*						
Soils							
Water							
Geology							
Vegetation cover							
Critical Environmental Concerns							
Summary							

Figure 4. Summary Matrix

*In an actual SRO matrix, summary information is included in the cells which describes the relationship between the components.

IIASA DISCUSSION PAPER

H. Swain

When I first read this paper I was somewhat confused. It was not at all clear to me for whom these subregional overview (SRO) studies were intended, nor why the TVA was preparing them. Conversations yesterday with Dr. Foster and Mr. Hinote cleared up several salient points. I understood the studies to be basically intended as materials for the planning staffs of the recently formed multicounty development areas and as such they are a recent additions to the TVA's portfolio of information services. The staff of five, all of whom have heavy responsibilities, are responsible for these studies. Thus, many of my technical qualms are allayed.

A new information service operating with miniscule resources for a management audience outside the parent organization cannot be expected to attain the high standards of scientific achievement. It would be somewhat picayune to attack the methodology in solely academic terms: simple trend extrapolation without changes in production coefficients, the absence of controlled feedbacks from one sector to another the lack of price mechanisms even as a subsequent clamp on reasonableness and so forth. My understanding of what the SRO process is meant to provide is a simple objective picture in maps, figures, and a few interpretative paragraphs of the state of things in a particular subregion, currently and in the near future. The work has to be done with limited resources, which is one reason for adopting a simple and uniform specification readily adaptable to semiautomatic and possibly computerized production.

Parenthetically though, before leaving the details aside, I would like to note that calling the dynamic and high potential tertiary and quaternity sectors nonbasic, repeats unconsciously the terminology used in several centrally planned economies where these sectors are labeled nonproductive. I would suggest that these innocent misnomers carry connotations which only encourage a lack of attention to those areas of the economy which will continue to play an increasingly crucial role in the quality of life.

Returning to the SRO's, however, things as usual are never quite so simple on second sight. I would like to single out five points for comment which might lead the discussion into areas of quite general interest. First, there appears to be a criterion of objectivity in the basic projection of subregional trends. This becomes a bit illusive on close examination. Is not the projection into the future of the present relations among land use, industry, and urban change inherently normative? If so, how can the analyst honestly deal with it? Both in scientific and ethical terms? To say that the projection is only a neutral base for sensitivity analysis and policy games belies the question. Or is it that the TVA in its delicate and sometimes bittersweet relations with state and local authorities must--like Caesar's wife--avoid even suspicion of partiality for particular futures? There is a sense in which the present SRO process is surely a temporary one. The TVA provides these common statistical bases to the multicounty development areas because these agencies and their state parents have not the competence, manpower, or resources to do it themselves. But as these other government agencies mature, taking on new roles and new resources from a share of the Federal revenue, as well as new people from Washington who are following the money to where the action is, is not the outlook for an ever greater demand, for ever more sophisticated information from the TVA's competing regional planners information that others can and invariably will construe to indicate the desirability of futures other than those that are the most comfortable for the TVA?

More generally, the TVA in its regional planning role must be one of the biggest generators and consumers of information in the United States. But in a democracy information must reach the people who endure policy as well as those who make it. The SRO package is specifically meant for the multicounty development areas and their technical staffs. But what is TVA's responsibility to a wider audience, not only with respect to subregional overview studies but also with all of the vast amounts of in-house planning and management work that goes on? How, for instance does the Freedom of Information Act impinge on the TVA? How should it? What is the TVA actually doing to back up its beliefs, whatever they may be? A real service that could be provided by the technical staffs of the TVA lies first in integrating SRO studies with its other sectoral and regional work, an integration not entirely apparent from the paper I read, and, second, in packaging this information in attractive formats using the best capabilities of modern audio-visual and mass media for direct public consumption. There is a distinction here between planning information which sets the terms of the choices that have to be made and advertising and public relations which seeks to avoid choices. The role I am suggesting for the TVA is almost inconceivable for a private corporation and is rare as hens' teeth in public administration for the reason alluded to above. However, much of the infrastructure for doing this already exists in the tributary area development program and in the various home and farm extension services for which the Authority has long been justly famous. But the real value, it seems to me, would be in making public these information packages in forms which emphasize the trade-offs which are central to any planning activity, public or private, and forms which elicit thought, debate, and informed feedback from the population which is the Authorities' raison d'etre.

Let me make a final point on the information economy. Several times in the Conference documentation, I have seen reference to surveys about what my socialist colleagues would call the objective conditions of the regional society in economy, sales levels, floor space ratios, housing quality, and the like. But nowhere have I seen reference to the direct gathering of information on the preferences, attitudes, beliefs, and values of the society being served. Surely it would be helpful and surely equally surprising for the management of the TVA and the Valley's population alike to learn more about what is cherished and what is changeable. What is valued and by whom? Governments and their agencies have been notoriously slow in using modern survey techniques to balance the picture of tangible behavior elicited by traditional means, and one can understand why when the potential explosiveness of some of this material is considered. But an agency like the TVA with its remote connection to direct and popular political control, on the one hand, and its traditional commitment to innovation on the other, could and maybe ought to make a lasting contribution to public administration everywhere by pioneering the wide and deliberate use of sophisticated survey instruments for citizen participation in public policy making. Mr. Chairman, if my remarks have strayed somewhat from the original overviews, I must apologize.

TVA COMMENTS ON DISCUSSION BY MR. H. SWAIN

Mr. Swain made the point that the purpose of the Subregional Overview (SRO) studies were not clear to him. An amplified statement on the purpose of the overviews is attached.

Although the trades and service sector are referred to as nonbasic in the paper, it should be apparent from the other papers and discussions that this sector is growing and is vitally important to the economic development and quality of life in the TVA region. In fact, the TVA has an active program to assist and promote the development and growth of trades and services.

One of the problems discussed was the determination of the number and kind of models needed (development, implementation, and use). The approach to this problem had been a pragmatic one. The models chosen as a part of the SRO process reflect the types of regional planning and economic research activities currently underway in both TVA and in the multicounty planning districts. For example, urban and industrial land use models and the trades and services model were derived from regular ongoing work of the Division of Navigation Development and Regional Studies. It is fully expected that as various TVA and non-TVA organizations examine other features of the regional system these tools will be improved and additional models will be employed. It is emphasized that the SRO studies provide a framwork for regional, state, and local planners to evaluate alternative futures. In other words, these studies provide a common base for understanding and coordination between TVA and non-TVA planners. The SRO is not a regional plan in the sense that alternative futures have been devised, analyzed and chosen. Rather it is a projection of trends and forces that are operating in the subregion and an interpretation of the development pattern and environmental conditions these trends are likely to produce in the future.

As pointed out in the discussion on the purpose of the SRO's, they are developed so that the user may gain an understanding of the spatial structure of the region and the trends that are taking place. Socio-economic norms, and responsibility for the current use of such norms, come from the user and the clients that the user serves. For example, each SRO is prepared for a multi-county development district's professional staff. Thus the analyses of regional trends and development problems and opportunities reflect not only the view of the TVA staff but also the view of the staffs of the multicounty planning agencies. These multicounty agencies are supported by the local governments in their area and also by the states and Federal government. Therefore they provide a means of soliciting informal local and subregional input into the planning process. This liason with the multicounty planning agencies assures the TVA that the socio-economic norms applied in the SRO's are in general agreement with those of the subregion.

planning agencies assures the TVA that the socio-economic norms applied in the SRO's are in general agreement with those of the subregion.

Mr. Swain in his remarks also alluded to the establishment of socio-economic norms when he stated that he had not seen any ". . . reference to direct gathering of information on the preferences, attitudes, beliefs and values of the society being served". In many cases, the multicounty planning agencies conduct goals studies by using randomly selected sample surveys of residents of the region, and these surveys are excellent sources of information about local attitudes and values. Citizens also have the opportunity to express their attitudes and preferences for present and future development through local organizations, state governments, the new media, and in direct contact with TVA staff and management. For example, all TVA Board of Directors mettings are open to the public. Furthermore, environmental impact statements are prepared for all future TVA and non-TVS projects of major significance; the process used in preparing these statements requires that socio-economic information be gathered, evaluated, and included in the decision-making process.

With regard to the question of the reliability of SRO's in actual decisions, it is somewhat premature to give an unqualified answer. To date, the SRO's have been primarily used by the professional staff, and they have been in an evolutionary stage as the staff assessed their potential usefulness in the decision-making process. The professional staff has found the SRO to be a useful tool for 1) providing information on the reigonal framework in which community redevelopment efforts will be operating and 2) providing a "firstround" assessment of potential local and regional problems associated with major power generating, power transmission and water projects. Indications are that the SRO's are becoming integrated into TVA's, Multicounty Planning Districts, and state's land use planning and decision-making processes.

Purpose of Subregional Planning Overviews

The Tennessee Valley region is completing its transition from an agricultural to an urban-industrial economy. With approximately 6% of the Valley labor force working on farms in 1973, it is essential that the urban-industrial environment being created by the remaining 94% be one that maximizes compatibility and minimizes conflict between the human and natural environment.

Historically man's efforts to strike a balance between needs and natural resource capabilities have not always been successful. Pending national land use planning legislation is recognition in part of man's past failures, as well as a realization that a planning and development process is not static but rather ongoing and dynamic. The TVA's regional development programs are important tools which contribute to the growth pattern which is present in the Valley today. Sensitivity to this, as well as to the effect management of TVA lands has on development, have culminated in the creation of a land use planning task force. Broadly, both the TVA's task force and pending national land use legislation have as a goal the development of a more rational and responsive land use planning process.

A key element in such a process is the interagency working relationships which are necessary for achieving the objectives of growth, development, and environmental quality in the Valley. It must be recognized that many agencies and groups, both public and private, make decisions regarding the use of Valley resources. These decisions are made in the course of ongoing regional functional activities, for example, industrial development, recreation and wildlife, transportation, law enforcement, agriculture, urban development, education, forestry, fishing, air and water quality, to mention a few. Cooperative regional planning, however, offers a framework through which functional agencies can achieve general agreement on the direction and objectives for growth. Once agreement is reached on basic directions, more detailed functional planning and program execution by the appropriate agencies can take place with greater assurance that the Valley's resources will be properly used in terms of overall needs.

To gain an understanding of the dimensions of existing and anticipated growth in relation to the Valley's growth-supporting resources, the TVA, in coorperation with state and regional agencies, is in the process of compiling subregional planning and development overviews of each of the Valley subregions, that is, the official state designated multicounty districts within the 201-county TVA region. Subregional overview studies use readily available sources of existing information dealing with physical characteristics of the subregions such as: the suitability of the land for open space, agricultural, and urban-industrial purposes; population and employment trends; plans for urban and industrial growth; and major project proposals for recreation, industrial, water resource, and other kinds of development. In addition, the subregional overviews reflect key features contained in the pending national land use planning legislation. This legislation would require states and Federal agencies to consider areas of critical environmental concern, public and private investment in key facilities such as power plants, highways interchanges, and major commercial and industrial development centers in their program planning.

The subregional overviews are prepared jointly with the appropriate regional and state planning agencies with the information being provided by several TVA divisions and staffs, and external agencies. Most of the data incorporated in the subregional overviews was in the reports and files of these staffs and agencies; a smaller part of the information was prepared specifically for the overviews. Considerably more information was available than was needed to portray the significant regional growth factors and changes, therefore, pertinent data were summarized and synthesized into a relatively broad analysis of the subregion's development trends.

The subregional overviews are organized in two major parts: a) a map at a scale of 1:125,000 with several transparent overlays depicting the existing land use, prominent environmental features, and the expected future development patterns; and b) a text containing a narrative description and analysis of development trends and a statement of conclusions and implications.

The information contained in the subregional overviews is intended to serve as a tool for viewing functional programs on a regular basis. The overviews were not developed to present a detailed interpretation of present and future development, but rather serve as a guide in directing development in each of the Valley subregions. They are designed to have a broad application: they can provide a basis for planning and directing functional programs in such areas as comprehensive water quality studies, regional environmental quality studies and Valley-wide forestry managment models, recreation plans, and assessment of water needs. They can also serve as an aid in evaluating special project proposals in terms of their relationship to the region and the environment. Futhermore, they are a means of compositing the various plans and proposals, comparing them to area growth projections, and achieving a broad understanding of regional growth potential.

The TVA suggests that the user use the maps and overlays for an introductory survey of the subregion's characteristics and to gain a general understanding of the most significant development problems and opportunities. Additionally, many users need to review the narrative to gain an adequate understanding, for their own particular purposes, of the spatial structure of the region and the trends that are developing.

SUMMARY OF DISCUSSION TOPICS

PART 2

In the discussions which followed the presentations the following people took part:

H. Hinote	TVA
M. Foster	TVA
H. Raiffa	IIASA
H. Swain	IIASA
A. Cheliustkin	IIASA
I. Lefkowitz	IIASA
W. Stoehr	Austria
J. Schechetman	Brazil
A. Straszak	Poland
J. Krutilla	US
T. Vasko	CSSR
S. Rosenthal	US
G. Kolb	FRG
K. Newlands	UK
M. Benedini	Italy
G. Meshtcheriakov	USSR

The main problem topics discussed were:

- The effect of the TVA within its own region.
- The effect of the TVA's existence and operation on the other parts of the United States.
- Alternative methods for coping with problems of regional integral development through e.g. modern communication techniques, systems simulation, data banks, etc.
- Incremental pricing system.
- Social costs of energy production.
- Practical ways in which to implement optimal pricing policies.
- Absence of integration of power demand forecasting with the regional simulation model.
- Sulphur dioxide pollution.
- Formal measures used by TVA management for evaluating R & D efforts of technical staffs.
- Explicit distribution equity goals.

- Evaluation of the impact of water resources availability in its development in the Tennessee Valley.
- Actual tendencies of structural changes compared with model forecasts.
- Planning time scales and horizons - comparison of short term plans with long term objectives.
- Power demand in homes and industry.
- Determination of the number and kind of models needed (development, implementation and use).
- Origins of the socio-economic norms and responsibility for the correct use of such norms in TVA models.
- Reliability of SRO's in terms of actual decisions.

PART 3

ORGANIZATIONAL ASPECTS OF THE TVA

Organizational Aspects of TVA

Introduction

TVA is unique in the Federal Government in that it is the only broadly based regional development program in the United States. Its program required sufficient flexibility to pursue multi-purpose goals, and a regional orientation coordinating Federal, state, and local concerns. As a result, a unique organizational structure was established.

TVA is a corporate agency of the Federal Government, operating with a reasonable degree of the autonomy and flexibility of a private corporation. It is an independent agency, not part of any Federal cabinet department, and employs about 23,500 persons. All powers of the corporation are vested in its three-member Board of Directors. The President, with the consent of the Senate, appoints the members of the Board.

The Act of Congress creating TVA provided the agency with administrative freedom to meet the special requirements of its programs and to adopt the methods of administration of successful private, as well as public, enterprise. The Board decides upon major TVA programs, organization, and administrative relationships. The General Manager is TVA's principal administrative officer. He is appointed by and is responsible to the Board for the overall administration and execution of programs, policies, and decisions adopted by the Board. Responsibility for conducting TVA programs, applying policies and methods, and performing services is delegated to several major organizational units within the agency.

TVA is an effective effort to decentralize the functioning of the Federal Government--to withdraw Federal power out of Washington and back into the region, states, and localities, insofar as the regional development of natural resources is concerned. The corporation's headquarters are placed by law in the region. Decisions are made where the work is done. This new kind of decentralization likewise promotes close cooperation with the states, one of the primary intents of the TVA Act.

The Corporate Form

The establishment of TVA in the form of a Federal corporation set a new administrative pattern in resource development, although it was not a device new to the Government. By 1933, a considerable amount of experience had accumulated in the United States with respect to the government-owned corporation, a form of government organization generally agreed to represent a useful addition to the older departments, bureaus, commissions, and boards.

The corporate form in the Government setting was particularly applicable to Federal projects aimed at supplementing, in some degree, the traditional operation of private enterprise; for example, in shipping, finance, and electric power generation. This form was used where the work to be done was of a larger scope than that permitted by privately owned concerns, where the national interest required a higher degree of integration than could be provided by private enterprise, or where the resources of the Federal Government must be concentrated on the accomplishment of a specific goal or mission apart from the traditional roles of departments and agencies.

In his message to Congress requesting legislation to create TVA, President Franklin D. Roosevelt spelled out the case for the corporate form:

> I, therefore, suggest to the Congress legislation to create a Tennessee Valley Authority--a corporation clothed with the power of government but possessed of the flexibility and initiative of a private enterprise. It should be charged with the broadest duty of planning for the proper

in the appropriations language, may alter TVA's proposals.

Organization of TVA

The organization of TVA, which is summarized on the chart in Appendix A, reflects the program assignments set forth in the TVA Act plus the normal auxiliary services of a managerial character. Thus, the pattern of organization meets the unique requirements of a multipurpose agency, reflecting the functional inputs of various professional disciplines as well as the need for a mission orientation.

At the apex of the organization is the full-time Board of Directors. The TVA Act empowers the Board to ". . .direct the exercise of all the powers of the corporation." Under the discretion vested in the Board by the Act, it (1) establishes general policies and programs; (2) fixes the basic organization through which programs and policies are executed; (3) reviews and appraises programs and results; (4) approves projects and specific items which are of major importance, involve important external relations, or otherwise require Board approval; and (5) approves the annual budget for submission to Congress.

The TVA Board consists of three members appointed to nine-year overlapping terms, with one term expiring every three years. This permits a continuity of policy and operations. Members of the Board are appointed by the President, with the advice and consent of the Senate, and the President designates one member as Chairman. All members of the Board are equally responsible for actions of the Corporation.

The Board appoints its principal executive officer, the General Manager, to carry out its policies. It is advised on legal matters by the General Counsel, who also serves as Secretary to the Corporation. Each of the directors is required to give full time to TVA and cannot be engaged in any other business during his term of office.

Evolution of the Organizational Pattern

The TVA Act was an unusual piece of legislation in that it spelled out organizational objectives but gave no detailed instructions for internal administrative arrangements to accomplish these goals. As a consequence, TVA's earliest years were marked by considerable evidence of "trail and error" as the Board of Directors sought to find the best administrative arrangements for a complex multi-purpose program characterized by extremely rapid growth.

At one of its earliest meetings, the first Board determined the primary organizations which would be needed to carry out the program; agreed to divide the administrative work load among its three members; and designated the Board Chairman as "general manager" for purposes of overall internal administration and coordination. The three natural points of focus of the overall program were on construction and engineering; natural resources, with emphasis on reforestation, soil erosion, and use of the Muscle Shoals chemical plant for the production of experimental fertilizers; and electric power.

Under this arrangement problems were evident from the start. The burden of detail on the Board members in their dual role of policy-makers and direct administrators inevitably resulted in the slighting of one or the other of these roles. It soon became clear that there was a need for improved administrative arrangements.

Although the Chairman retained general direction of the administrative aspects of the program, his designation as general manager was soon eliminated and a Coordination Division was established in the organizational line between the divisions and the Board. As the Coordination Division grew in size and importance, it made a major contribution to shaping administrative methods in TVA. It was never given the authority and control to play a clear-cut general management role, however, and herein lay its fatal weakness.

The administrative problems arising out of the early failure to distinguish between the policy-making and trusteeship functions appropriate to the Board level and those activities commonly identified with general operating management, sharpened by divergent beliefs within the three-man Board, resulted in TVA making its most significant organization change. In June 1937, the Board officially established the General Manager as chief administrative officer. Shortly thereafter, it adopted a basic administrative structure which has carried through to today with relatively few modifications.

The General Manager

As TVA's principal administrative officer, the General Manager is delegated by the Board responsibility for directing and coordinating the execution of programs, policies, and decisions of the Board, subject to such controls as it may establish. He assigns duties and delegates authority to the TVA offices, divisions, and staffs, and approves major management methods, appointments, and organization changes. He brings before the Board matters which require its consideration.

The General Manager must have "executive reach" over all TVA operations. On matters flowing upward from the units for Board approval he must exercise final judgment on the adequacy of staff preparation of background materials which the Board must have as a basis for decisions. More specifically, he must be in a position to assure the Board that all relevant considerations are reflected in the recommendations which they are asked to review and approve.

On the administrative follow-through of Board-approved policies, he must give attention to those aspects of organization and procedure necessary to assure effective execution of Board policies. Thus the General Manager is the primary communication link between the staff and the Board. In technical and professional matters related to program, he must rely on the judgment of the responsible program managers. In the coordination of these matters, and in the determination of overall administrative methods, he looks to the management service divisions and the specialized staffs of his immediate office for appropriate review of completed staff proposals and to provide the necessary checks and balances to assure the effective execution of programs and missions.

In addition to his immediate staff, the Office of the General Manager includes the Planning Staff, Budget Staff, Information Office, Equal Employment Opportunity Staff, Power Financing Officer, and Washington Office. The Divisions of Personnel, Law, Finance, Purchasing, and Property and Supply also provide the General Manager with specialized staff assistance in carrying out his management responsibilities for TVA. (A summary of the specific responsibilities of these and other organizational units within TVA is contained in Appendix B).

Basic Administrative Concepts and Practices

The nature and scope of TVA's program assignments required that the agency put together the talents of engineers, chemists, foresters, agricultural specialists, land planners, and many others. These specialists had to be organized into reasonably homogeneous organizational units which could be effectively supervised and held responsible for results. Concepts and procedures, therefore, had to be devised which took full advantage of the professional skills of many specialists without creating a series of isolated organizational compartments which would serve as a bar to effective integration of effort.

The teaming of a great variety of specialists to tackle complex problems inevitably led to differences of opinion as to the best methods of solution. These specialists, while organized within TVA along the lines of professional disciplines, were required to function as a team in the implementation of the TVA mission. An effective integrative device to facilitate a team approach was the council concept. During three of TVA's formative years (1937-1940) the Regional Planning Council and the Management Services Council served as forums in which the division directors raised questions, pooled ideas, shared facts, insights, and imagination, and prepared advisory opinions. After the participants had ample opportunity to explore the major program and managerial areas, the councils began to play a decreasingly important role and were finally abandoned.

Meeting Coordination Needs

TVA program managers have traditionally been given all of the authority and responsibility necessary for them to do their jobs effectively. Thus, the multidisciplinary input requirements for the accomplishment of most TVA programs requires effective coordination of effort between offices and divisions.

A system of written administrative releases is an effective device for securing coordination and collaboration among the various departments.

These are TVA's basic means for the development, approval, recording, and communication of management policies and procedures. Principal elements are organization bulletins, codes, interdivisional instructions, and announcements.

TVA Organizational Bulletins define the basic organization structure of TVA and the functional areas of responsibility of the Board, the General Manager, and offices and divisions. They are supplemented by separate organizational bulletins which describe the internal structure of offices and divisions and the kinds of functions assigned to their principal components.

The TVA Codes document major administrative policy determinations in specific areas of continuing TVA-wide significance. The codes contain three distinct elements: (1) a statement of policy, which serves as a guideline for administrative action; (2) reservations of administrative control by the Board and the General Manager; and (3) delegations of authority and responsibility to designated offices and divisions. These basic policies may be supplemented as necessary with explanatory, procedural, or other detailed material which will facilitate carrying out administrative actions, especially in situations where uniform interdivisional handling of details is clearly needed. Announcements publicize administrative information of general interest but of temporary significance.

The Board approves the TVA Organization Bulletin and policy and reservation statements in TVA Codes which deal with broad areas and relationships appropriate to its overall accountability. The General Manager approves all other TVA Codes and Organization Bulletins, TVA Instructions on interdivisional matters where it is not appropriate for specific offices or divisions to have primary responsibility, and TVA Announcements which relate to the responsibilities of his office.

Maximum responsibility is placed upon the units initiating administrative releases to secure the participation of other divisions affected by the policies and work methods proposed through a central management staff. In their "bottom-up" development, the releases are subjected to appraisals as to technical soundness, administrative feasibility, legality, budgetary justification, coordination, and integration with other TVA policies and procedures before submission to the General Manager and the Board for approval. Through this process program managers are schooled in the requirements of self-coordination essential to effective management of a comprehensive, unified regional resource development program.

Management Improvement

TVA's corporate status as a Federal agency permits freedom to make administrative changes readily. This freedom carries with it an obligation to improve operations and get better results. TVA's broad responsibilities in the area of economic and social development within the framework of a quality environment in the Tennessee Valley present a unique opportunity to demonstrate good management in many fields of activity.

As used here, management improvement means planning and implementing changes in organization, policies, methods, and supervision to increase the efficiency of TVA's operations and the effectiveness of its programs. To do this, programs, activities, and procedures are systematically and periodically reviewed to identify opportunities for improvement and to develop plans for implementing appropriate management improvements.

Management improvement is a normal responsibility of supervisors at all levels, and the special procedures, reviews, and services employed do not relieve employees of responsibility for initiative which is inherent in every job.

TVA's programs and the organizational relationships which support them are systematically reviewed through a structured planning process. A periodic assessment of the internal and external operating environment is made to provide a basis for updating long-range and intermediate-term program plans.

Program evaluations and management audits of selected programs and activities are made to determine (1) their current appropriateness for achieving TVA's objectives, and (2) changes in concept, operations, or scale necessary to achieve desired effectiveness with a minimum of resources. A management information system is operated to provide current financial and output performance indicators. Special reports or staff studies of particular problems are initiated by the Office of the General Manager as the need arises.

The preparation, examination, and supervision of organization budgets provides a formal method of review and appraisal. While this process is continuous, the Office of the General Manager gives it particular attention during the preparation, submission, and approval of organization budget documents; in the adjustment of estimates to presidential and congressional allowances; and in connection with periodic reviews of budget experience during and at the close of the current fiscal year.

Offices and divisions also prepare reports to the General Manager at periodic intervals or in special situations. The General Manager uses such reports for administrative review. The one chiefly used is an informal quarterly report which identifies current program or activity emphasis and problems, and provides a concise statement of steps being taken or contemplated to deal with the problems identified.

Monthly financial statements are used regularly to review and appraise TVA activities. These statements point up cost trends by prompt reporting on both an organizational and a functional basis, enabling management to relate cost with accomplishment. When a cost trend indicates the need for a careful study of a particular program, activity, or organization, special analyses are prepared.

Management improvement in TVA involves the cooperation of all employees and supervisors, successively coordinated at ascending levels of authority. Offices and divisions are responsible for appraising the effectiveness, efficiency, and economy of overall programs, policies, organizations, and methods within the spheres of their delegations. They conduct reviews, identify problems, and take appropriate action to effect improvement.

Within offices and divisions, opportunity is afforded all employees to discuss problems and ideas with management representatives through joint employee-management conferences and committees, and intramanagement groups. These groups provide a means of evaluating and taking action on the suggestions of supervisors and employees for improving the efficiency of operation, health, and morale of employees and increasing the safety of the working environment.

Personnel Administration

The framers of the TVA Act recognized that the complex missions given TVA could only be accomplished by persons who were selected based on high professional and managerial competence rather than political beliefs.

The TVA Act provides, and TVA Boards have emphasized, "merit and efficency" in the appointment and promotion of employees and the prohibition of any political test or qualification in their selection. The Act authorizes the President to remove any member of the Board found in violation of this requirement, and instructs the Board to deal in a similar manner with its appointees who are in violation.

In 1934, TVA broke new ground for public service employees in the United States by recognizing the right of its employees to organize and bargain collectively with management concerning wages and conditions of employment. This action differed sharply with the then prevailing theory that employees in the public service did not have the same collective bargaining rights as their private industry counterparts.

Today, TVA has agreements with two organizations representing trades and labor employees (construction, operation, and maintenance) and salaried employees (clerical, professional, and administrative). These two organizations and their constituent unions are the exclusive bargaining agents for practically all nonmanagement employees.

The TVA Act provides that TVA shall pay those wages that prevail in the vicinity, with due regard to those set by collective bargaining. TVA and representatives of the two groups meet annually to decide what rates prevail and to make adjustments in salary and pay schedules, which are then published. Management positions are assigned to separate pay schedules.

Employee Development

TVA may be characterized as employee development oriented. This emphasis on employee development through education, training, and experience originated in part from the deficiency of skills in the Tennessee Valley of the 1930's and the demands of TVA for a wide variety of highly skilled workers and administrators.

One of the strong aspects of TVA labor relations is the emphasis placed on training employees to meet the needs of the agency. Much of this training and the encouragement of apprenticeship has been carried out in cooperation with labor unions. While this has helped TVA meet its needs for trained personnel, it has also helped create a large and skilled labor force for the region.

TVA divisions are responsible for the training of their trades and labor employees. Employee organizations may take part in planning and administering training through joint labor-management training committees.

Induction training activities are designed to inform new employees about TVA and make them effective in their work as soon as possible. Work-improvement training is planned to improve the knowledge and skills of employees in their present jobs, including training in new methods and techniques. Qualifying training develops the abilities of employees so they may become qualified for placement, promotion, or transfer to new jobs.

Salaried employees, who are normally recruited with the basic qualifications required to do their jobs, are given informal on-the-job training by their supervisors on a continuous basis--by supervision of work assignments, through the use of staff meetings and conferences, and by demonstrating in the supervisor's own work the application of TVA's policies and procedures. Formal programs include rotation training for engineers, office training for secretarial and clerical employees, courses related to electronic data processing, supervisory training, and manager development.

TVA presently administers one training program within the agency for first-line supervisors and middle managers to enhance basic managerial skills. Middle and top managers are also selected to attend managerial training programs conducted by the Civil Service Commission and private organizations in various parts of the country Several divisions within TVA also conduct programs for their own managerial personnel.

TVA has traditionally guarded against the establishment of an internal education system, drawing instead on the resources of institutions throughout the country in order to maintain its unique characteristic of bringing together a multiplicity of disciplines and diverse backgrounds and interests.

Relationships With Other Federal Agencies

Congress, in establishing TVA, charged it with responsibility for the unified development of the Valley's resources. Except for a few well-defined program areas, the establishment of TVA did not supplant the roles and authority of other Federal agencies such as the Department of the Interior, the Department of Agriculture, and the Department of the Army. Thus, TVA was placed in the role of persuading, by demonstration and other means, departments and agencies to adopt policies, procedures, and methods which contribute to unified development of resources in the Valley.

To date, resource development in the Federal Government continues to be fragmented among agencies having diverse interests. In contrast, TVA's resource development program continues to demonstrate the practicality of interdisciplinary studies, decisions, and administration, taking into full account the interrelationship of resources within the region.

TVA's operating program brings it into contact with many other Federal agencies for the purposes of cooperation and coordination. For example, TVA is responsible for the operation of its multiple-purpose system for flood control, one of the purposes of which is to help reduce floods in the lower Ohio and Mississippi River basins as well as the Tennessee Valley. The U. S. Army Corps of Engineers is responsible for the construction and operation of flood control works on the Ohio and Mississippi as well as other streams. Hence, a system of close coordination and cooperation has been developed, supplemented by formal procedural agreements which establish operating priorities during times of flood.

TVA is presently conducting studies in cooperation with the Environmental Protection Agency, an independent Federal agency, to compare the feasibility of various processes of sulfur oxide removal from coal-fired generating plant stack gasses. Many other examples of cooperation and coordination between TVA and other Federal units could also be cited.

Relationships With State and Local Governments

The TVA Act envisaged a broad spectrum of cooperation with the states and local government agencies in the region, and the authority it provided in this regard has been used by TVA to build strong relationships with states, municipalities, counties, cooperative associations, and private interests in carrying out the objectives of the Act. The creation of TVA strengthened rather than supplanted the roles of state and local governments, and this continues to be a primary objective of TVA.

Early in its history TVA embarked on a plan of cooperative program planning in the field of agricultural development. TVA cooperated with states and agricultural colleges of the region to start thousands of farm test demonstrations to introduce new fertilizers and their use to the farmers of the region. With the development of an electric power supply, TVA helped farmers organize electrical cooperatives to distribute the power in rural areas as well as helping urban communities organize their own distribution systems. Cooperative efforts with state forestry and agricultural agencies also resulted in highly successful programs of forest protection, timber management, wood utilization, and strip mine reclamation.

When TVA was established, there was not a single state park in the Tennessee Valley, so TVA established several demonstration parks on TVA lakes and later transferred them to the respective states. State park departments soon followed and state forest, fish, and wildlife agencies greatly expanded their staffs and activities.

TVA worked with the states to establish active planning organizations, providing assistance in drafting legislation and in some instances initial financing so staffs could be employed by these agencies to provide technical help to Valley cities and counties. Today, TVA works with state, regional, and local planning organizations to develop and implement general community and area plans and on planning work in TVA project areas Through its Tributary Area Development program, TVA is working with citizens' associations and other development organizations that face special needs and opportunities for economic growth.

In the electric energy field, the TVA Act provided that preference in the sale of electric power be given to states, other public agencies such as municipalities, and nonprofit cooperatives. Today, TVA sells electric power to 160 such agencies, which distribute it at low TVA rates. Local management of retail distribution systems means close attention can be given to local problems and needs. There is also a local sharing of responsibility to achieve TVA's objectives.

Many other examples of TVA-state-local cooperative relationships could be cited. A cooperative approach to regional resource development has done much to strengthen the position of state and local government both in the region and in the regional program. Most of TVA's programs, with the exception of physical plant construction, are dependent upon the cooperation of the

Valley's people. They must be convinced, through education and demonstration, that their participation in Valley development is worthwhile. This necessity has influenced the attitudes and practices of TVA personnel in all levels of the organization, with the result that comprehensive development has become a reality.

The TVA Experiment

The task of organizing, controlling, and coordinating the operations of TVA, with functions varying so widely in nature and characteristics, has been one to challenge the courage and resourcefulness of the most able group of administrators. Through the ideas expressed in its enabling legislation, and from its geographical location within the region with which it works, TVA has been an experiment in public administration at the regional level.

Its success in bringing about a major change in the social and economic development of a region without supplanting existing governmental entities and without having sole responsibility for administering Federal resources in the region is remarkable. While it has not been adopted as a model for other regions, TVA methods and innovations have served as models for Federal programs in the field of social and economic development.

As an experiment, TVA has been subject to constant review and criticism both from within the agency and without. TVA reacts to this scrutiny by applying a simple criterion to any suggestion of change: Will it work to the benefit of the people of the Tennessee Valley region and the Nation? This principle has provided the foundation for the organization and operation of TVA over the past four decades, and will continue to do so.

ORGANIZATION OF THE TENNESSEE VALLEY AUTHORITY

The Board of Directors approved the following statement of organization for the Tennessee Valley Authority to be effective January 1, 1973. It supersedes the organization statement effective November 12, 1970.

The Board of Directors, under the TVA Act, is vested with all the powers of the Corporation. The Board establishes general policies and programs; reviews and appraises progress and results; approves projects and specific items which are of major importance, involve important external relations, or otherwise require Board approval; approves the annual budget; and establishes the basic organization through which programs and policies are executed.

The General Counsel advises the Board on legal matters. He, or the representative he designates to act in his absence, serves as Secretary to the Corporation.

The General Manager is the principal TVA administrative officer. He serves as liaison between the Board and the offices and divisions in the handling of matters of Board concern, and is responsible for coordinating the execution of programs, policies, and decisions which the Board of Directors approves or adopts. He brings before the Board matters which require its consideration or approval; assists the Board in presenting the TVA budget to the Office of Management and Budget and to Congress; affirms to the Board the adequacy of staff coordination and contribution in matters presented for its consideration, including judgments relating to broad public consequences, social and economic effects, and planning and program direction; interprets the Board's instructions to the offices and divisions; originates or approves administrative controls to ensure integrated execution of the total TVA program; and reports to the Board on overall efficiency, effectiveness, and economy of TVA operations.

The General Manager assigns duties and makes delegations to the TVA offices, divisions, and staffs in their execution of programs and policies which the Board of Directors adopts, subject to such controls as it may establish. He reviews and approves major TVA management methods, major organization changes within offices and divisions, and major staff appointments, and recommends to the Board basic changes in the TVA organization. He is responsible for ensuring that appropriate matters are presented in coordinated form to the Board at the proper time and that the Board has pertinent related information. He provides for the formal definition and communication of TVA programs, policies, procedures, and continuing delegations of authority and responsibility.

The Office of the General Manager includes the Planning Staff, the Budget Staff, the Information Office, the Equal Employment Opportunity Staff, the Washington Office, the Power Financing Officer, and such other assistants as the General Manager may require to perform specialized duties or to aid him in expediting, coordinating, and disposing of current business. The functions of the above groups are set out in the Organization Bulletin, "Office of the General Manager" (I GENERAL MANAGER).

The Division of Finance formulates, recommends, administers, and evaluates policies related to accounting, auditing, financial reporting, and the handling of TVA funds; establishes systems of accounting and internal control, including accounting controls over TVA property and other assets; develops related instructions and procedures; and advises and assists on matters pertaining to these functions. It performs accounting and administrative work for the TVA Retirement System.

The Division of Law handles all litigation, legal proceedings, claims, and other legal problems relating to TVA's activities; advises and assists on legislative matters in which TVA has an interest; gives legal advice, opinions, and assistance; and prepares or approves and construes all documents affecting TVA's legal relationships.

The Division of Personnel formulates, recommends, administers, and evaluates policies in the field of personnel administration, including those related to recruitment, selection, classification, compensation, and training of personnel, union-management relations, organization, administrative relations, personnel management information, and related aspects of personnel administration; conducts negotiations with unions representing employees; develops personnel standards and procedures; and advises and assists in the handling and execution of matters and actions related to TVA personnel administration.

The Division of Property and Supply formulates, recommends, administers, and evaluates policies related to the acquisition, transfer, and disposal of real property and to the provision of computing services, transportation services, and office services, and analyses of office methods; and develops related standards and procedures and advises and assists in their application and use.

The Division of Purchasing formulates, recommends, administers, and evaluates policies relating to the procurement, shipping, transfer, and disposal of equipment, materials, supplies, and services, except personal services, and issues instructions and advises and assists on matters related to the application of these policies.

The Office of Agricultural and Chemical Development formulates, recommends, and carries out plans, policies, and programs for research in and development of experimental new and improved forms of fertilizers and processes for their manufacture; for testing and demonstrating the value and best methods of fertilizer use as an aid to soil and water conservation and to improved use of agricultural and related resources; for developing, operating, and maintaining facilities to serve as a national laboratory for the dual purposes of research in chemistry and chemical engineering in the development and production of experimental fertilizers and the design and testing of improved manufacturing processes, and for the production and provision of basic chemical materials and services in the munitions field essential to national defense; for readjustment of agricultural areas affected by TVA operations; and for related activities having to do with the management and use of agricultural resources and with national defense.

The Office of Engineering Design and Construction participates in the planning and provides or obtains the architectural treatment, engineering design, and construction of all permanent structures and permanent engineering works which are authorized to be built in the TVA program, in accordance with the requirements determined by the offices and divisions having program responsibilities for such structures and works, except for power transmission, distribution, and communication facilities and switchhouses at substations not adjacent to generating stations; and provides other engineering, architectural, and construction services as feasible and economical.

The Division of Environmental Planning recommends, develops, coordinates, and carries out programs and activities related to TVA's interests in environmental quality of the region. It reviews and evaluates the environmental impact of programs and activities proposed and carried out by other offices and divisions and provides technical guidance and assistance as needed to assure that appropriate environmental protection features are planned and implemented. It conducts field monitoring and environmental quality studies and investigations at TVA installations. It provides environmental data and technical assistance to state and local agencies. It coordinates and administers environmental research and demonstration projects carried out by TVA in cooperation with other agencies and organizations. It serves as TVA's liaison with other governmental agencies concerned with environmental planning and protection. In collaboration with other divisions, it develops and applies programs to assess and control potential hazards in the work environment of TVA employees.

The Division of Medical Services develops, recommends, and executes plans and policies related to the health of employees and of the public affected by TVA activities, and to TVA's interests in community health education and health planning. It participates in medical research and development activities, demonstrations, and other cooperative activities with Federal, state, and local agencies and other organizations.

The Office of Power develops, recommends, and appraises objectives, plans, policies, and programs, and carries out approved policies, programs, and activities for the generation, transmission, and utilization of electric power; forecasts future needs of the power program and plans means and methods of meeting those needs; and cooperates with other TVA organizations in carrying out TVA's multiple-purpose programs involving power activites.

The Office of Tributary Area Development administers TVA's interests in comprehensive activities designed to obtain maximum economic progress in tributary areas of the Tennessee Valley region. It works with state and Federal agencies and with local governmental and citizen groups in organizing for, planning, and carrying out unified resource development programs in individual areas. It administers contracts for related studies and demonstrations. It coordinates the participation of other TVA offices and divisions in all stages of tributary area planning and development.

The Division of Forestry, Fisheries, and Wildlife Development formulates, recommends, and conducts investigative and development programs in forestry, fisheries, and wildlife, directed toward maximum sustained production and use of these resources for their contribution to the regional economy and environment. It maintains cooperative relationships with Federal, state, and other appropriate agencies and industries concerned with these resources.

The Division of Navigation Development and Regional Studies develops, recommends, and carries out plans, policies, and programs for the navigation engineering development of the Tennessee River system and for its full and effective use in development of the region; conducts studies and research and advises and assists the General Manager, offices, and divisons on social, economic, governmental relationships, and regional planning problems and opportunities of importance to development of the region; and performs related activities.

The Division of Reservoir Properties develops, recommends, and carries out plans, policies, and activities relating to TVA's interests in recreation resources development, administration of TVA lands not managed by program divisions; operation and upkeep of dam reservations; site planning and landscape architectural services; property protection and law enforcement; visitor information at appropriate TVA properties; coordination of nonmilitary defense measures; and employee housing and related facilities. It provides specialized services on TVA lands and reservations for other programs when in the interest of efficiency and economy.

The Division of Water Control Planning develops, recommends, and administers plans, policies, and programs for flood control and for multipurpose river system control and regulation in cooperation with other TVA organizations and in accord with the requirements of the TVA Act; and for study of local flood problems and development of relationships with state and local governments and groups to assist them in development and promotion of control measures. It cooperates with other TVA organizations and outside groups in planning water resource projects with total economic development of local economies as a basic objective.

Land Between the Lakes develops, recommends, and carries out plans and activities for the 170,000-acre area to demonstrate the unified use of its natural resources for outdoor recreation, conservation education, and related purposes for the economic, social, and educational benefit of the Nation and the region.

IIASA DISCUSSION PAPER

H. Knop

As a basis of the discussion in plenary session III the paper on "The Organizational Aspects of the TVA" was presented It was prepared by the TVA management at our special request in order to meet our demand in detailed information on throughgoing problems of organizational design and functioning. We have to thank them for these special efforts.

After having received all the papers we found that many other papers on the history of the TVA, on the different fields of TVA activities, and on the future of the TVA could and should be taken into account when we try to identify the scientific problems and questions of our interest. It also had to be observed that the TVA case is not the only experiment of regional development carried out through a unified approach to all economic, social, and ecological aspects. Especially after World War II, many experiments of regional development were performed in Western Countries (for example, Italy, France, Great Britain), and they have to be considered as interesting sources of useful information as well; let me also mention socialist countries where the integrated planning approach to regional as well as national problems is at the base of any state activity.

Two Main Fields of Interest

From our side, that is, the scientists from different countries now working in the Large Organizations Project, there are two main fields of interest for the following discussion on organizational problems:

1) questions concerning the concepts and principles of the internal structure of the TVA and the evaluation of the TVA's systems feasibility (that is, its capability to function as designed);

2) questions concerning the mechanism of decision making, and the organizational functioning in the TVA derived from the structure chosen in the TVA.

Concepts and Principles of the TVA's Internal Structure

The TVA case can be considered, at least in the first phase, as the process of generating a complete new system interacting with all the components of (local) society and having a specific goal assignment under given environmental conditions. These conditions are meant in the sociological broader sense: historical, economic, social, and political. The papers give an idea of the economic and social reasons leading to the TVA project. The methodology and the conceptual framework of such an integrated regional project which has changed its general goals at least three times and which is still developing is of great practical and scientific interest.

In this respect our questions are: Why has the "public authority" system been chosen as opposed to other systems such as privately operated projects under strict regimentation? Or in other words: Why was the TVA created? Why were the existing socio-economic and organizational structures not used to fulfill given tasks? The question of necessity which may be relevant to almost any organization is especially important for the TVA. For we must be conscious of the fact that the TVA was created as a government agency, and even government corporation, in the most typical society of the capitalist world of the early thirties. It surpasses, or simply overlaps, the geographical stretch and the field of activities of all the local authorities involved--be it county or state. So the TVA is neither a business corporation trying to attain its hypothetical optimum in competition with many other subjects involved, nor a normal administrative authority imposing some constraints. It is this uniqueness of the position of the TVA that provokes the question of its necessity. What could replace the TVA in such a way that this would not break the social rules? The lawsuits against the TVA when it was created were proof that the rules were forced, the congressional legislative acts and the supreme court decisions.

It would also be interesting to appraise the basic concepts and principles of the internal organizational structure of the TVA. On this subject some other questions arise: In the structure of the TVA two types of divisions, can be identified:

1) operational divisions which are oriented to the production of external outputs of the TVA;

2) functional and staff divisions (including law, personnel, finance, information, etc.) which are oriented to pursuing the normal functioning of the TVA as a separate organization.

Why was this line-functional type of organizational structure chosen although the subjects are programs for different fields of activity?

The most interesting organizational decisions from the conceptual point of view were made in organizing the TVA's top level management. History has demonstrated the necessity for separation of strategic management functions from administrative and operational ones within the TVA. Three full time members of the Board of Directors direct the exercise of all the powers of the corporation. The appointment of each of them to nine-year overlapping terms with one term expiring every three years permits a continuity of policy and operations within the TVA. But all administrative authority on fulfillment of the established strategies, policies, plans and programs is placed on the General Manager. Why was this organizational pattern with highly centralized top management chosen? What are the results?

Another question in this context also arises. It is the question of "organizational self-consciousness" reflected by two events in the history of the TVA. One is the creation and then the liquidation of the Coordination Division in order to establish a better organization, and the second is a "natural" disappearance of the two Councils. What was the evolution aiming at?

The TVA's medium-level management is organized in such a way that the project managers are the linear supervisors of the separate programs and projects (this is the so-called pure project management). In such a structure only the General Manager has the power to be the coordinator. Will not difficult problems of coordination of interprogram activities arise in this situation?

For example, the construction of a new dam has influence on power production, floods, soil configuration, recreation resources, etc. Where is the organizational unit or what is the organizational mechanism for fitting all these elements together? This is closely related to the "social rules" question mentioned above. The social regulations which the TVA was to follow, and federal interventions created specific situations where instruments and power were not uniformly allocated to the TVA's goals. This fact provoked great variability of the ways the TVA divisions work. The Legislative and the Supreme Court actions provided the TVA with dam building, power generation, and sale possibilities, but they left the TVA with information and advisory tasks in other fields. Since the different divisions do not have quite the same working principles, has there been a negative influence on their possible cooperation, and even communication?

What are the reasons for using documents (such as organizational bulletins, codes, documents and the like) as the main instruments for coordination of activities in the TVA? Why were such forms of coordination as management committees used only in 1937-1940 in the initial stage of the TVA operations? Are temporary teams, liaison officer functions, and other organizational forms of lateral communications used or not? Why?

Does a well-developed management information system operate in the TVA? How does this system influence the organizational interactions within the TVA? Has there been any deep reorganization in the organizational operations since introducing the computer system?

Has the TVA experiment been transferred to other national areas or problems? What is the scope of the TVA's experience applicability? Asking these questions we have one important thing in mind: the uniqueness of the TVA certainly causes the same phenomenon as the one that is observed in experimental schools where teachers are above the average level, and so are the children, and that is, partly, why everything is alright The second factor is that in cases of unique and new, that is, not thoroughly petrified organizations, even if their structure is far from optimal, some structure which is nearer to the optimum may "virtually exist."

Organizational Functioning and Mechanism of Decision Making

All explanations in the TVA papers about history, the organizational structure, and the different TVA activities stimulated interest to learn more about the actual functioning of the TVA's organizational structure and the mechanism of decision making. The mechanism of decision making, the hierarchy of goals, interests and constraints characterizes a given organization to a high degree. Therefore, we want to raise several questions in this context in order to clarify what type of organization was created in the TVA, and what are its advantages and disadvantages. In this respect, our questions are directed to the following problems:

There might have been and there still might be a certain private part of private property of land in the TVA territory. The interests of farmers, ship owners, and of industrial producers in the case of water regulation, flood control, navigation, power production, and environmental protection cannot always have been the same and still might not be the same. These examples and probably others as well lead to the assumption that there must have been and still must be competing interests of different social groups which might be reflected within the TVA and which have a certain influence on the TVA decisions. What were and are the fields of such competing interests? Which groups were involved? How were the problems solved?

Closely connected with the problem of competing interests is the problem of determination of priorities. An impressive example can also be the coordination between flood control and power generation goals. How and by whom were these and other--in particular long range--priorities determined? How could the consistency of different goals be ensured? In this connection the following question is of great interest: Can the determination of priorities be described in examples of key decisions made by the TVA in the various periods since it was originally formed?

The papers gave us the impression that well known and widely used computational or conceptual methods for planning (for example, forecasting methods, planning methods, optimal allocation procedures of plants and facilities and so forth) were also successfully utilized within the TVA. Technical details might be of interest for the technical sessions. In the framework of the discussion on organizational problems we want to focus the discussion on the problem of interactions between planning and decision making tools. This concerns the decisions to be taken before you can start, for example, a certain model calculation and also after you finish. On the one hand, you always need to make certain decisions on the choice of a target function and on certain constraints which in many cases also represent a part of the goals you want to achieve. On the other hand, you need evaluations of the results and decisions after model calculations because the models are always poorer than the reality and you also have to take into account the neglected factors of reality.

How recent are the models described in the papers? How did these models change the decision making procedure? How was a particular model imbedded in the real organizational process of the decision making? Did it really influence the practical policies and operations? Did the TVA top management take part in model building or did they influence it? What is the organizational mechanism of the feedback for implementation and possible correction of the courses and actions recommended by an applied model? These questions could be answered by using the examples given in the papers on Water Systems Optimization, Resource Allocation, and Power Systems Operation. In this context the general question arises as to the impact, if any, of computers, systems analysis, etc., on the basic administrative structure as established in June 1937.

The implementation of decisions already taken in another field of interest from the organizational point of view. In this connection it would be of great interest to have it explained in a more detailed way than it was done in the papers. For example, what are the ways and the means by which the TVA general management influences the TVA subsystems (for example, state and local government offices, industrial enterprises, farmers, cooperations, etc.) in respect to the way they make their individual decisions in accordance with the common TVA interests. (This is another explanation of the well known problem of the general optimum in relation to the suboptima).

Some Final Questions of General Character

In the forty years of the organization's existence, what have been the major changes in the TVA's own definition of what would make it a successful organization? What are TVA's current criteria of its own success as an organization and how are such criteria measured?

Concerning the relationship between the prospected directions and results of the TVA development and what was actually achieved, we would also like to receive a kind of TVA self-evaluation in answering the following question: Which program elaborated and implemented in the TVA was the best and which was the worst compared with its realization? Why?

The TVA is a unique blend of public and business organizational mechanisms. In this context, the TVA's organizational character and function can be very well characterized by its funding. What are the TVA's sources and uses of funds, and what has changed through the years? How does the TVA function in its characteristic as a product-oriented corporation? How do Research and

Development activities fit in financially and functionally with production activities? In which ways do financial factors and incentives influence the style and procedure of management and the actions of the manager?

Concerning theory and practice, which forms of collaboration between practitioners and scientists were established for the purpose of design of the organizational structure and of the mechanism of decision making within the TVA?

Final Remarks

I suppose, not all of our questions can be sufficiently answered in this plenary session. I am sure that some further explanations will also be given in the following technical sessions. A direct investigation on the spot done by a IIASA team would be even useful in order to complete this retrospective case study on the TVA.

The continuation of this case study will meet the IIASA interests in the organizational field. We are now establishing a project group on large organizational problems here at IIASA. It deals with organizational problems with a focus on planning and decision making in Large Organizations characterized by multiple objectives and goals, hierarchical control, and short-medium and long-range preparation of present decisions. The main directions of its activities are:

- conceptual research including retrospective case studies on the TVA and other large-scale programs;
- collaboration with applied IIASA projects on their special topics, for example, Integrated Industrial Systems, Urban and Regional; and
- applied research on our own pilot project (currently under preparation).

This brief information about our activities should help to determine the field of common interest for further discussions and collaboration with the TVA.

TVA COMMENTS ON DISCUSSION BY H. KNOP

The TVA was created as an experiment in organization as well as in function. Traditional forms of organization both public and private had failed to perform the regional function of unified resource development, and typical methods of direction and control by governments at all levels had not secured the proper development of regional resources, some of which were privately owned (for example, land), some of which were amenable to development only by Federal action or consent (for example, water development on navigable streams), and all of which would make their ultimate social and economic benefits in a free enterprise system (for example, electric power use, fertilizer, navigable streams).

It appeared to President Roosevelt that a "new" organization was needed that combined the better parts of government and business and that would use methods of persuasion and discussion rather than the exercise of governmental authority or economic power to secure the needed unified development.

There seems to some confusion as to the relationship of the TVA program divisions and service divisions. It should be clear that the service divisions exist only because there are program divisions to be served. The alternative to this arrangement would be to make each program division self-supporting logistically, which would be inefficient.

The decision to have a highly centralized top management was made because a loose control structure involving the Board members as managers had failed. The TVA is if anything pragmatic. It has no such doctrinaire approach to matters that it would perpetuate failures for the sake of theory. The results of the centralization of top management--successful performance of a highly complicated mission--would appear to justify the direction and control device selected.

The TVA's "project orientation" does create problems of coordination. To a degree these problems are diminished through the "program manager" device. However, difference of opinion sometimes arises as to what program manager is responsible in a specific rather than a general situation, and in such cases the General Manager must become the coordinator.

Division goals and methods differ, and interdivisional competition is sometimes sharp. This has a negative influence, to be sure, and every effort is made to bring counter-productive activities of this nature to the "negotiating table." This is a function of the General Manager.

Documentation for coordination purposes (organization bulletins, codes, etc.) provides the surest way to secure consistent responses. Committees are proper if they are clearly recognized as ad hoc and pro tem. As continuing management devices they are weak, tending to diffuse authority and to obscure assignments of responsibility. They often provide the basis for unacceptable compromise rather than the development of a reasoned concensus. They are not good substitutes for firm leadership. The TVA uses task forces, teams, and committees as fact-finding, advisory groups. They are not decision making groups.

The TVA is now in the process of developing a modern management information system. For many years, the TVA's relatively small size and organizational form permitted it to operate effectively unencumbered by bureaucratic procedures. Recent growth in size and complexity have rendered the less complex information system inadequate. Computer systems are being developed which may be expected to lead to further and more obviously significant changes later.

As a total organism, the TVA remains unique. The TVA's organization and methods were developed to perform its mission in its environment. Therefore, there is no reason to expect complete transference of the TVA experience to any other national area problem. However, <u>elements</u> of the TVA experience can be, have been, and should be <u>utilized</u> for other areas and problems.

Except in the case of its power program, the TVA has not sought to substitute public ownership for private ownership. There are now and always have been competing interests in the development and use of resources. In a free enterprise system there always will be. Farmers, developers of industrial and residential lands, hunters, sportsmen, foresters, and recreationists must always compete for a finite amount of land, water, and the products of each. Problems are solved by efforts to find the best uses, over time, for the society generally.

Some priorities are set by the TVA Act--for example, flood control takes precedence over power generation, fertilizer is to be improved rather than just produced, power is to be sold at low rates to a wide domestic market. Other priorities are set administratively. Decisions made by the TVA Board that determine priorities can be documented.

Involvement of the TVA's Board and top management in the models mentioned in the other TVA papers has been limited to approval of the budget funds to pursue the basic concept. In the case of the Water Resource Management Program, it was understood that the model would take its priorities for water allocation from the existing policies.

Since the TVA has no regulatory control over the people of the Tennessee Valley region, their political institutions, and their economic enterprises, some other means had to be used to encourage their decisions in the direction of TVA interests. This means has been described as "appealing to the enlightened self-interest of individuals." Put another way, it has been presented as "the art of letting the facts make the decision." This means that the TVA, being unable to dictate, must cooperate. This involves determining the relevant facts, working cooperatively to develop alternatives, and helping Valley people to choose the course that over time will produce the best results for the individual and his society.

TVA is financed from two sources of funds: appropriations from the Federal Treasury, and corporate funds, which are further identified as proceeds and borrowings. TVA proceeds are described as those generated by power sales and those from other sources, primarily from the sale of fertilizers and other products of the National Fertilizer Development Center. The principal change in funding through the years has been the shift in financing additions to the power system from dependence on appropriations to borrowings.

Research and development in the TVA falls into three major areas: fertilizer research and development performed in response to a specific mandate in the TVA Act; research and development performed to improve efficiency, effectiveness, and economy of TVA operations, particularly power generation and transmission; research and development in the interest of regional resource devleopment. Research and development is financed at levels determined by relative priorities and opportunities.

SUMMARY OF DISCUSSION TOPICS

PART 3

In the discussions which followed the presentations the following people took part:

M. Foster	TVA
J. Krutilla	US
T. Raup	US
A. Straszak	Poland
M. Raman	USSR
A. Freitas	Brazil
C. Howe	US
T. Vasko	CSSR

The main problem topics discussed were:

- Conditions of the organization's creation, its goals and sense of existence.
- External interactions and influences.
- Organizational mechanisms - structure, coordination, centralization-decentralization dilemma.
- Planning.
- Financing.
- Effectiveness.
- Computers in management.

PART 4

ELECTRICAL ENERGY SYSTEM OF THE TVA

Page

Decisions Relating to the Provision Of Ample Electrical Energy for the Tennessee Valley Region

Introduction

In 1933, while testifying before the congressional committee in opposition to the enactment of the proposal to establish TVA, a vice president of one of the Nation's private electric utility companies stated that he could foresee no market at that time for the power to be produced by TVA.

By 1940, however, TVA was generating three times as much electricity as had been produced in the Valley region seven years earlier. In fact, the agency had to use all available water power and operate standby steam plants at near-capacity to meet the demands of its customers.

In fiscal year 1973, generation on the TVA system was over 70 times as much electricity as was generated in the same area in 1933. Generating capacity of the TVA system was about 26 times as much as the combined capacity of all generating stations in the same area 40 years before.

At the heart of this rapid development is the basic philosophy which underlies all TVA programs and activities--the natural resources of the Tennessee Valley region must be developed in a unified manner for the benefit of all the people. This philosophy, clearly reflected by Congress in the TVA Act, was the first and most basic decision in the development of the TVA power program. Electricity must be made available at low cost to the farmer as well as the city dweller, to the poor as well as the wealthy.

This basic tenet has been the basis for all decisions as regards the development of the TVA power system. It was reflected in TVA's decision to build coal-fired steam plants when the region's demand for electricity first showed signs of outstripping the river's power generation capacity. It was the basis for Congress' decision to allow the agency to sell bonds or notes so that needed power generation facilities could be constructed without relying on the uncertainty of Government appropriations. Today, it supports the decision of TVA to construct nuclear power plants so that the region will continue to enjoy an ample supply of electricity at reasonable prices.

This paper will discuss these and other major decisions leading to the growth and development of the TVA power system--decisions generated by the vision of Government leaders and TVA planners, economic and social factors

MORE

within the region, and technological advances in the power field. The cornerstone of each of these decisions, however, is the basic concept of unified resource development for the good of all the Valley's people.

The TVA Act

Congress made clear in the TVA Act its intention to preserve for the people the benefits which would result from the development of the Tennessee River. It ordered that municipalities, cooperatives, and other public agencies not distributing power for profit were to have first call on the power TVA produced. It directed that power operations be managed in such a way as to permit "domestic and rural use at the lowest possible rates." Congress thereby established TVA as consumer-oriented--a marked departure from the traditional profit-oriented power company.

The TVA Board was authorized to make studies and experiments to promote the wider and better utilization of electric power for agricultural and domestic use, and for small industries. TVA was directed to cooperate with state governments and their subdivisions, with educational and research institutions, and with cooperatives or other organizations in the application of electric power to the fuller and better balanced development of the resources of the region.

Congress established TVA power operations as a "yardstick for comparing the cost of its operations with that of the private utilities. It ordered the agency to accumulate cost data "useful to Congress . . . and to the public." The TVA "yardstick" gave legislative recognition to some unique characteristics of the electric power industry in the United States.

For one, electricity is a source of energy for which, in most cases, there is no substitute. For another, the industry is capital-intensive, requiring heavy investment prior to marketing its product. In nearly all instances, therefore, it is uneconomic for two power systems to attempt to serve a single community. The industry is essentially monopolistic, and thus set apart from the conventional American norm of free competitive enterprise. Thus, the TVA power system provided a substitute form of competition--competition by comparison--available to regulatory bodies throughout the United States.

Congress further directed that TVA power operations become financially self-supporting and self-liquidating.

High Dams

One of the first important actions in the development of the TVA power system was the decision to build a series of high dams on the main stream of the Tennessee River. These dams would enable TVA to generate power to the maximum capability of the stream, while their multiple-purpose character would also allow maximum control of the river for the purposes of navigation and flood control.

Engineers outside TVA disputed the agency's contention that flood control and power generation were compatible partners in multipurpose river regulation. Economists argued that a region with an economy based primarily on agriculture would never utilize the huge amounts of power capacity contemplated and the public investment would be wasted. Biologists predicted that fish could not long survive in the great reservoirs which would become "biological deserts." The successful operation and compatibility of the TVA reservoir and power systems soon silenced these early critics.

Lowering the Rates

Among the early tasks facing TVA was that of deciding on its electric rates and developing a market for TVA power. The most revolutionary aspect of the TVA power program stemmed from the agency's decision to adopt a low-rate policy. This decision has had a lasting impact on electric utility pricing down to the present day.

Forty years ago, private utilities in the United States held to the opinion that rates must remain high until after operating costs went down and earnings went up. TVA took the opposite view--low rates would be the means of lowering costs and achieving sound earnings. Low-cost power would encourage use of electricity, creating a mass market which in turn would enable TVA and the retail distributors to put to use the economies of mass production and mass distribution. TVA rates to consumers provided savings of as much as 60 percent below what they had been paying. In Tupelo, Mississippi, the first city to receive TVA power, average home use doubled in the first year and the number of homes using electricity increased 30 percent.

In the 1930's, when consumers were paying six cents per kilowatt-hour for their electricity, the biggest part of that price was going not for generating electricity but for its final distribution to the consumers. TVA reasoned that once the poles and the line were in place, it cost the electric system very little more to supply the individual user with a larger amount of power. Consequently, as power use gradually increased, the unit cost of distribution went down and average rates to consumers also went down.

Finding a Market

The decisions as to which communities would receive TVA power was made largely by popular vote in the communities. The initiative of the people, both urban and rural, hungry for low-cost electricity, expressed itself convincingly. Between 1933 and 1947, 92 municipally-owned distribution systems were formed in seven states to market TVA power.

Power distribution into the rural areas had to take another course since electric service to the countryside was all but nonexistent in 1933. Only three farms in 100 had electricity, and in some areas only one in 100. Cooperatives were the mechanism chosen by the farmers, and they had to start from scratch. TVA attorneys helped draft the state legislation giving operating authority to such organizations. TVA engineers developed standards which lowered the cost of building rural distribution lines. TVA loan financing was made available to enable these early organizations to begin operations. In a few areas, TVA built the rural lines and served the customers directly until cooperatives could be established. By 1947, 47 cooperatives were marketing TVA power.

From its beginnings, the TVA power system was hampered by legal opposition from private power companies that brought lawsuits against TVA claiming that its power operations were unconstitutional. In general, the private systems refused to sell their properties until the constitutional issue was settled. In 1939, the U.S. Supreme Court ruled in favor of TVA and, with that decision, the private systems agreed to sell. Congress thereafter enacted legislation providing the financing under which TVA and many local communities in the Tennessee Valley purchased the properties of private companies then serving them.

From Hydro to Coal

As the market for TVA power broadened, it became clear by the late 1940's that future demand for power on the TVA system would soon exceed the generating capacity of the Tennessee River system. Very little hydroelectric capacity remained to be developed. As a result, TVA elected to meet these future power demands by embarking on a program of constructing coal-fired steam electric generating plants.

In 1948, the agency requested Federal funds to begin construction of such a plant at a site on the Tennessee River near Johnsonville, Tennessee. Because Watts Bar, the first steam plant built by TVA, was constructed to meet the power demands of World War II, it had been relatively immune to criticism. Johnsonville, proposed to meet the expanding peacetime demand of the region, was different. Opposition to its construction was strong, coming mainly from neighboring power systems who underestimated the demand for power.

After lengthy congressional debate, the request for construction funds was approved, and the TVA power system entered into a new era. Coal-burning steam plants were built, and TVA bought the largest and most efficient generators. Today, coal accounts for about 80 percent of system power generation.

Entering the Money Market

For many years, the funds needed by TVA for constructing power facilities came from revenues and appropriations from the U.S. Treasury. Revenue from the sale of power was used to help finance construction of new power facilities. If the TVA Board of Directors found at the end of the year that its revenues were greater than needed for operations and construction, it was required by the TVA Act to pay these excess revenues to the U.S. Treasury.

In the early years, TVA's earnings were insufficient to permit payments to the Treasury, either to repay appropriations or as interest or dividend on appropriations. However, by 1948, the power system had matured to the point that some annual payments could be made, and the Congress called for systematic payments that would repay appropriations invested in power facilities within a period of about 40 years.

As the TVA power system expanded, it continued to need very substantial amounts of new capital. Congress recognized that TVA had a "public utility responsibility" to its service area and, for many years, provided what appropriations were needed to supplement the agency's power revenues in adding power plant capacity. However, there was one period in the 1950's in which appropriations were not made available for starting critically needed new generating facilities.

Following four years of controversy, Congress authorized TVA in 1959 to sell bonds and notes to raise construction funds for new power facilities. At the same time, Congress required TVA to make two kinds of annual payments with respect to appropriations invested in power facilities. One was an annual dividend equal to the interest rate paid by the U.S. Treasury applied to the amount of appropriations outstanding. The other was an annual payment to retire appropriations, which is set by law at $20 million.

In fiscal year 1974, TVA payments to the U.S. Treasury totaled more than $83 million, about 9 percent of TVA's electric power revenues for the year. These payments included the $20 million repayment and $63.4 million as a return or dividend on the Federal appropriation investment. This dividend resulted from a Treasury average interest rate of 6.1 percent at the start of the year, applied to the remaining appropriation investment of $1,035 million.

In Lieu of Tax Payments

TVA also makes payments in lieu of taxes to state and local governments in eight states in which it either sells power or owns power properties. As provided by law, the total TVA payments represent 5 percent of the previous year's taxable power revenues, excluding sales to certain Government and military installations. In addition, the municipal and cooperative distributors of power make payments in lieu of taxes to their respective jurisdictions in conformity with the laws of the states in which they operate. In fiscal year 1974, TVA payments in lieu of taxes totaled over $31 million, an increase of nearly $4 million over the year before.

At present, TVA has about $4.4 billion invested in power assets. This investment is financed with a little more than one billion dollars of appropriations; about $2.5 billion of borrowed money; and almost $900 million of reinvested earnings and depreciation funds.

Congress required that the TVA power program be self-supporting, and it has been. Power revenues cover all operating and maintenance expenses, including an allowance for depreciation and payments in lieu of state and local taxes, and provide enough earnings over and above expenses to keep the system financially sound.

Efficiency in Operations

Because its electric loads grew so rapidly and became so very large, the TVA power system has been able to adopt many engineering and design innovations and operating procedures which have led to efficient operation for the benefit of its power consumers.

TVA was the first to operate a 500,000-kilowatt turbogenerator, and the first to put into operation 500,000-kilovolt interchange facilities with neighboring companies. TVA's modern turbogenerators--the largest now 1,300,000 kilowatts--use about 20 percent less coal to generate a kilowatt-hour of electricity than the 60,000 kilowatt units in the Watts Bar plant built in 1942.

Operating experience over the years has emphasized the importance of strong interconnections between TVA and other electric systems. TVA and neighboring companies are able to share generating capacity not only during temporary emergencies, but also on a seasonal basis. TVA, where electric heat causes peak use to occur in the winter, has capacity available during the summer to send power to utilities to the south and west where the peaks occur in summer because of the air-conditioning load. Conversely, those utilities have capacity available to send power to TVA in the winter.

A prime example of TVA's efforts to discover and put into practice advanced technologies that lower costs and improve system efficiencies and reliability is a new underground Power System Control Center nearing completion close to Chattanooga, Tennessee. From this control center, the entire power system--all generation and transmission facilities--will be constantly monitored, controlled, and activated as necessary. Every five minutes a computer will "read" the generation in order to select the most economical power source, determining the need for a generation change, and sending control signals to the generating plants to bring about the required change.

From Coal to Nuclear

In 1966, as electric energy use in the Tennessee Valley continued its upward trend, TVA let a contract for equipment for its first nuclear-fueled, steam-electric generating station. Construction started the following year on Browns Ferry Nuclear Plant in north Alabama, which will have a capacity of nearly 3,500,000 kilowatts in three units.

TVA's decision to build Browns Ferry was based on studies conducted in 1965 which showed that the first cost (capital investment) was about the same for nuclear as for fossil fuel plants. The cost of the nuclear fuel, however, was less than the cost of coal. Bus bar cost of energy from the nuclear plant was estimated at 2.39 mills/kWh, as against 2.90 mills for a comparable coal-fired plant.[1]

---

[1] Comparison of Coal-Fired and Nuclear Power Plants for the TVA System, Office of Power, Tennessee Valley Authority, Chattanooga, Tennessee, June 1966.

TVA presently has two additional nuclear plants under construction--Watts Bar and Sequoyah--and is in the licensing stage on a proposed fourth plant--Bellefonte. A fifth plant is presently being planned, with the proposed site near the town of Hartsville in middle Tennessee. Over the next 10 years TVA plans to expand its present generating capacity of 23.3 million kilowatts to around 41 million kilowatts. Of the total generating capacity to be added between now and 1977, 86 percent will be nuclear, and 92 percent of added capacity between 1978 and 1982 will be nuclear. This is the largest commitment in the entire United States by a single utility to nuclear power generation--an investment of over $6 billion.

Although these nuclear plants will qualify as "heavy industry" in terms of their size, their impact on the environment will be a different story. A nuclear plant can be designed to fit attractively into its setting. It requires no coal-handling facilities with accompanying dust and noise, no coal stockpile. It does not emit smoke or ash from stacks.

One element in this construction program has been the delay in completing the nuclear plants. The first generating unit at the Browns Ferry plant was originally scheduled for operation in 1970; however, the unit was not accepted for commercial operation until August of this year. The other two Browns Ferry units have also been delayed, and slippage has occurred in the original schedules for Watts Bar and Sequoyah.

A number of factors are involved in these delays. The Atomic Energy Commission and the U.S. Environmental Protection Agency have revised and tightened their requirements for environmental and engineered safeguards during the course of construction, making it necessary to redesign some features and add others. Codes, standards, and design criteria have been changed. In some cases there have been delays on the part of manufacturers in the fabrication and delivery of critical components. The development of engineering information associated with the emerging nuclear technology has also been a retarding factor. These are the same factors, however, which have delayed the completion of nuclear plants built elsewhere in the United States during this period.

<u>The Breeder</u>

Nuclear power will be an important new source of energy, but the type of reactor generally used in today's power plants can utilize only a tiny fraction of the potential nuclear energy available in uranium that provides the fuel. A new kind of reactor, the fast breeder, can provide a way to put much more of this energy to work--and to meet electric power needs for centuries to come. Development of the breeder reactor in the United States has reached the point where the next step is to build a full-size prototype power plant.

The first large breeder reactor power plant in the United States will be built on the TVA system at a site near Oak Ridge, Tennessee, as a national demonstration project sponsored by the Atomic Energy Commission and the Nation's electric power industry. TVA and Commonwealth Edison Company of Chicago, Illinois, have jointly established a project organization to build and operate the plant, which is expected to be completed in the 1980's.

There is general agreement in the Nation's electric power industry that progress toward commercially practical breeder power production is vital to help meet the country's future energy needs. The breeder reactor project also is a major milestone for the country's electric power industry in another aspect. Electric systems across the United States--utility corporations as well as public and cooperative systems--have joined in pledging nearly $250 million toward the cost of this national project. This appears likely to be the forerunner for similar large-scale support for a broad research and development program to help meet both energy resource and environmental protection needs in electric power production.

Several other developments offer possible future help in meeting the energy squeeze. Although many of the power plants now in use will continue to be part of TVA's power supply for several decades, new methods of producing power may be part of the additional and replacement generating capacity that will be needed in the future. TVA and the Nation's electric power industry is conducting or sponsoring research on several of these new methods, laying the groundwork for future decisions which will have to be made if the TVA region is to continue enjoying an economical and abundant energy supply.

A Commitment to the Region

TVA was created in 1933 with a congressional mandate to develop in a unified manner all of the resources of the Tennessee Valley for the benefit of all the region's people. Congress, through the TVA Act, and TVA, with its implementation of the statute, recognized that the availability of an abundant and low-cost energy supply was an integral part of the unified resource development concept. The resulting development of the region's power resource, and the decisions which guided this development, are testimony to TVA's commitment to this concept.

Today, TVA's ability to provide energy at reasonable cost is under test again, just as it was in 1933. A combination of factors--inflation, concern for the environment, decreasing natural fuel supplies, and the expensive requirements of a new nuclear power technology--are tugging power costs upward. Despite the powerful influences of these forces on the price of electricity, TVA will continue to stress the consumer interest in electric power. This commitment is just as meaningful and binding to the agency today as it was 41 years ago.

IIASA DISCUSSION PAPER

W. Häfele

Having listened to the presentation on the very interesting paper on "Decisions Relating to the Provision of Ample Electrical Energy for the Tennessee Valley Region" by Mr. Seeber, I would like to make some comments from the point of view of our work in the energy project, thereby trying to stimulate the general discussion.

1) At the beginning of the work of the Tennessee Valley Authority there was, among others, the decision to provide as much electricity as possible and at lowest cost for the whole region. From my own observations in Oak Ridge in the early 1960's I can judge what impact this policy had on the regional development and the life-style of the population. There seems to be a lack of energy models that describe the impact of zero electric energy generating cost.

2) If one considers the resource problem of the TVA historically one can find some characteristic periods. Originally cheap water was available. Then came coal. Then after World War II, when cheap uranium was available, the light water reactors came. Now the breeder reactors which virtually eliminates the resource problem comes. This resource is characterized among others by the following facts:

   - only 1% of busbar costs go to fuel,
   - the uranium resources are used better by a factor of 100 compared to light water reactors, and this means also that dispersed uranium reserves can be used,
   - the plutonium and other aspects to be handled call for exacting technology.

   Does the TVA see these in a similar way?

3) There is a trend away from the exclusive consideration of the resource problem at least in the cost of electricity: soft aspects such as licensing, standards questions, assessment, seem to become the driving forces of modern technology. In addition, contrary to the situation up to now, implications of water management and other ecological aspects, settlement patterns and other sociological aspects have to be considered. This means the decision-under-uncertainty problems comes to the fore.

As the TVA has been for a long time the forerunner in this framework, I would be happy if the discussion would concentrate on these points.

4) The problems mentioned above are system problems. In this connection, the following aspects seem to be the most important ones:

   - the timing of the energy problem in the sense of the short-, medium-, and long-term phase: the short-term phase is characterized by our current oil problems, the medium-term phase by the use of advanced technologies (for example, coal gasification), and the transition to the lasting solutions, and the long-term phase by the use of at least one of the options for infinite energy supply,
   - the evaluation of the four options for an infinite supply of energy: fission, fusion, solar energy, and geothermal energy,
   - the analysis of the transition phase where the capital investment problem seems to be the most important one.

I would like to end with these remarks, which I hope will help to structure the discussion of the paper presented by Mr. Seeber. I now leave the floor open for general discussion.

TVA COMMENTS ON DISCUSSION BY W. HÄFELE

TVA will limit its discussion to Mr. Häfele's comments on the breeder reactor:

1. "Only 1% of busbar costs go to fuel." Estimates by the American nuclear industry at this time indicate that approximately 20% to 30% of busbar costs go to fuel.

2. "The uranium resources are used better by the factor of 100 compared to light water reactors and this means also that dispersed uranium reserves can be used." The breeder's major appeal is, of course, conversion of energy resources--an essential element in the pursuit of US energy self-sufficiency. With the breeder, there is a substantial increase in fuel utilization efficiency--the prospect of utilizing perhaps 60% of the energy in uranium instead of 1% or 2% as at present. The economic benefits of such increased efficiency are compelling. With this efficiency, the life of US uranium supplies would be stretched from decades to centuries. Adequate supplies of nuclear fuel will help keep energy costs down.

3. "The plutonium and other aspects to be handled call for exacting technology." Sodium and plutonium--two distinguishing characteristic materials of the Liquid Metal Fast Breeder Reactor--do require special care in order to utilize their unique advantages. However, considerable experience in the handling of both has provided the bases necessary to assure protection of the public health and safety. The breeder will impose less burden on the environment than other sources of electric power generation. The plants' systems will effectively control chemical, thermal and radiological discharges--actually improving upon the excellent light water reactor performance in these areas.

THE TVA POWER SYSTEM TODAY

INTRODUCTION

The influences that caused the TVA power system to develop in the particular ways it has are many and varied. They include the basic objectives assigned in the TVA Act, the administrative decisions that gave effect to these onjectives, the economic and political events of the past forty years, available resources, and the changing technologies. These influences have been covered in earlier papers that explained how the system developed. This paper describes in some detail the TVA power system, the facilities it operates, its financial operations, and some of the major challenges it faces.

AREA SUPPLIED AND CUSTOMERS

TVA supplies power in an area of 80,000 square miles located in southeastern United States that includes most of the state of Tennessee, northern Alabama, northeastern Mississippi, and southwestern Kentucky, and small portions of the states of Georgia, North Carolina, and Virginia. The population of the area supplied is about 6,000,000.

TVA is primarily a wholesaler of power. Its customers are composed of three major groups: (1) 160 local distribution systems, consisting principally of municipal electric systems and rural electric cooperative systems; (2) about 50 industries that have large or unusual loads and are served by TVA directly rather than by the distributors; and (3) a few Federal agencies, including two gaseous diffusion plants of the Atomic Energy Commission.

The 160 local distribution systems serve nearly 2-1/2 million electric customers, including homes, farms, businesses, and all of the industries and Federal agencies in the region except the few that TVA serves directly. The areas served by these systems is shown in the map, Figure 1.

THE TVA POWER SYSTEM TODAY

To meet the region's growing need for electric power, TVA maintains and operates the Nation's largest electric power system. It consists of an integrated system of dams and reservoirs, steam plants, and gas turbine installations with about 600 substations which are connected by a network of nearly 17,000 miles of transmission line circuits. See maps, Figures 1 and 2.

Generating capacity - The TVA hydroelectric system consists of 29 dams built or acquired by TVA. Nine are on the Tennessee River, 19 are on tributary streams, and one is in the Cumberland River Basin. Twelve other hydro plants on the Tennessee River system, owned by the Aluminum Company of America (Alcoa), have been integrated with the operation of TVA dams for mutual benefit. There are also 8 Corps of Engineers dams on the Cumberland River which contribute to the TVA power system. These hydro plants--TVA, Alcoa, and Corps of Engineers--have a total installed capacity of 4,472,645 kilowatts.

To meet the growing electrical demands of the 1950's and 1960's, TVA turned to coal-fired plants. Generating capacity on the TVA system grew from about 3 million kilowatts in 1950 to more than 23 million in 1974, with coal-burning plants providing most of that increase. Today coal accounts for about 80 percent of system power generation. There are 12 steam plants with a total capacity of nearly 18 million kilowatts.

Two of the steam plants also have gas turbine installations on the site. These gas turbine installations were added in the 1970's to provide additional generating capacity to assure a reliable power supply after delays in the operation of new generating units were experienced. The total installed capacity of the TVA generating system was 23,319,030 kilowatts on June 30, 1974.

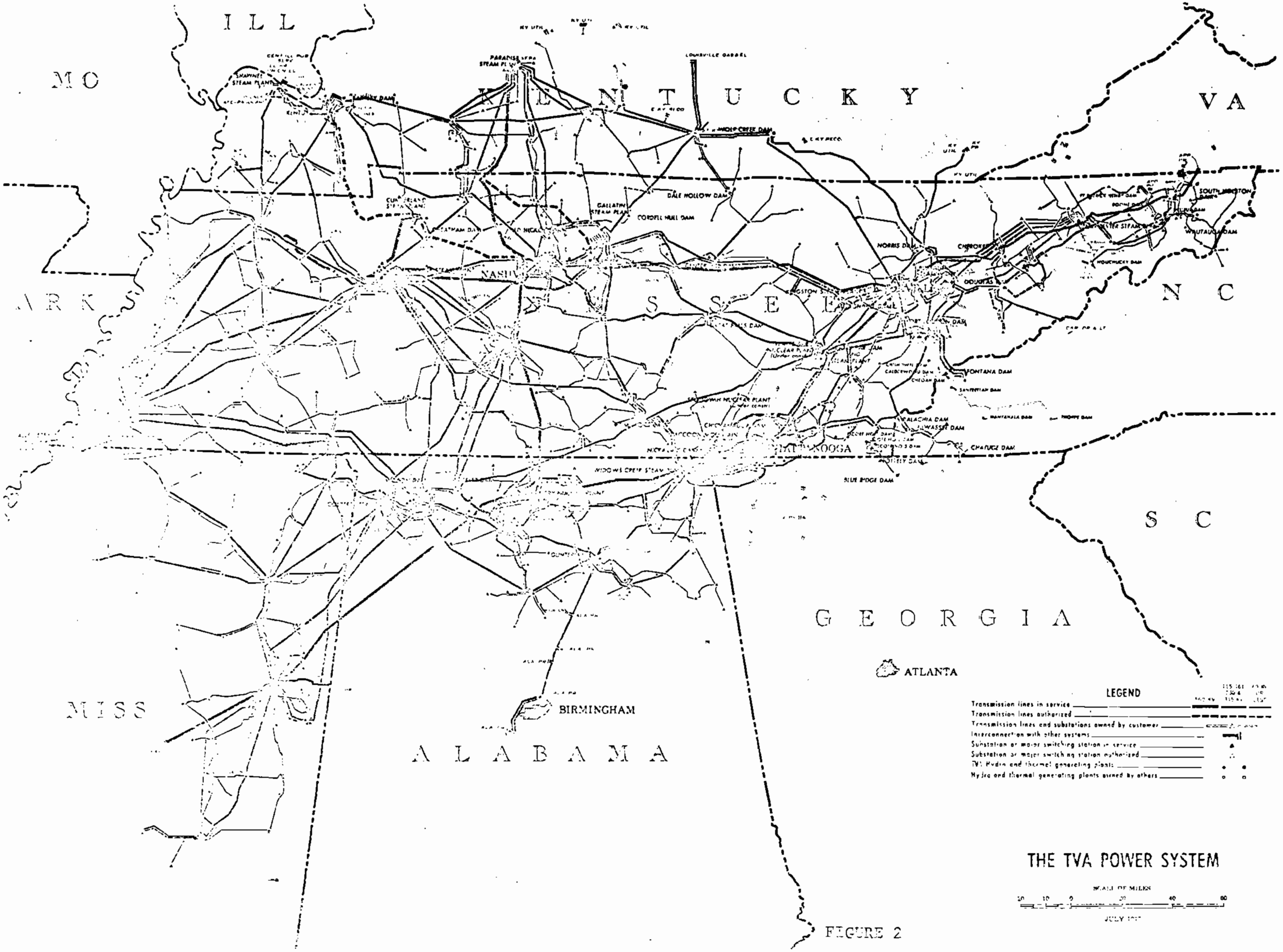

THE TVA POWER SYSTEM
LEGEND
Transmission lines in service
Transmission lines authorized
Transmission lines and substations owned by customer
Interconnection with other systems
Substation or major switching station in service
Substation or major switching station authorized
TVA Hydro and thermal generating plants
Hydro and thermal generating plants owned by others
SCALE OF MILES
ILL
MO
KENTUCKY
VA
NC
SC
GEORGIA
ATLANTA
ALABAMA
BIRMINGHAM
MISS
ARK
TENNESSEE
NASHVILLE
CHATTANOOGA
SHAWNEE STEAM PLANT
PARADISE STEAM PLANT
WOLF CREEK DAM
DALE HOLLOW DAM
CORDELL HULL DAM
GALLATIN STEAM PLANT
CUMBERLAND STEAM PLANT
NORRIS DAM
CHEROKEE DAM
DOUGLAS DAM
SOUTH HOLSTON DAM
WATAUGA DAM
FONTANA DAM
CHATUGE DAM
BLUE RIDGE DAM
WIDOWS CREEK STEAM PLANT
SEQUOYAH NUCLEAR PLANT

FIGURE 2

Since 1970 coal has continually increased in cost. This, compounded with the serious problems of environmental protection, resulted in TVA constructing nuclear power plants to supply future power needs. At June 30, 1974, TVA has 18.4 million kilowatts of generation planned for service of which about 90 percent is nuclear fueled. Some 10 million kilowatts of this new generating capacity is presently under construction, with the remaining new capacity having been ordered.

Transmission system - Just as TVA's generating capacity has increased to keep pace with consumer demands for electric power, the TVA transmission system has expanded and has undergone many changes and developments through the years to ensure an economical and reliable power supply from the generator to the customer. TVA's transmission system provides a vehicle for power transfer to the 80,000 square-mile power service area.

Prior to the 1950's, the TVA power system was primarily a hydroelectric system with low-voltage 46-, 69-, and 115-kV and some 161-kV transmission lines connecting load centers to generating plant locations along the Tennessee River and its tributaries.

As system loads increased and industrial development expanded into the rural areas, TVA was unable to keep pace with load growth by expanding the hydroelectric generation base and extending the use of low-voltage transmission lines. Therefore, after 1950, with the addition of large thermal plants to the system, the low-voltage transmission systems yielded to an accelerated growth of the 161-kV system for more efficient bulk power transfer.

As distinguished from lower voltage lines, the 161-kV transmission system provides a very reliable system which is primarily operated as a closed loop network. This high degree of reliability has been accomplished through the effective application of modern high-speed relays, protective equipment, and switching schemes. While the majority of the 161-kV transmission system is loop operated, radial operation has been utilized effectively in some areas.

During the early 1960's it was apparent that the 161-kV transmission system needed to be supplemented by an extra high-voltage transmission system to transfer large blocks of power over relatively long distances. These large power transfer requirements were brought about by the need to transfer large power to large load centers and the need for seasonal exchanges of power with neighboring utilities. These requirements led to the planning and rapid development of TVA's 500-kV extra high-voltage (EHV) transmission system.

TVA's initial use of EHV transmission was inaugurated in 1965 when two 500-kV transmission lines were constructed to establish major east-west system ties capable of transferring significant quantities of power between TVA and utilities to the southwest and between subregions of the TVA power system.

Subsequently, 500-kV transmission lines were extended into the eastern portion of TVA's service area and were later supplemented with north-south ties which further unified the EHV system grid and formed the present bulk power transmission system. Today this EHV grid consists of approximately 1,500 miles of 500-kV transmission lines with 8 substation and 8 switching points.

By the end of FY 1974, TVA had a total of 626 substations and 16,550 circuit miles of transmission lines in operation. The following tabulation provides a further sub-grouping of these facilities by voltage class:

Operating Voltage	Facilities In Service June 30, 1974	
	Substations*	Miles of Lines
46 kV	162	2,686
69 kV	242	3,489
115 kV	6	176
161 kV	199	8,637
230 kV	1	30
345 kV	-	2
500 kV	16	1,530
Total	626	16,550

*Excludes generating plant switchyards

Interconnections - Over the years, as the power system has been expanded, TVA has found it advantageous to establish numerous transmission line interconnections with neighboring utilities. Through these connections, power flows automatically from one system to another to aid temporary, relatively minor emergency conditions on systems in the network such as the sudden loss of generation, load, or major intrasystem transmission line connections. The interconnected system also provides for the flow of power under major losses and prevents cascading outages.

Transmission connections between systems tend to reduce the reserve capacity that each system must maintain to achieve the necessary level of reliability. They allow for better use of generating capacity when the seasonal load characteristics of a system permit it to transmit power to another system from large units which operate at higher, more efficient rates than those which the other system might have available. When seasonal load diversity exists between two systems an interconnection capable of exchanging 1,000,000 kW between the systems, for example, can be roughly equivalent to adding that amount of generating capacity to each system. TVA now has diversity interchange agreements in force which represent a total seasonal exchange of 2,060,000 kW with neighboring utilities. These interconnections result in considerable savings in cost and conservation of resources.

In addition to emergency assistance and seasonal diversity interchange, TVA has established special agreements with 17 privately owned utility companies and 2 cooperatives for (1) short-term power and energy sales, (2) economy interchange, (3) energy assistance for replacement power when generator units are out of service for maintenance, and (4) the use of facilities for access to other (remote) power systems for energy exchange or emergency assistance.

Through the numerous power connections established with neighboring utilities the TVA system has become an integral part of a huge power network covering much of the United States. Therefore, the importance of the TVA system is by no means limited to the supply of electric power consumed in the Tennessee Valley area. In times of power emergencies, operation of the TVA power system can contribute significantly to power supply conditions from the Great Lakes to the Gulf of Mexico and from New England to Oklahoma and Texas.

<u>TVA Customer Characteristics</u> - TVA generates and transmits power; it has no distribution system. Electricity is produced at generating plants and sent along transmission lines to delivery points where it is purchased by TVA's customers, which include power distribution systems, some very large industries, and several Federal defense systems. TVA sells at wholesale to the

distribution systems which in turn distribute power at retail rates to their customers--the homes, farms, businesses, and nearly all of the industries in the region. The accompanying table shows the sources of TVA's energy input and output for fiscal years 1974 and 1964. Also, see Figure 3.

Municipalities and Cooperatives - TVA supplies power to 160 locally owned and operated electric distribution systems. The 110 municipal systems range in size from the Memphis system which serves more than 265,000 customers to the Chickamauga, Georgia, system which serves about 700. Other municipal systems with more than 50,000 customers are Nashville, Knoxville, and Chattanooga, Tennessee, and Huntsville, Alabama. There are 11 municipal systems with fewer than 2,000 customers. The size range of the 50 cooperatives is not so great; the smallest serves about 3,200 customers, and the largest just over 40,000.

SOURCE AND DISPOSITION OF ELECTRIC ENERGY
Fiscal Year 1974

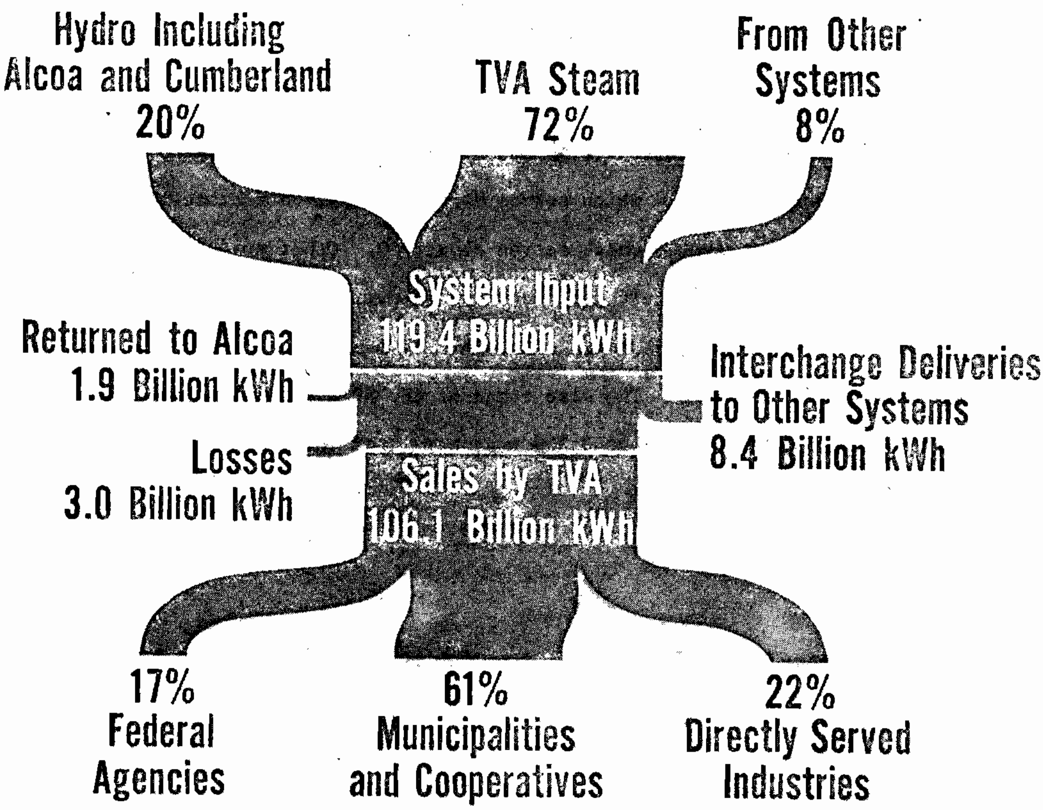


FIGURE 3

SYSTEM INPUT, SYSTEM OUTPUT

(Millions of Kilowatt-Hours)

	Fiscal Year 1974	Fiscal Year 1964
SYSTEM INPUT		
System generation		
Hydro		
TVA plants	17,485	13,255
ALCOA plants	2,408	2,044
Cumberland plants	3,643	1,533
Total Hydro	23,536	16,832
Steam plants	84,084	56,536
Nuclear plants	1,948	-
Gas turbine plants	292	-
Total net generation	109,860	73,368
Purchased	1,046	-
Interchange received	8,521	3,041
Total input	119,427	76,409
SYSTEM OUTPUT		
Sales		
Municipalities & cooperatives	64,183	27,848
Federal agencies	17,388	25,362
Industries	23,790	14,077
Electric utilities	122	442
Total outside sales	105,483	67,729
Interdivisional	662	721
Total sales	106,145	68,450
Return to ALCOA*	1,849	1,866
Interchange delivered	8,408	3,839
Losses	3,025	2,254
Total output	119,427	76,409

*In return for energy delivered to the TVA system from the ALCOA plants.

The following table indicates the varied size of the local distribution systems served by TVA.

Consumers	Municipal Systems	Cooperative Systems	Total
Under 7,500	64	7	71
7,500 - 14,999	28	17	45
15,000 - 29,999	12	21	33
30,000 or more	6	5	11

TVA's total sales to municipal and cooperative distributors in FY 1974 were 64.2 billion kWh, 61 percent of TVA's sales to all customers.

Directly served industries - Most of the industries served from the TVA system as direct customers use large amounts of electric energy, primarily in various electro-chemical and electro-metallurgical manufacturing processes. Major industries represented in this group are the aluminum, chemicals, and ferroalloys industries.

Power demand under contract to directly served industries amounted to over 3.6 million kW in FY 1974. Energy sales to the group in FY 1974 amounted to 23.8 billion kWh and to 22 percent of TVA's total energy sales.

Directly served Federal customers - Ten Federal customers were served directly by TVA in FY 1974. Energy sales to the group amounted to 17.4 billion kWh in FY 1974 and to 16 percent of TVA's total energy sales. By far the largest of these Federal customers are the AEC installations at Oak Ridge and Paducah to which TVA supplied 16.2 billion kWh in FY 1974, or 94 percent of sales to the Federal groups.

Federal sales within TVA identified as "interdivisional" are for TVA's chemical operations and other small uses such as for visitor buildings and navigation locks at TVA dams.

Distributor Customer Characteristics

Residential - The local electric systems serve 2.1 million homes and farms; 80 percent are single dwellings, 15 percent are multiple dwellings of two units or more, and 5 percent are mobile homes. These customers have an annual average use of about 15,000 kilowatthours.

More than half of the region's homes are partially or completely air conditioned. Nearly 800,000 (38 percent) of these customers use electricity for winter heating. In a normal winter, they will use an average of about 10,000 kilowatthours of electricity for their full winter space heating requirements and have a total annual average use of 23,000 kilowatthours. The remaining 62 percent use other fuels for space heating as well as frequently using other fuels for water heating and cooking and have an annual average use of 11,000 kilowatthours.

Commercial and industrial - The local electric systems also provide retail electric service to 260,000 businesses and industries billed under the General Power Rates. Some 237,000 of those customers have demands under 50 kilowatts. The other 23,000 have demands ranging up to 50,000 kilowatts.

Outdoor lighting - Electric lighting of streets, roadways, and parks, athletic field lighting, and the "Light Watchman" service use some 200 million kilowatt-hours.

TVA SYSTEM CAPACITY

Units in Service on June 30, 1974

Plant	No. Units	Nameplate Capacity - kW
TVA Hydro		
Appalachia	2	78,900
Blue Ridge	1	20,000
Boone	3	75,000
Chatuge	1	10,000
Cherokee	4	120,000
Chickamauga	4	108,000
Douglas	4	115,000
Fontana	3	225,000
Fort Loudoun	4	135,590
Fort Patrick Henry	2	36,000
Great Falls	2	31,860
Guntersville	4	97,200
Hiwassee	2	117,100
Kentucky	5	175,000
Melton Hill	2	72,000
Nickajack	4	97,200
Norris	2	100,800
Nottely	1	15,000
Ocoee # 1	5	18,000
Ocoee # 2	2	21,000
Ocoee # 3	1	27,000
Pickwick	6	220,040
South Holston	1	35,000
Tims Ford	1	45,000
Watauga	2	50,000
Watts Bar	5	153,300
Wheeler	11	356,400
Wilbur	4	10,700
Wilson	21	629,840
Total TVA Hydro		3,195,930
TVA Fossil Fuel		
Allen*	3	990,000
Bull Run	1	950,000
Colbert	5	1,396,500
Cumberland	2	2,600,000
Gallatin	4	1,255,200
John Sevier	4	846,500
Johnsonville	10	1,485,200
Kingston	9	1,700,000
Paradise	3	2,558,200
Shawnee	10	1,750,000
Watts Bar	4	240,000
Widows Creek	8	1,977,985
Total TVA Fossil		17,749,585

Plant	No. Units	Nameplate Capacity - kW
TVA Gas Turbines		
Allen	20	620,800
Colbert	8	476,000
Total TVA Gas Turbines		1,096,800
Total TVA Fuel		18,846,385
Total TVA Hydro & Fuel		22,042,315
Alcoa Hydro		
Bear Creek	1	9,000
Calderwood	3	121,500
Cedar Cliff	1	6,375
Cheoah	5	110,000
Chilhowee	3	50,000
Nantahala	1	43,200
Santeetlah	2	45,000
Tennessee Creek	1	10,800
Thorpe	1	21,600
Minor Plants		6,240
Total Alcoa Hydro		423,715
Corps of Engineers Hydro		
Barkley	4	130,000
Center Hill	3	135,000
Cheatham	3	36,000
Dale Hollow	3	54,000
Old Hickory	4	100,000
Percy Priest	1	28,000
Wolf Creek	6	270,000
Cordell Hull	3	100,000
Total Corps Hydro		853,000
Total Hydro		4,472,645
Total Fuel		18,846,385
Total System		23,319,030

*Leased from Memphis Light, Gas and Water Division

In planning for the growth in power demands for the system, TVA investigates alternate sources of energy considering economics, engineering, and protection of the environment.

Under current technology hydroelectric, coal-fired, gas-fired, oil-fired, and nuclear generation are reviewed as the best available types of generation to fill energy needs of the system. Other means may be available in the future, including solar heat, geothermal, and magnetohydrodynamics; however, these means do not appear to have promise or wide-scale application within the next 10 years. It appears that nuclear power will be required to fill the bulk of the generating requirements in the short-term future.

As additional generating capacity is planned, evaluation of such factors as environmental impact, economics, competitiveness, and fuel available will be made. Since these evaluations are made against a changing factual background, the mix of generation may differ from time to time.

At present, TVA is adding 18.4 million kilowatts of generating capacity, most of which is in 13 nuclear units of more than one million kilowatts each for a total of 16.2 million kilowatts. To provide additional system peaking capacity, construction is also under way on a pumped storage hydroelectric project with four reversible pump turbine units totalling about 1.5 million kilowatts, together with additional combustion turbine units with a capacity of .6 million kilowatts. These generating plant additions, when completed in 1982, would increase the total system capacity to nearly 42 million kilowatts.

TVA is also expanding its network of extra-high-voltage (500,000 volt) transmission lines and substations and its other transmission facilities, principally 161,000 volts.

In addition to the above construction, TVA is participating with the Atomic Energy Commission, Commonwealth Edison Company of Chicago, Breeder Reactor Corporation, and Project Management Corporation in the construction and operation of the Nation's first large-scale demonstration Liquid Metal Fast Breeder Reactor Project. The plant, which will be in the range of 350 to 400 megawatts, is proposed to be located on the TVA system in Oak Ridge, Tennessee.

CORPORATE FINANCING

The TVA Act provides that the power program shall be self-supporting, and power revenues have been sufficient to meet the current operating and maintenance expenses of the power program. Earnings have not been sufficient nor is it reasonable to expect them to be sufficient to finance by themselves the cost of building new power facilities to meet load growth. For the first 27 years of operation the cost of building new power facilities was financed almost entirely from money appropriated by the Federal Government supplemented with revenues from the sale of power—the one exception being $65 million in bonds issued in 1938 and 1939 and since retired. For the past 14 years, however, little or no appropriations were made to TVA for power facilities, and construction costs have been financed almost entirely through the sale of bonds and notes supplemented with power revenues.

One authorization, available to TVA since the beginning, stands out above all others by its contribution to efficient management. This is the authority to use revenue from the sale of power in the operation of its power facilities and in conducting its power business. As a rule, the funds received by a Federal agency are passed directly to the United States Treasury, but TVA has had the freedom customarily found in private business but seldom found in government to use its revenues to meet its current expenses and its capital requirements.

The following table presents a summary of TVA power earnings for each of the 'ast five fiscal years ended June 30.

Fiscal Year	Operating Revenues	Operating Expenses (Excluding Depreciation	Approximate Net Power Proceeds	Depreciation	Interest Charges Less Other Income and Deductions	Net Income
			(Millions)			
1970	$479.6	$299.1	$180.5	$75.1	$30.8	$ 74.6
1971	598.0	369.5	228.5	80.0	29.5	119.0
1972	641.8	397.9	243.9	83.4	48.4	112.1
1973	749.3	487.9	261.4	89.5	65.5	106.4
1974	883.6	582.4	301.2	97.0	98.0	106.2

In 1959, the TVA Act was amended to authorize TVA to sell bonds, notes, and other evidences of indebtedness to assist in financing the construction of power generating and transmission facilities. These borrowings are not obligations of nor are they guaranteed by the United States, but are secured solely by TVA's power revenues. The original authorization of $750 million was increased to $1,750 million in 1966 and to $5 billion in 1970. As of June 30, 1974, TVA had $2,772 million of borrowings outstanding.

TVA bond issues have been sold by competitive bidding through nationwide syndicates of underwriters. They have been received favorably in the market, with each issue receiving the highest ratings of the principal rating agencies.

Interest costs for the bond issues have ranged from a low of 4.44 percent in November 1960, to a high of 9.29 percent in June 1970.

The 1959 legislation required TVA to make two types of payments from power proceeds to the Treasury each year, one payment to reduce the appropriation investment (currently at the rate of $20 million a year) until $1 billion has been repaid, and the other to pay a return (or dividend) on the appropriation investment outstanding. The annual dividend is determined by applying to the appropriation investment the average interest rate payable by the U.S. Treasury on all of its marketable obligations. Since passage of the 1959 amendment, the total of these two payments to the Treasury, through fiscal year 1974, has totaled over $883 million. Although the appropriation investment has been reduced by $205 million during this period, the payment of the yearly dividend to the Treasury was $63.4 million in fiscal year 1974 compared with an initial payment of $41.4 million in 1961. This increase, of course, reflects the rapid rise in interest rates during the period. For fiscal year 1961 the applicable interest rate was 2.891 percent; the rate applicable for fiscal year 1974 was 6.129 percent.

THE FUTURE

There are a variety of future opportunities and future challenges that might be discussed, some of which are vital to the immediate future of TVA's power system and to other power systems in the United States, and some of which are concerned with the more distant future. It seems best for the purposes of this presentation to look at but one of them--at research--because the wide range of research projects under way touches on all the opportunities and all the challenges.

Until recently, most research in the field of electric energy that was done in the United States was done by manufacturers of electrical equipment, such companies as General Electric, Westinghouse, and others; the U.S. electric systems themselves sponsored relatively little research. That situation is changing.

TVA will spend about $30 million during the current fiscal year on research, mostly for the installation of experimental and demonstration sulfur dioxide removal equipment on one large coal-fired generating unit, but also for other air quality studies, for strip mine reclamation and for studies of the effects on aquatic life of heated water discharges and in support of research jointly financed with others. Other electric systems also are increasing their in-house research.

In addition to in-house research, all of the electric systems in the United States, those that are privately owned and those that are publicly owned, have combined their financial resources in support of a new organization--the Electric Power Research Institute--that is sponsoring and guiding research in the entire spectrum of electric energy, from fuel supply through generation, transmission, distribution, and use of electricity. In a similar manner, America's electric systems are jointly financing a demonstration breeder reactor. In addition, the United States Government also is putting a great deal of money into fundamental research in the energy field. America's expectation is to develop sources of energy that are economical, plentiful, and environmentally acceptable.

The United States is blessed with a great wealth of natural resources that, for the most part, have supported a high rate of industrial growth and a high standard of living for the American people. In the energy field, the U.S. has large reserves of basic fuels, but research is needed so there can be a shift in the ways these fuels are used. An understanding of what the United States needs to do is revealed by a look at the energy resources available to it and how those resources are being used:

--42 percent of the energy used in the United States comes from oil, but only about 4 percent of the proven energy reserves in the United States are in oil.

--33 percent of the energy used in the United States comes from natural gas, but less than 6 percent of the proven reserves in the United States are in natural gas.

--18 percent of the energy used in the United States comes from coal, but coal constitutes 86 percent of this Nation's known energy reserves.

Unfortunately, there are many problems associated with the burning of coal, and it is especially difficult to meet some of the existing and proposed environmental standards. These standards are being described in other papers, so will not be detailed here.

Hopefully, this critical situation will be overcome with new technology that will permit coal to be mined and to be burned in ways that are compatible with a clean environment in combination with a modification of whatever environmental standards prove to be unduly restrictive.

A great deal of work is being done in energy technologies that have the potential of producing large quantities of electric energy with minimum depletion of natural resources, and this includes research to improve the efficiency with which fossil fuels are burned in conventional plants and MHD and research in non-conventional fuels, such as the breeder reactor, fusion power, solar energy, and geothermal conversion.

Fossil fuel research includes low and intermediate Btu coal gasification; coal liquefaction; improvements in the ways to use coal directly as with fluidized combustions systems to produce clean power from coal, char, or solid waste; development of technologies to remove the wastes from fossil fuels after they are burned; and basic research in the extraction and use of fossil fuels.

Advanced systems research includes studies of electrochemical energy conversion and storage, including, for example, fuel cell technology, storage batteries, the role of hydrogen in future utility systems, and the feasibility of using electric vehicles on a large scale. It also includes studies of electromechanical energy conversion and storage, including improvements in steam turbines. And, of course, advanced systems include work in fusion power, solar energy, and geothermal energy.

In the field of transmission, research is being done to improve AC overhead lines, AC underground lines, AC substations, and DC systems.

The list of research activities could be expanded, but the above should provide a suitable glimpse of the breadth of what the United States is attempting to accomplish. Because TVA is involved directly and intimately in the development of the breeder reactor, additional details will be provided on that one research project.

CLINCH RIVER BREEDER REACTOR PLANT

The first large demonstration Liquid Metal Fast Breeder Reactor in the United States will be built on the TVA power system, under a unique cooperative program of the Nation's electric industry and the Atomic Energy Commission.

The objective of the plant is to demonstrate operating performance, reliability, maintainability, environmental acceptability, and help confirm the economics of the breeder reactor in a working utility situation.

It will be constructed on a site provided by TVA on the Clinch River in Oak Ridge, Tennessee. It will be designed to generate about 400,000 kilowatts of electricity.

It is expected that on-site construction will begin in 1976 and will be completed in five years. The plant startup phase will be followed by five years of "demonstration" operation in the mid-1980's after which the plant is expected to take its place as a regular part of the TVA system.

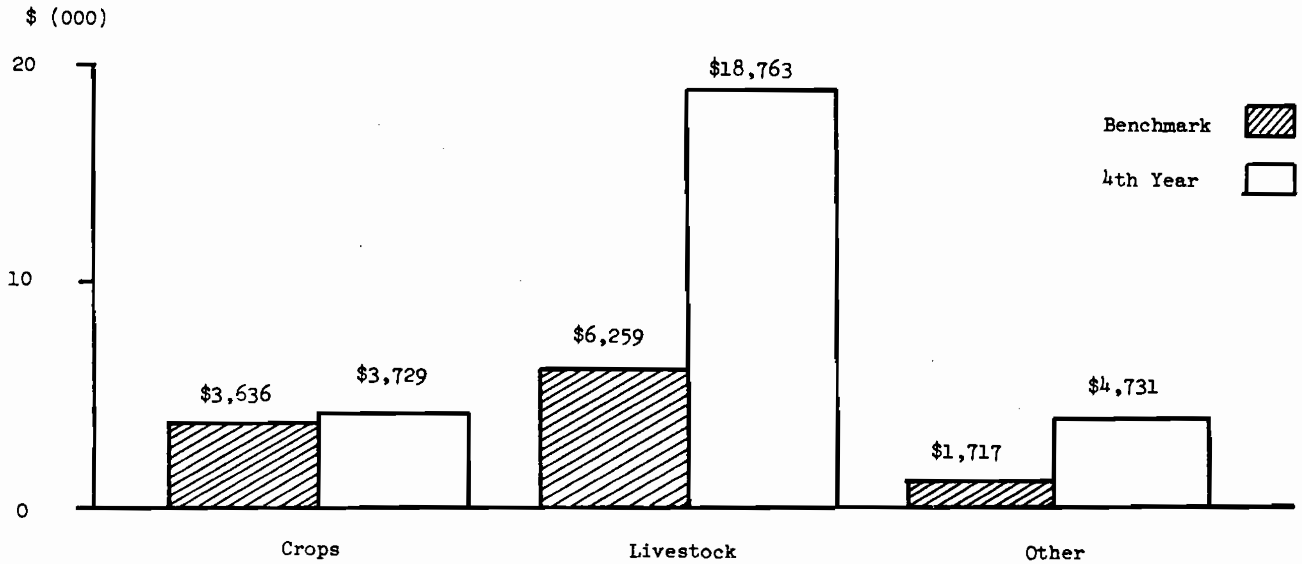
An example was with the University of Georgia. There real farms were selected. Technicians from many agricultural disciplines at the university worked together in developing the input/output data for enterprises that were required to mathematically consider several profit seeking alternatives at one time. In 1956 results of this attempt were published.

In 1960 the Tennessee Valley Authority and the cooperating universities were examining their operations as they do at the end of each 5-year agreement. In examining how they might improve their combined operations to help develop agriculture, they recognized a need for more sophisticated planning techniques. In the planning agreements drawn up that year the rapid adjustment farm activity was included. The time frame was approximately 30 years.

APPENDIX 2

FARM PRODUCT SALES

GRADUATE RAPID ADJUSTMENT FARMS



IIASA DISCUSSION PAPER

J. P. Charpentier

On behalf of IIASA I would like to raise some questions that occured to me when I read the excellent description of the TVA power style.

1. First I would like to emphasize some orders of magnitude in order to get a clear idea of the scale of the TVA.

On the Aggregate Level

I must apologise, because owing to the pressure of time, I was not able to present data other than for the year 1970. As the information given in Mr. Zumwalt's paper applies to 1974, we can only make a rough comparison.

data for 1970	land area x $10^4 km^2$		popualtion x 10^6		installed electric cap. $10^6 kW$	electric transmission lines km
TVA	21*		6*		23*	27,000
USA	900	2%	207	3%	310	≈400,000
UK	24		56		60	
FRG	25		58		47	≈30,000 to 50,000
France	55		52		34	
Austria	8		7		7	

*Data are for 1974.

On the Individual Level of Electricity Consumption

In the household sector, the report mentions an annual consumption of:

- 23,000 kWh if the consumer uses only electricity (including heating and climatization);
- 11,000 kWh if other fuels be used for heating.

By assuming that one family is made up of four people we can conclude that the annual per capital consumption of primary energy is in both cases roughly:

1.7 kW-Y $_{th}$

0.8 ______ .

Now let us have a look at two other statistical values in order to compare

- the US average use of household electricity per year and capita given by Hammond and Weinberg:

0.5 kW-Y $_{th}$; and

- the average of the total use of electricity per capita in Europe (including all sectors):

≃ 0.8 kW-Y $_{th}$.

These figures speak for themselves and point out the very high level of electricity consumption in the Tennessee Valley.

2. Related to this very high electricity consumption rate let me now raise three sets of questions:

   a) The first set is related to investment problems:

      - What are the main criteria taken into account by the TVA for choosing the type of new plant?

      - Do you use any kind of investment model?

      - How do you manage long range choices versus short range necessities?

      - How do you take into account some external problems such as air and water pollution or public acceptance of nuclear plants?

      - What discount rate do you use?

      - The paper mentioned the research of future technological possibilities such as solar, geothermal, or magnetohydrodynamic energy; how do you incorporate them in your optimization models of investment?

   b) My second set of questions deals with the sale price of electricity:

- Could you give us some information about your tariff versus the type of consumer and the time of consumption. More precisely, do you use the marginal cost as sale price?

- In the same area, I would like to know more about the kind of contract you signed with other big companies such as ALCOA to which you supply electricity?

c) Finally, my last question is related to the specific electricity consumption in some sectors:

  - Concerning your conservation program did you make any analysis of energy content for the different industrial goods? For example, do you know how much electricity is used or could be used or will be used in future processes for the production of one ton of aluminium, steel, copper, etc? According to your viewpoint, what could be the evolution of the future uses of electricity?

TVA RESPONSE TO DISCUSSION BY J.-P. CHARPENTIER

The main criterion for choosing the type of new plant is the production of electricity at the lowest possible cost, with reasonable reliability, and with minimum impact on the environment. Therefore, factors considered over the life of plant are production and capital costs, cost and availability of fuel, cost of money, siting, social acceptability, safety, environmental impacts, load shape, mix and type of existing units, etc. An investment model is used to determine the impact of additional capacity on rates.

Properly done, the long-range choice of a new plant will cover the short-range necessities. If unforseen short-range necessities do occur, the alternatives are limited. But short-range necessities generally can be overcome with capacity that can be installed quickly, by importing power from other systems, by interrupting deliveries to customers who contracted for that quality power, and by adjustment of maintenance schedules.

Preliminary and final environmental statements are prepared for each new installation. These are reviewed by all appropriate levels of government and by the general public through scheduled hearings. In the case of nuclear plants, safety analysis reports are prepared and reviewed by appropriate government agencies and by the public. A discount rate of 8.5% is used.

Although research is conducted in methods of generation that may not be commercial until late in this century or early next century, we do not incorporate such exotic energy sources in our models of investment. The rates charged by TVA are based on the cost of service to the broad classes of consumers. Average cost has been the main basis for rates; the TVA is considering alternative rate structures, but any modification of present cost-of-service rates likely will result from perceived changes in cost. At present, the long-run incremental cost is approximately the same as average cost because existing generation is about 75% coal fired, with high and rising fuel costs, while the great bulk of planned new generation is nuclear, where relatively low fuel costs offset the inflated capital costs. The question concerning the energy content for the different industrial goods was covered in previous correspondence sent to IIASA.

SHORT- AND LONG-TERM LOAD FORECASTING MODELS

I. Introduction

Efficient planning of the operation and design of an electric system depends upon reasonably accurate forecasts. Rapid load growth, large financial investments necessary to serve growing loads, long lead times for planning and construction, rapidly rising fuel and other costs, fossil fuel shortages, new unknowns inherent in long lead times such as the effectiveness of conservation programs, and consumer responses to rising prices have combined to make accurate forecasting both more difficult and more important. The future is always uncertain, especially in terms of the need for capital commitments a decade in advance, as with large nuclear units in the United States. The future is especially uncertain now on a world-wide basis because of the world-wide problem of inflation and the increasingly complex problems encountered in developing national energy policies. These conditions emphasize the importance of systematic load forecasting methods to the planning and decision processes of electric utility management.

The load forecast is a planning tool, never a prophecy. It is the load reasonably expected in some future year, based upon study of past and present conditions and upon assumptions about the future. The function of forecasts is to minimize the unknown factor in the future so that planning can proceed. Forecasting methodology exists and has progressed because it is apparent that planning is typically more effective when it is based upon appraisal of future risks and opportunities than upon historical growth patterns alone.

A variety of load forecasts are prepared in the TVA to meet a range of planning needs. Forecasts of total TVA area monthly peak demands and energy* are prepared for 9 years in the future because 9 years is the approximate current lead time for the planning and construction of nuclear plants. Long-range forecasts to 1990 and beyond are essentially extensions of forecasts for the first 9 years. Total area forecasts are used in several ways, the most important use being the determination of the amount and timing of needed additional generating capacity. They are also the basis of revenue forecasts. These total area monthly load forecasts are supplemented by two other kinds of forecasts. Seasonal peak forecasts are prepared for the next 20 years for each of the approximately 700 delivery points at which TVA delivers bulk power. These independently prepared forecasts are used mainly in planning the transmission system but summations of these 700 individual forecasts are used as a check against total area forecast. A second supplementary forecast consists of forecasts of normal weather hourly MW loads for all hours of the future year or years under study and extremely hot and cold week hourly loads for use in planning the optimum mix of the various types of base load and peaking generators.

II. Characteristics of TVA Loads

To a considerable degree, the selection of TVA forecasting methods are influenced by the characteristics of loads in the TVA area. For example, about 800,000 residences (4 of 10) are electrically heated resulting in

*TVA area loads as discussed in this paper are the loads imposed on the TVA system by consumers located within the service area. Area loads frequently differ from generation loads because the TVA exchanges capacity via high voltage lines with neighboring utilities on a seasonal basis.

annual area peaks in winter. However, summer peaks are pronounced also because 1,200,000 residences (6 of 10) and nearly all of the 250,000 commercial establishments are air conditioned. Residential appliance saturations are high; 7 of 10 homes use electricity to heat water and 8 of 10 cook electrically. Base loads which are not responsive to weather in any significant degree include a number of very large gaseous diffusion, primary metals, and chemical product plants characterized by high load factors. Some indication of the range of TVA area loads is given by selected area peaks in 1973.

Annual peak - January	18,888 megawatts
Summer peak - July	15,906 megawatts
Lowest monthly peak - May	13,326 megawatts

Total energy requirements for the year ending June 1974 amounted to 111 billion kilowatthours. The annual load factor was 68 percent.

III. Short-Term Forecasting

Forecasts of the integrated hourly loads for all hours of the next day are prepared daily. These forecasts consist of two types of loads. Large, high load factor, industrial loads are forecast as a total with hourly variations being limited to changes expected by a few individual customers. The remaining TVA loads are very weather sensitive and are forecasted as a total by hours to reflect both the current and the predicted weather for the next day. These latter forecasts are based on actual loads of days with similar weather to that predicted. A recent day is chosen when possible, and the hourly loads of that day are subject to limited adjustment. When necessary, a day in the same month of the previous year is chosen; those hourly loads are increased to reflect expected annual load growth. Weather elements considered include temperatures, wind, sky cover, precipitation, and humidity.

When weather conditions are significantly different from those forecasted the day before, forecasts of load for the balance of the current day are revised. The revised forecast reflects consideration of current deviations from forecasted loads and expected weather deviations later in the day. An economic dispatch computer program also forecasts revised loads one hour ahead based on current loads and a normal load pattern based on actual loads of recent days.

Weekly forecasts are made of the average loads for the current week and the following two weeks. These forecasts are based on present weather conditions converging to normal weather conditions in the second week.

Monthly forecasts are made of the average and peak loads of each of the following 12 months. The large, high load factor, industrial loads are forecast individually based on historical data, contractual information, and information obtained monthly from the customers. Forecasts of the total simultaneous peak loads of these industrial customers reflect a diversity factor of about 6 percent, which is reviewed periodically. The remaining weather-sensitive loads are forecast as a total. Historical records of these latter loads are adjusted to reflect normal weather. Then forecasts are made by two independent methods, with discrepancies being resolved by analysis.

With one method, a separate forecast is made of the load for each month, utilizing the weather-adjusted historical data for the same month of the previous years to establish a trend. The second method is described in the following section.

Forecasts of weekly peak and average loads for the next 12 months are derived from the monthly forecasts. The weekly peak loads are interpolated from monthly peak loads which are assigned dates of most likely occurrence. The weekly average loads reflect more gradual seasonal variations than do the monthly averages. Minimum, maximum, and average temperatures are associated with the weekly load forecasts, permitting adjustments to reflect other than normal temperatures. Such adjustments require the development of load-temperature relationships for each month of the year.

IV. Forecasting Total Area Intermediate-Term Requirements

Forecasting total area requirements for the next 9 years is a process consisting of a series of major steps beginning with data collection.

1. Data Collection - Systematic data collection is a basic step in load forecasting. Load, weather, economic, and demographic data are acquired at intervals ranging from hourly to annually.

Electric Utility Data

A. System loads - hourly
B. Monthly peaks and energy sales by TVA
C. Retail sales and customers

Weather Data

A. Hourly temperatures
B. Other (humidity, windspeed, etc.)

Economic Data

A. National and regional activity trends

B. Current regional development activities

C. Competitive fuel prices

Demographic Data

A. Population and households

B. Regional migration

C. Jobs

D. Housing characteristics (mix of new dwellings, appliance saturation, etc.)

E. Special information (confidential plans for new industrial plants or expansions, expected output levels of large industries, resort developments in remote areas, planned suburban developments about large cities, etc.)

2. Load Data Categories

Loads are grouped for analysis by broad classes of consumers. Business and industry consumers for which demands are available are further divided by size of demand.

There are about 180 business and industry loads with demands of 5,000 kW or more. These include large aluminum producers, chemical industries, ferroalloy plants, a variety of other industries, and several Federal establishments. Predictions of these loads are based on contract demands, historical loads, stated plans of the consumer, and future markets for products. To provide for growth beyond stated plans, amounts of undesignated power are added to known loads. The amounts added are based on past trends, inquiries for power, analysis of power use by industry groups, and study of factors influencing industrial development.

Loads under 5,000 kW are divided into seven geographic areas: five large cities, a group of smaller municipalities, and a group of cooperatives. Loads for each of these seven geographic areas are divided into four classes of service. These classes are home and farm consumers, commercial and industrial under 1,000 kW commercial and industrial 1,000 to 5,000 kW, and outdoor lighting.

3. Preliminary Work

(1) Preparation of written assumptions, background and specific, covering next decade

(2) Review of load data (billing data changes, classification of customer changes, etc.)

(3) Update studies of load-weather relationships

(4) Update other continuing studies such as regional share of aluminum production

(5) Prepare new studies as appropriate, such as estimation of the effect of conservation programs

(6) Adjust peak and energy data responsive to weather to normal weather conditions

(7) Seasonally adjust load data having seasonal patterns

(8) Prepare graphic and tabular presentations and other work papers for use in preparing forecasts.

4. Forecasting Methodology

The two major forecasting methods are extrapolation and correlation. Essentially, extrapolation is extending a historical series of data into the future by studying the pattern of past growth and assuming that forces which affected past growth will influence the series in a similar manner in the future. There are numerous extrapolating techniques, some simple and some intricate. Among these are: fitting mathematical growth curves; using a straight edge or curve with plotted data; calculating historical percentage increases from year to year, averaging them over the last 5 or 10 years, and using that average in estimating loads for the future; computing compound rates of growth and extrapolating the series at that rate; statistical techniques, such as time series analysis; and others.

One extrapolation method is to plot historical data on selected graph paper and extend the curve. For example, a series growing at a constant geometric rate makes a straight curve on semilog paper, and a rising curve or parabola on arithmetic paper. When visual methods are used in extrapolation, choice of the type and size of scales is an important consideration.

The pitfall of extrapolation lies in blind use of these methods. Forecasters relying entirely upon extrapolation methods may fail to recognize underlying changes in the growth trend. For example, a series of successively warmer summers might conceal a declining growth rate in base loads.

The second group of methods may be classified as correlation methods. In these methods, loads are related to other factors, such as weather and economic data. The major advantage of correlation methods is that they lead to better understanding of the factors that affect growth and of the relative importance of these factors. Further, relationships between loads and other factors, such as weather, are quantified. Correlation methods are also helpful in identifying [illegible]es when forecasts deviate from actual loads. Some correlation methods are scatter diagrams, regression analysis, and multiple regression analysis.

One problem in the use of correlation methods in forecasting is that the independent variables which affect load must be independently projected. The forecaster can usually project future electric loads more accurately than he can forecast other factors. Despite this difficulty, correlation methods are useful because they lead to consideration of the factors which affect load and to better understanding of how electric power loads grow in a context of other factors.

While extrapolation and correlation are the two main categories of load forecasting methods, two other elements are essential to effective forecasting: special information and judgment. Special information is used to modify or support forecasts prepared by the above two methods. For example, confidential information concerning the location of a new large industrial plant, knowledge of a planned new industrial park, plans for conservation campaigns, results of appliance surveys, reports on current national business activity, and statements by industrial plant managers as to expected levels of operations in the months ahead are examples of such special information.

Judgment is essential in weighing the factors which affect load, in evaluating the quality and importance of special information, and in selecting methods used in preparing the forecast. Judgment is important also in cases where there is little factual data. For example, past rates of growth of residential sales may not be indicative of the future in a given area because of the spread of suburban areas into presently rural areas.

5. Preparation of the Forecast

Forecasts are prepared for 28 load series under 5,000 kW consisting of 4 load categories for each of 7 geographic areas with emphasis on statistical methods including time series analysis and extrapolation techniques. Kilowatthours monthly sales data which are adjusted to remove the effect of seasonal forces and abnormal weather, customers, and average uses are extrapolated. Figure 1 illustrates the highly seasonal nature of residential loads in the TVA area. Figure 2 illustrates residential sales with the seasonal component removed and an extrapolation of the historical trend. Monthly average use and customer historical data and extrapolations are shown also.

Extrapolations of historical growth are frequently modified on the basis of the assumptions, special information, and studies, such as expected additional growth resulting from oil and gas shortages or load reductions expected from conservation programs.

To the fullest extent reasonable, trend extrapolations are reviewed and verified by alternate methods. Residential forecasts provide an illustration. The customer forecast is reviewed by an alternate method to verify the reasonableness of extrapolation. Forecasts of U.S. population, customers, households, and jobs are used with projected ratios of the TVA area to the United States data as shown in Figure 3 and Table 4. The resulting customer forecast is compared with the customer extrapolation. Differences are resolved by restudy and judgment.

The residential average use extrapolation is verified by an alternate method also. Projected saturations for several appliances which account for the bulk of residential sales including space heating are multiplied by estimates of respective annual kilowatthour uses of the various appliances. Each product is the contribution of that appliance to total average use. The sum of these products plus an amount for other appliances constitute an alternate forecast of average use for comparison with the extrapolation of average use. This method is illustrated in Table 5.

The residential energy trend extrapolation prepared earlier may be revised on the basis of revisions of average use and customer projections. Seasonal indexes are extrapolated and multiplied by corresponding values of the final energy trend extrapolation to obtain the residential monthly energy sales forecast as shown in Figure 6. As a final check, customers and sales may be calculated as a percentage of the U.S. data and projected and used with U.S. forecasts prepared by public and private organizations other than the TVA as shown in Figure 7.

Peak and energy forecasts for loads of 5,000 kilowatts or more served by the municipalities and cooperatives are prepared for seven geographic areas on the basis of past history, stated plans for operating levels, types of products, contract demands, and other information.

The large Federal and industrial loads served directly by TVA are studied and forecast on an individual basis. Directly served industrial loads are also grouped in such categories as aluminum and chemicals for further analysis. An allowance for growth in addition to known expansion and new loads is included on the basis of past growth by industry groups and studies such as the examination of past and present regional share of aluminum production capacity.

Projections of kilowatthour trends by classes of service are added for each of the seven geographic areas. Estimates of distribution losses and projections of seasonal indexes and load factors are used in computing energy requirements and peaks by months for each of the seven geographic areas. The system peak forecast is obtained by adding the predicted peaks of loads over 5,000 kW, loads of the seven geographic areas under 5,000 kW, estimates of system transmission losses, and the effect of demand diversity. Energy forecasts by months are obtained similarly.

Forecasts of the municipal and cooperative distributors' peaks are checked by preparation of independent peak forecasts for each of the seven geographic areas. Methodology includes temperature adjustment of historical peaks, time series analysis to remove and identify the seasonal factor, separate extrapolation of the peak and seasonal trends, and combination of the two to obtain peak forecasts. An additional check on distributor peaks is available through summation of delivery point peak forecasts as discussed below.

Forecasts are the responsibility of the Market Analysis Branch of the Division of Power Marketing. The branch chief actively reviews preliminary forecasts, raises questions, and suggests additional studies. The division director also reviews the entire forecast in some detail. He may invite others to offer expert opinions on specific items. The manager of the Office of Power also reviews the forecast and gives final approval.

The area requirements forecasts are examined together with contractural arrangements with other utilities for the sale or purchase of power and for seasonal capacity and other exchange to determine system requirements as opposed to area requirements.

V. Forecasting Area Long-Term Requirements

Long-term forecasts for periods from 10 to 25 years in the future are essentially extrapolations of the intermediate-term load forecast. They are used as indications of long-term load growth but final investment decisions are typically based upon the intermediate-term forecast.

VI. Forecasting Area Hourly Loads for Selected Years

The forecasts of area requirements are used primarily to determine the amount and timing of necessary new capacity. Hourly load forecasts are used to examine the alternatives in obtaining an optimum mix of the various kinds of base load, intermediate load, and peaking generators.

Hourly load forecasts for the year or years under study are of two kinds. The first is a forecast of hourly loads under normal weather conditions for the year under study. The method includes selection of historical loads experienced during approximately normal weather conditions. An index of hourly loads to peaks is calculated and applied to the monthly peaks forecasts of total area requirements to obtain estimated hourly future loads.

Such forecasts are supplemented by studies of future hourly loads during a week of extreme summer and winter weather. These extreme forecasts are inputs in sensitivity studies of optimum future generator mix.

VII. Forecasting Substation Loads

Summer and winter peaks forecasts are prepared for each of the nearly 700 delivery points at which TVA delivers bulk power. These forecasts are used in various transmission system studies, including the future need for new transmission lines and substations, reliability studies, and interchange studies. These forecasts are prepared 20 years in the future for summer and winter, normal and extreme weather, coincident and noncoincident, peak and offpeak, and real and reactive loads.

Preparation of delivery point forecasts results from a systematic process beginning with data and information collection, as in the preparation of area requirements forecasts. Among the data collected are figures for updating records of power factors, coincidence factors, offpeak ratios, and load factors. This collection of data, computation, and data storage is an extensive system in itself because of the large number of delivery points involved. The collection of useful current information concerning the loads at all of these delivery points is a rather extensive system also, including perusal of reports, study of problems, and interviews. The remaining steps are analogous to those in forecasting total area requirements.

SELECTED BIBLIOGRAPHY

Forecasting Methods

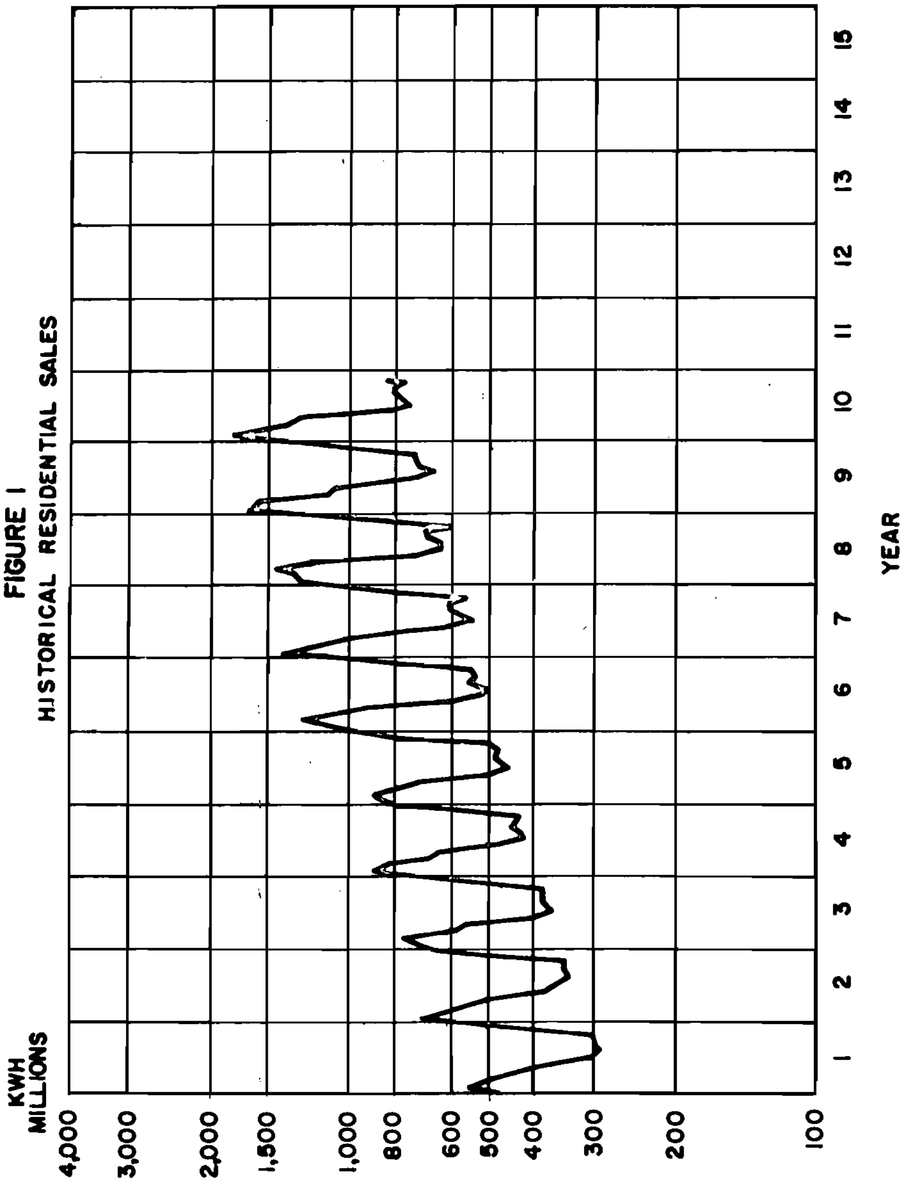
Hooke, R. G. Forecasting the Demand for Electricity, AIEE Power Apparatus and Systems, October 1955.

New, W. R. Load Forecasting on the TVA System, Part III - Residential, IEEE Conference Paper No. CP63-222, Tennessee Valley Authority, Chattanooga, Tennessee, January 1963.

New, W. R. Load Forecasting on the TVA System, Part IV - System Forecasting, IEEE Conference Paper No. CP63-955, Tennessee Valley Authority, Chattanooga, Tennessee, June 1963.

Technical Advisory Committee on Load Forecasting Methodology for the National Power Survey, The. "The Methodology of Load Forecasting," The National Power Survey, Federal Power Commission, Part IV, Appendix A.

FIGURE I
HISTORICAL RESIDENTIAL SALES



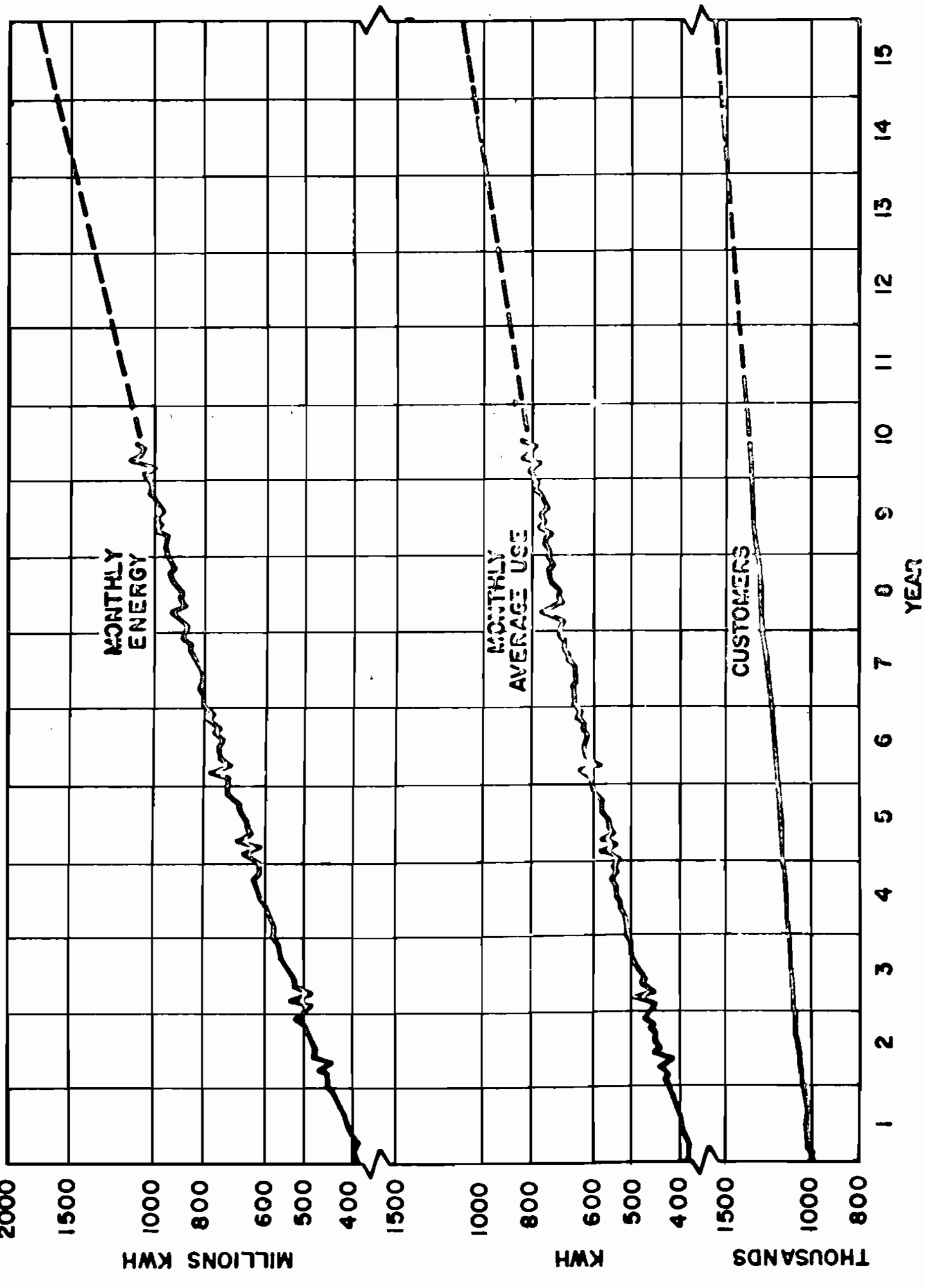


FIGURE 2
SEASONALLY ADJUSTED RESIDENTIAL SALES

FIGURE 3
SELECTED RELATIONSHIPS – TVA AND U.S.

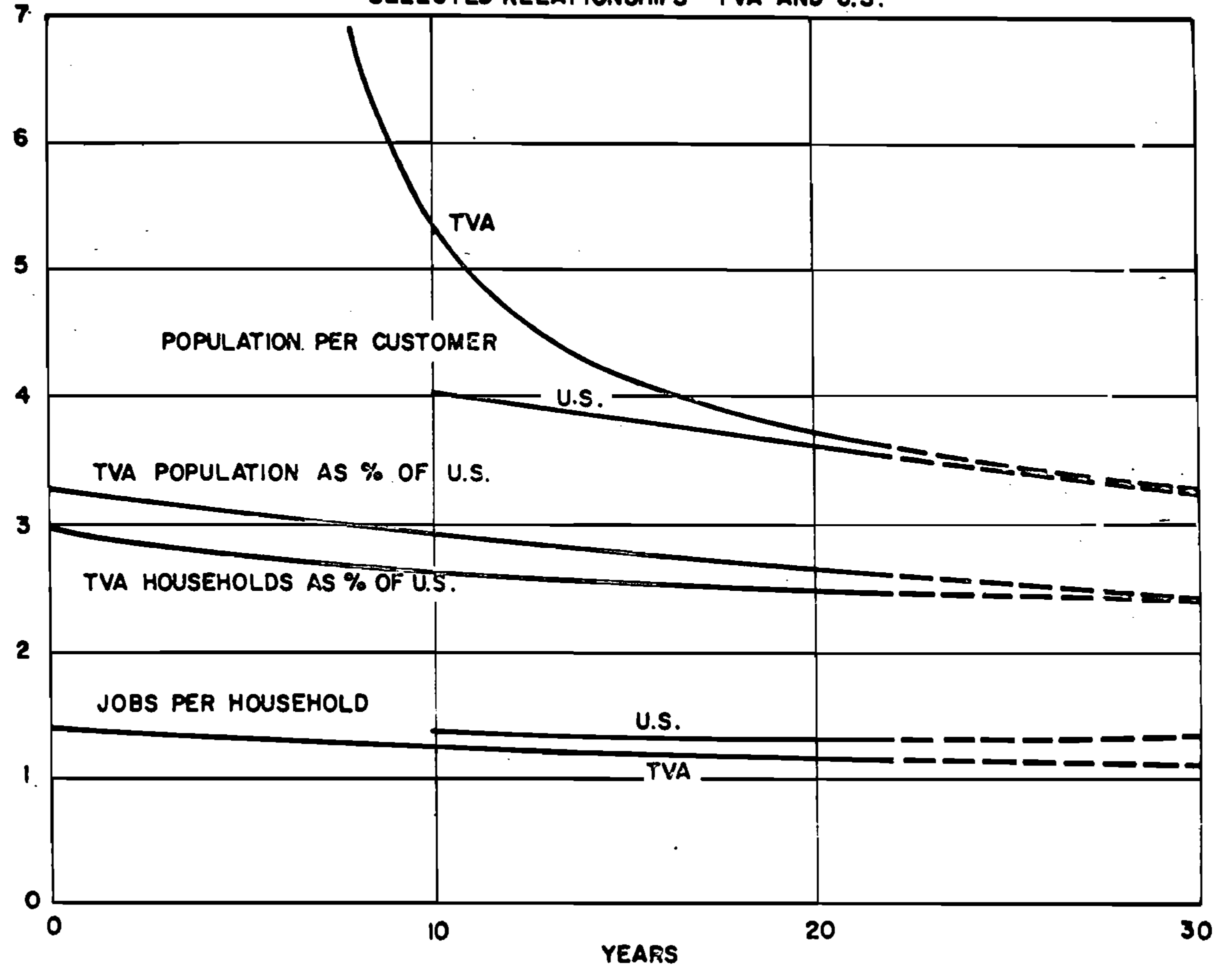


TABLE 4

POPULATION, HOUSEHOLDS, JOBS, AND CUSTOMERS

Calendar Year	Pop. July 1	H.H. July 1	Jobs	Res.Cust.	Pop. as % of U.S.	H.H. as % of U.S.	Jobs as % of U.S.	Pop. Per H.H.	Pop. Per Job	Pop. Per Cust.	H.H. Per Cust.	Jobs Per H.H.	Jobs Per Cust.
170 Power Service Counties (Thousands)													
1940	4,725	1,137	1,510	329	3.58	3.25	3.18	4.15	3.13	14.37	3.46	1.33	4.59
1945	4,449	1,099	1,644	514	3.36	3.06	3.11	4.05	2.71	8.65	2.14	1.50	3.19
1950	5,059	1,331	1,701	970	3.32	3.05	2.85	3.80	2.97	5.21	1.37	1.28	1.75
1955	5,071	1,371	1,829	1,229	3.06	2.86	2.91	3.70	2.77	4.13	1.13	1.33	1.49
1960	5,349	1,483	1,787	1,418	2.96	2.81	2.69	3.61	2.99	3.77	1.05	1.20	1.26
1965	5,630	1,635	2,026	1,635	2.90	2.85	2.85	3.44	2.78	3.44	1.00	1.24	1.24
1970	5,882	1,819	2,181	1,838	2.87	2.83	2.77	3.23	2.70	3.15	0.97	1.20	1.17
1975	6,037	2,039	2,370	2,218	2.82	2.83	2.71	2.96	2.55	2.72	0.92	1.16	1.07
1980	6,442	2,233	2,582	2,579	2.87	2.90	2.70	2.88	2.50	2.49	0.87	1.16	1.00
United States (Millions)													
1940	132.0	34.9	47.5					3.78	2.78		1.36		
1950	151.2	43.6	59.7	37.5				3.49	2.53	4.03	1.16	1.37	1.59
1960	180.7	52.8	65.8	51.3				3.42	2.75	3.52	1.03	1.25	1.28
1965	194.3	57.3	71.1	57.6				3.39	2.73	3.37	0.99	1.24	1.23
1970	204.9	63.4	78.6	64.0				3.23	2.61	3.20	0.99	1.24	1.23
1975	213.9	70.8	87.4	72.7				3.02	2.45	3.02	0.97	1.23	1.20
1980	224.1	77.0	95.8	81.4				2.91	2.34	2.75	0.95	1.24	1.18

TABLE 5

APPLIANCE SATURATIONS AND CONTRIBUTIONS TO ANNUAL AVERAGE RESIDENTIAL USE NASHVILLE

Appliance	Fiscal Year 1973 Saturation	Fiscal Year 1973 Avg. Use of Appliance	Fiscal Year 1973 Contribution to Annual Avg. Use	Fiscal Year 1983 Saturation	Fiscal Year 1983 Avg. Use of Appliance	Fiscal Year 1983 Contribution to Annual Avg. Use
Lighting	100	1,070	1,070	100	1,250	1,250
Television	99	400	396	99	400	396
Refrigerator	99	1,160	1,148	99	1,675	1,658
Range	89	1,350	1,202	93	1,350	1,256
Water heater	78	5,400	4,212	82	5,870	4,813
Washer	64	100	64	62	100	62
Air conditioning	82	3,342	2,740	90	3,528	3,175
Freezer	30	1,040	312	36	1,165	419
Dryer	47	1,395	656	59	1,515	894
Electric heat	58	10,400	6,032	65	10,000	6,500
Dishwasher	25	350	88	38	385	146
Other			1,357			2,600
Average use - kWh			19,277			23,169
Average customers (thousands)			162.5			210.8
Energy use (millions kWh)			3,131.9			4,884.0

FIGURE 6
RESIDENTIAL SALES WITH FORECAST

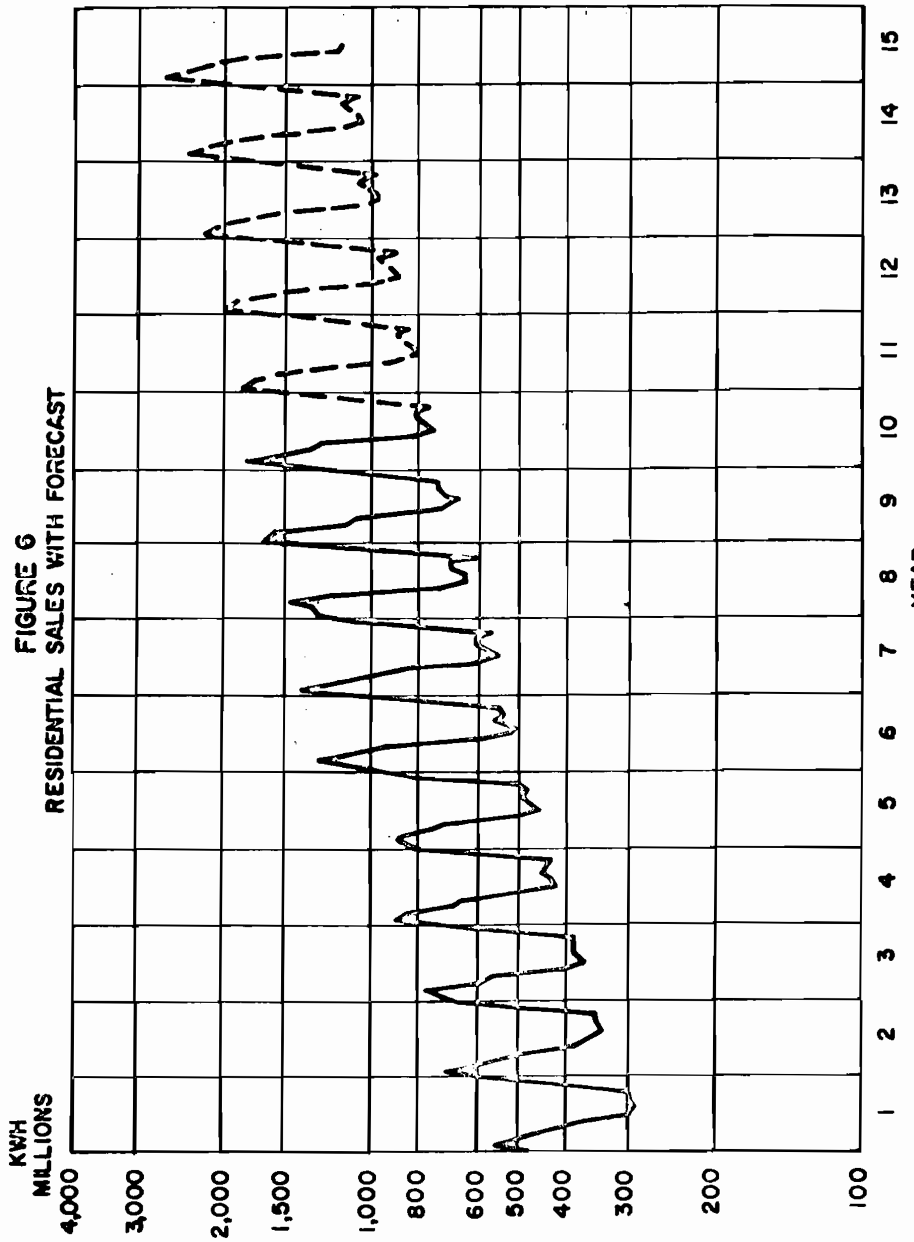
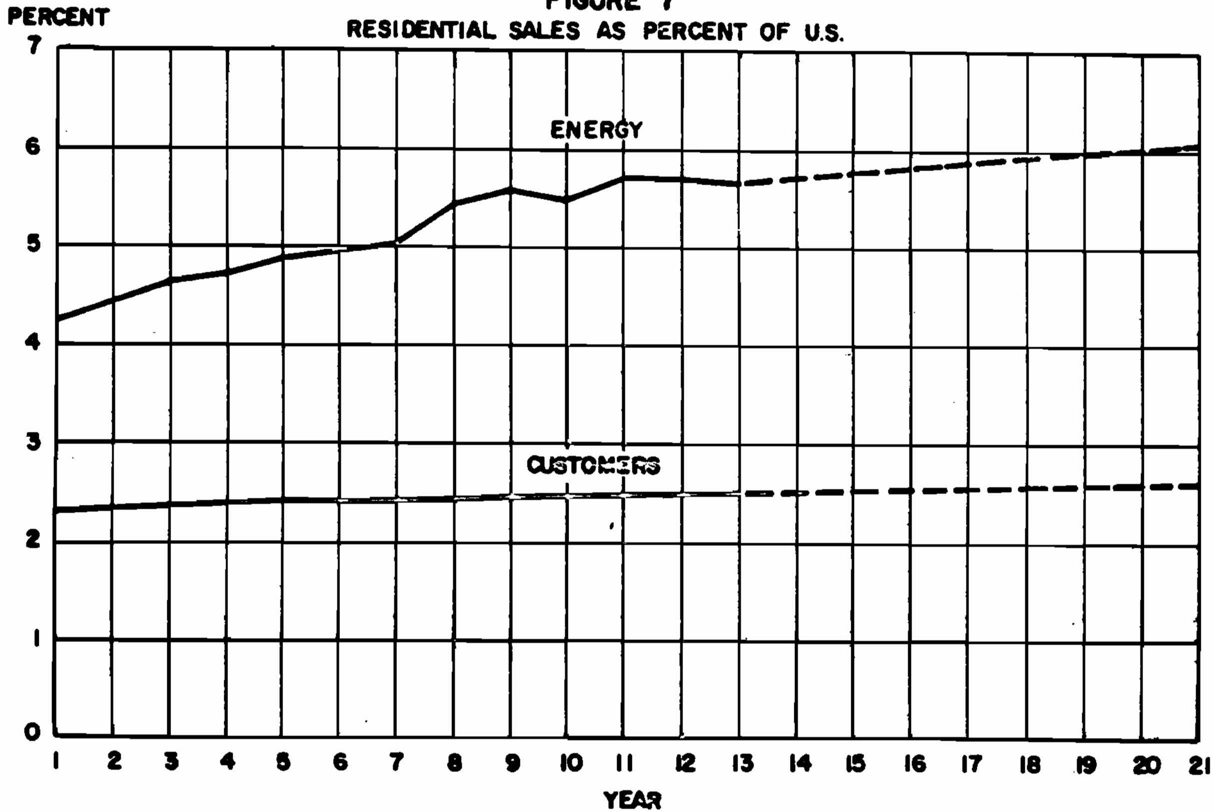


FIGURE 7
RESIDENTIAL SALES AS PERCENT OF U.S.



IIASA DISCUSSION PAPER

J.-P. Charpentier

This morning I plan to raise only five questions in relation to the paper describing how the TVA forecasts its load curves.

1. The first question deals with the estimiation of the long term demand. The paper mentions that the two main methods used by the TVA are extrapolation and correlation. In my opinion methods based on past trends can be used only for a certain length of time; for what length of time can this kind of technique remain reasonably available? Do you use any normative technique for your long range forecast?

2. My second question is related to the evolution of the place occupied by the nuclear plants within the annual load curve. More precisely: when do you expect the nuclear plants to shift from the base-load of the annual diagram? Do you plan to couple gas-turbines with nuclear plants in order to supply the peak period?

3. My third quesion is similar to the second. Do you plan in future to supply hydrogen by using the electrolysis technique during the peak period in order to get a smooth load curve?

4. Could you give us more information on the factors that influence the industrial development mentioned on the sixth page of the report.

5. Finally, I would like to get some information concerning the saturation level for household appliances in the TVA area. Similarly, what do you know about the possible future introduction of electricity in the different industrial processes?

TVA RESPONSE TO QUESTIONS BY J.-P. CHARPENTIER

1. Extrapolation of historical trends supported by correlation methods and judgement can produce sufficiently reliable forecasts for planning purposes up to about 10 years in the future. The reliability of a forecast produced by the extrapolation of historical trends or by any other method 10 to 25 years into the future is questionable. The long-term forecast beyond 10 years in the future is an extrapolation of the 10 year forecast. The forecast is based on historical data that has been normalized for deviation of weather from normal and for peak shaving.

2. TVA plans at present to base-load nuclear plants. A change in this philosophy would depend on several factors--new technology, fuel cost, retirements of existing units, changes in load factor, effects of load management, etc. Gas turbines will be used only for peaking and then as a last resort because of fuel cost and availabilty.

3. TVA has under study several load management plans. However, for the very near future it does not appear that hydrogen supply by the electrolysis technique is applicable in the TVA system.

4. The following are some of the factors that influence service area industrial development:

   a) Reliable source of electricity and other energy forms;

   b) Price of electricity competitive with that of other areas and other sources of energy;

   c) Availability of reasonably priced land suitable for industrial development;

   d) Favorable tax structure, relative to other geographical areas;

   e) A developed transportation system, railroad, waterways, and highways;

   f) Proximity to raw materials and markets;

   g) Ample supply of water for industry;

   h) Ample labor force, skilled and unskilled;

   i) Governmental and other industrial development groups within the area actively seeking new industry for the area.

5. The following are the saturations of the appliances that are major users of electricity for fiscal year 1974:

Appliance	Saturation - %
Air conditioner	61
Clothes dryer	43
Clothes washer	74
Dishwasher	22
Electric heat	42
Electric range	79
Freezer	45
Lighting	100
Refrigerator	99
Television	97
Water heater	71

We have no information on possible future uses of electricity in different industrial processes except those discussed in trade publications. We have recently conducted a survey of large directly served industrial customers, during which we inquired into the possible substitution of electricity for other source of energy. Representatives of large electricity intensive industries indicated that, while this was technically possible in many cases, they had no plans to convert to electricity at this time. For smaller industries and larger commercial consumers, the potential for the use of electricity supply, is great. It is anticipated that a significant increase in the use of electricity by such customers will occur. In many instances electricity has already replaced other energy forms in the production of steam, space heating, water heating, and cooking.

POWER GENERATION ADDITIONS MODEL

Introduction

The present TVA power system began in 1933 with one main river hydro project and one steam plant, both at the same location. However, the steam plant was not operated as a part of its system until 1939. The first integrated operation began with the completion of the first tributary project in 1936 which was then coordinated with the operation of the acquired main river project. The system was operated solely as a hydro system during the following 3 years in which three hydro projects were added. In 1939 these became a part of the integrated system operation with the acquisition of the Tennessee Electric Power Company.

In the first two decades after 1941, power supplied by the Tennessee Valley Authority more than tripled in each decade, then exceeding a 6 million kilowatt growth in the decade from 1961 to 1971.

The guiding principle in adding capacity to meet this extraordinary growth in demand has been to provide electricity to the consumer at the lowest possible cost. Figure 1 depicts this historical growth of generating capacity on the TVA system.

The development of a large proportion of electric heating and air conditioning loads has been a major factor in the rapid load growth in the TVA system.

Twenty years ago TVA system capacity totaled 3 million kW, consisting of approximately 85 percent from hydro and 15 percent from coal-fired, steam-electric units.

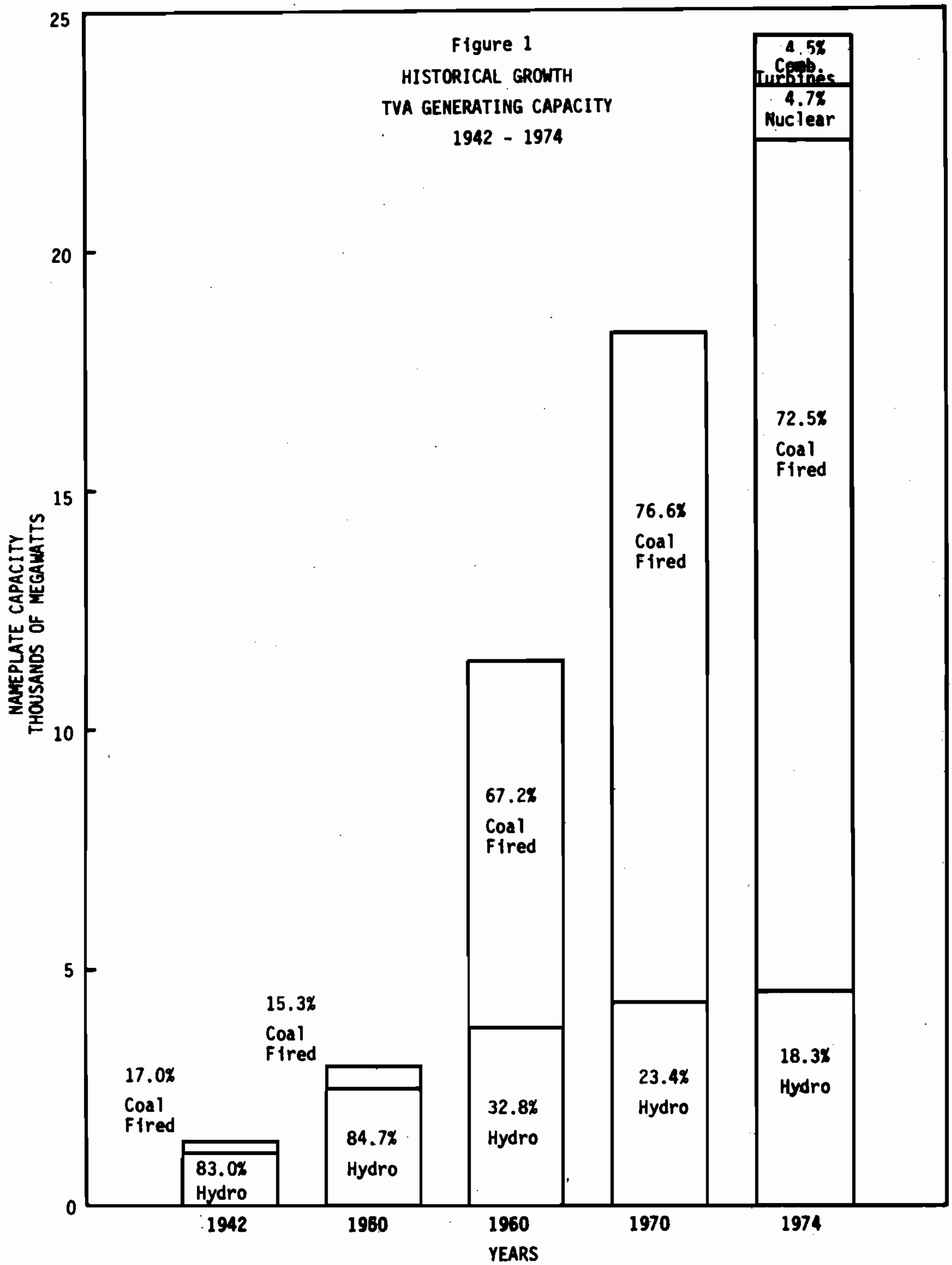


Figure 1
HISTORICAL GROWTH
TVA GENERATING CAPACITY
1942 - 1974
NAMEPLATE CAPACITY
THOUSANDS OF MEGAWATTS
25
20
15
10
5
0
17.0%
Coal
Fired
83.0%
Hydro
15.3%
Coal
Fired
84.7%
Hydro
67.2%
Coal
Fired
32.8%
Hydro
76.6%
Coal
Fired
23.4%
Hydro
4.5%
Comb.
Turbines
4.7%
Nuclear
72.5%
Coal
Fired
18.3%
Hydro
1942
1950
1960
1970
1974
YEARS

The power system currently operated by TVA consists of approximately 23.4 million kW. This is made of 4.5 million kW of hydro, 17.8 million kW of coal-fired steam, and 1.1 million kW of combustion turbines. Under construction or authorized there are approximately 15.1 million kW of nuclear, 1.2 million kW of combustion turbines, and 1.5 million kW of hydro pumped-storage in the period 1974-1982. TVA has in commercial operation its first nuclear unit, a 1,152-MW nuclear unit. This unit is a General Electric boiling water reactor. To our knowledge it is the first nuclear unit to produce in excess of 1,000 MW electrical. At the Browns Ferry Nuclear Plant a second unit of the same size is scheduled for late 1974 and a third unit for late 1975.

In the early days the planning of expansion policies to supply this demand required the consideration of a relatively small number of options. The planner had to choose between hydroelectric and thermal additions. The fuel was very clearly defined and the major decision involved the capacity of new units. Generating units were steadily improving in efficiency, and the planner normally specified an expansion using base-loaded units, loading these newer, more efficient units first. Planners were concerned with size, timing, and determination of special features that should be added to the thermal unit.

The planner would generate a limited number of competitive expansion plans and calculate the cash flow associated with each plan. Even though the alternatives examined were limited, the study required many hours of the planner's time.

With the rapid growth and complexity of the TVA system and the emergence of the digital computer for solution of power planning problems, early pioneers in system planning realized the need for more sophisticated techniques for utility expansion. The types of available generation capacity have multiplied and the choice of alternatives has become more complicated because the assumption that new capacity should be base-loaded is no longer valid. Nuclear, gas turbine, combined-cycle, base or intermediate fossil, hydroelectric, and pumped-storage units must now be considered as possible expansion schemes. TVA early recognized that application of probability methods to system planning problems using high-speed digital computers was the only way that some of the many complex problems could be answered. Factors such as forced outages on generating units, daily and seasonal load change, maintenance outages, uncertainties of load forecast, river flow for hydro capacity, interconnections, and interruptible power all affect the planning for the future TVA power system and, for the most part, can only be analyzed with the use of probability techniques.

Briefly it can be stated that generation planners are concerned with the following basic determinations:

1. How much capacity.
2. When.
3. Type.
4. Capital and operating cost.

TVA has made a concerted effort to utilize the latest techniques consistent with the state-of-the-art. Therefore, the following discussion will first discuss the models for determining "how much and when," that is, reserve requirements for reliability, and secondly the mix of generating capacity for minimum capital and operating cost.

Capacity Determination - Reliability

Several methods--such as the loss of load method, loss of energy method, frequency and duration method, and Westinghouse power costing method--have been developed over the last several years to measure the reliability of a power system. Most power companies using probability techniques use one or more of these methods or some variation thereof.

TVA has concentrated most of its efforts in the application of the loss of load probability method adapted to the characteristics of the TVA system. Although the loss of load method is TVA's basic model, the loss of energy method and the frequency and duration method are used as supplementary models for checks and special applications. However, we will limit our discussion to the basic concepts of the loss of load method and TVA's application to generation expansion.

The application of the loss of load method involves two submodels, the capacity and the load submodels.

A detailed study of the power supply which serves the system is essential in order to apply the loss of load method. Therefore, a capacity model is a means of quantitatively expressing the degree of unreliability in this supply due to the fact that each of the generating units which make up the supply is subject to failure. Therefore, it is desirable to have a detailed and adequate forced outage history of each generating unit on the system. From the outage history a determination of the forced outage rate for each unit may be determined by the following equation:

$$\text{Forced Outage Rate} = \frac{\text{Time on Forced Outage}}{\text{Time on Forced Outage + Time Operated}}$$

Probability methods make it possible to compute the overall source reliability from the forced outage rate of each generating unit which comprises the system supply. Basically the capacity model is a cumulative probability table reflecting the probabilities that the capacity will be available to serve the projected load. Such a table is developed by taking each individual unit's capacity and forced outage rate in all combinations with each other unit on the system. Figure 2 is a simple illustration of a capacity model for a 2-unit, 200-MW system with the indicated forced outage rates. On the TVA system this represents some 2.5×10^{27} combinations. This is clearly an indication of the requirements for a high-speed digital computer.

In TVA the hydro system is rather unique in that power system operators do not control the level of the hydro reservoir. The reservoir levels are controlled by the flood control and navigation phase of the TVA operation. We introduce the hydro capacity in the capacity submodel as a block of dependable capacity which is considered to be 100-percent available capacity. The dependable hydro capacity is the capacity obtained from the hydro system with the storage reservoirs at 10-percent full plus the capacity of the main river projects. We do not consider the hydro system on a unit-by-unit basis because the forced outage rates on the hydro units are so small as compared to the thermal units and because the effect upon reliability of the power supply is negligible.

CAPACITY MODEL

Figure 2

UNITS IN GENERATING SYSTEM

Unit	Capability MW	Forced Outage Rate	Inage Rate
1	100	.02	.98
2	100	.03	.97

EXACT OUTAGE PROBABILITY

On Outage			
Unit	MW	In Service	Probability
None	0	1, 2	.98 x .97 = .9506
1 or 2	100	1 or 2	.02 x .97 + .03 x .98 = .0488
1, 2	200	None	.03 x .02 = .0006

CUMULATIVE OUTAGE PROBABILITY

X MW	Probability of X MW or Greater
0	1.0000
100	.0494
200	.0006

After development of the capacity submodel the next step then is to combine the probabilities of existence of forced outages with the probabilistic nature of the system load.

System load requirements can be predicted for several years hence; however, the magnitude of the load depends upon several factors or variables. Some of these are:

1. Customer load growth.
2. Business trends.
3. Weather conditions.

Uncertainties in these factors must be recognized in the development of the load submodel. System planning engineers must plan for adequate capacity to meet the uncertainties of load forecast as well as the predicted load forecast.

Since no predicted load is a certainty but rather a function of its probability of occurrence, it is necessary that we have the best information that can be obtained on probable range of forecast load and associated probabilities of occurrence. This information is normally presented as a probable forecast error for a particular load forecast.

It would be desirable to have forecast error curves for every month of the year due to the variability of the weather from winter to summer. We realize that this is a difficult and time-consuming job to accomplish for several years in the future; therefore, we normally settle for a seasonal forecast error curve, say, one for each summer, spring-fall, and winter period where capacity must be planned.

In the development of the load submodel it is necessary to forecast each daily peak load for the month, year, or whatever period to be analyzed. Normally we look at weekday peaks only in the loss of load method and exclude weekends and holidays. This can best be accomplished through the use of monthly daily peak diversity patterns as percent of monthly peak for the weather sensitive loads. The monthly pattern may be developed from a statistical analysis of historical data and projection of trends. In TVA the monthly loads for the Federal agencies--those for the Space Program, Air Force Research Program, Atomic Energy Program, etc., and the large industrial customers--are normally assumed to be 100-percent load factor throughout the month. The representative daily peak loads for any month are determined by the following expression:

$$\text{Daily Peak} = \left(\frac{\text{Percent}}{100} \times \text{Distributor Monthly Peak}\right) + \text{Directly Served Customers}$$

Where: Percent is taken from the daily peak diversity pattern in percent of monthly peak, the distribution monthly peak is the sum of all of the weather sensitive loads that the system is forecasted to serve per month, and the directly served customers is the total industrial and Federal agency load from the forecasted monthly load estimate.

The next step in the planning process is the calculation of the loss of load probability. For any determined daily peak load any capacity outages which are equal to or less than the system reserve will produce no loss of load. The contribution to the system loss of load probability, therefore, is made by capacity outages of greater magnitude than the system reserve. The summation of the probability of existence of all outages greater than reserve multiplied by one day is the contribution made by the particular daily peak load being analyzed to the system loss of load probability for the period being analyzed. However, this is only part of the story for a daily peak load. Since the occurrence of a particular load is not a certainty, it must be weighed by the probability of occurrence of a load of that magnitude which is taken from the forecast error curve.

Actually each daily peak load is extended through the entire forecast error range; and, for each probable load level, the probability of occurrence is multiplied by the contribution to the loss of load associated with each probable load level. The summation of the incremental contributions throughout the forecast error range will be the total contribution to the loss of load for each day which includes the uncertainties of load forecast.

When all of the daily peaks in a month have been analyzed, the summation of the contributions made by each of the daily peak loads, including their forecast accuracy range, represents the loss of load for that month. A yearly value can be obtained by summing the 12 monthly quantities thus determined.

No numerical calculations can alone establish a satisfactory level of system reliability or determine a proper value for the index of system reliability. Therefore, an index of reliability must be selected. TVA, as most other utilities, has adopted an index of reliability of one day in ten years. The significance of this index is that TVA's planning is based on the criteria that one day in ten years the load will exceed the installed generating capacity. The selection of a satisfactory level of reliability or a corresponding index which will be appropriate to any method of measurement will require at some point the exercise of informed judgment.

Once a level of system reliability is acceptable to system planners and management, it can be fixed arbitrarily. A basis for comparison or, in other words, a risk level is now established. System planners can now, with the established index of reliability, make a consistent measurement of the effect on system capacity requirements of:

1. Larger unit sizes.
2. Variability of forced outage rates.
3. Maintenance requirements and scheduling.
4. Change in load characteristics.
5. Interconnections and interchange.
6. Uncertainties of load forecasts.

In TVA we have established a monthly risk level which we use in our probability planning studies. This is based upon the annual peak months' contribution to an annual risk level of 0.1 day per year (a 1-day-in-10-year loss of load probability).

TVA is a winter peaking system. But contiguous utilities to the south, west, and northwest are summer peaking systems. As a result of this inherent diversity in loads between TVA and these utilities, diversity interchange contracts were executed for capacity savings. TVA receives 2,060 MW during its winter peak period and then transmits 2,060 MW to the other utilities during the summer peak period. When we began our studies on the interchange of large blocks of capacity with our neighboring utilities, it became apparent that an annual loss of load study using one day in ten years as a criteria for system reliability was inadequate to plan the system, primarily because of the change in the annual load shape. As a result of this, we developed what we call the monthly constant risk method of probability planning.

The philosophy of this method is that if we are willing to maintain a certain risk level, which is theoretically the month in which our annual peak occurs, then we should be willing to maintain this same risk level in any other month in the year. We determined a numerical value for this risk level by finding January's contribution to an annual loss of load of 0.1 day per year (one day in ten years). With an established monthly risk level or index of reliability it is now possible to determine for each month the following information.

1. The monthly load carrying ability of a system of capacity at the desired risk level.
2. The reserve required to protect against multiple forced outages and the uncertainties of load forecast for any month.
3. The margin between load obligations plus reserve and system capacity in which maintenance, contract interchange, and additional sales can be fitted.
4. The deficit of capacity in those months where there is not adequate capacity to meet the load plus reserve requirements.

This is accomplished with the use of a computer program which will compare the loss of load for the particular month studied (we discussed the calculation of loss of load in the load model) to the monthly index of reliability. Basically the computer program performs the following operation. If the loss of load is greater than the index of reliability, each daily peak in the month will be reduced in 5-MW incremental steps until the load plus reserve and capacity relationship is in balance within the limits of the index of reliability through an iterative process. Conversely, if the loss of load is less than the index, each daily peak in the month will be increased in 5-MW incremental steps until the system is in balance. The final results of this iterative process will be an indication of the monthly margin or the deficit of capacity in each month.

System maintenance is a problem to any utility that applies probability techniques to power supply planning problems. The magnitude of the problem is a function of the size and the complexity of the system. There are several methods of approach to this problem.

One method is to develop a maintenance schedule for each unit on the system and reduce the capacity available to serve the load requirements by the units scheduled for maintenance. This is done by dividing the year into maintenance intervals and determining the probable loss of load for each interval based on the available system capacity. This method is particularly adaptable to a small-sized system with a fixed maintenance policy. We have tried this method on the TVA system, but its size and the complexity of our maintenance policy makes long-range maintenance scheduling 10 to 20 years in the future an unwieldy task. Another consideration in using this method is the large amount of computer time involved in developing a new probability table of reliability of the power supply for each maintenance interval.

Another method would be to add the total capacity of the units out for scheduled maintenance to the daily peak loads affected in each maintenance interval and then consider all units that make up the system supply to be operating or on forced outage as far as the loss of load calculation is concerned. It is recognized that this introduces a small inherent error into the problem in that a unit will be considered as operating when it might actually be on scheduled maintenance; however, the overall effect will be negligible. Here again, this method would involve long-range unit-by-unit maintenance scheduling.

The method that we are now using with the monthly constant risk program is to maintain the system in the marginal area between the load plus reserve requirements and the system capacity on a megawatt-month basis. From actual experience we know the number of maintenance days that each unit on the system should be maintained, and on future units we can estimate the maintenance days required. We can then convert this to total system megawatt-months of maintenance required for a time period, normally a year. We then fit the megawatt-months of maintenance requirements into the megawatt-months of marginal room in each month as calculated by the constant risk program. By using this method it is not necessary to try to guess at long-range maintenance schedules, add maintenances to the daily peak loads, or reflect maintenance outages in the capacity probability tables as far as computer probability planning program is concerned.

In addition to firm power sales, TVA executes power contracts with industrial customers for limited amounts of interruptible power. This type of power contract gives TVA the right to interrupt these loads on a 5-minute notice within specified constraints, such as to the number of interruptions per day, of hours per interruption, of hours per day and month, and for a total interruption of 2.5 or 3.0 percent of the time in a 10-year contract period.

Our present thinking on the use of interruption rights in probability studies is that interruptible power will be used to substitute for a portion of the reserve that would otherwise be needed to protect the system against the uncertainties of load forecast and still maintain a fixed system reliability. The use of interruptible power for this purpose is not on a megawatt-for-megawatt basis; i.e., the calculated system reserve requirements are not reduced megawatt-for-megawatt by the amount of interruptible power. Instead, the use of interruptible power is based upon the probable need of usage which in turn is based upon the probability that the load forecast will be higher than estimated due to adverse weather conditions. To reiterate our use of interruptible power, whenever the winter temperature gets colder than normal, interruptible power will be used to substitute for a portion of the increase in system demand due to the lower temperature limits. The use of interruptible power then is a function of the probability of occurrence of temperatures in the lower range and is weighed by the probability of the need.

Production Costing - Determination of Types of Capacity, Cost of Alternatives, and Operating Characteristics of the Future System

In addition to determining the magnitude and timing of future generation expansion from a reliability point of view, there is a consideration of types, costs, and operating characteristics of the proposed expansion.

Here again, the uncertainties associated with reliability also are factors in determining the operating cost.

TVA uses a probabilistic simulation technique in the production costing studies. The method in use is based on a technique developed by Dr. R. R. Booth of the State Electricity Commission of Victoria, Australia. Briefly, the method determines the system operating cost by considering the probabilities that the generating sources and the load have inherent uncertainties.

For example, the magnitude of loads and their pattern through time are roughly known, although there will be a significant uncertainty in the figures. After all, who can predict the weather, living habits, the actions of Government leaders, etc.?

To meet these loads we have on any system a mix of generating plants, old and new, large and small, cheap and costly to operate, some more reliable than others, and even some with more environmental problems than others.

These plants use fuel--water, oil, gas, uranium, and coal of different grades, cost, and combustion quality. The cost of these fuels or their availabilities may or may not be known.

The planner will take these plans and put them together to supply the load at any point in time at the lowest cost that it is possible to obtain. Therefore, the problem at hand is to model all of this and to estimate how much energy each plant will produce, when, and for how much.

Briefly, the probabilistic simulation determines the system operating cost, capacity factors, the energy produced, the energy not served, and other pertinent information useful in planning, while considering the probabilities associated with the availabilities of the generating sources.

Unfortunately the energy production capability depends on the availability and sometimes the energy that will be produced from any low-cost plants and thus be inexpensive, but sometimes will need to be produced from some high-cost plant and be very expensive. Thus the actual energy production will be obtained by many varied periods of time operating with increments of energy being produced at varying costs.

Also, the load curve shape and magnitude will vary and, while this will not affect the low-cost plants much, it will have quite an effect on the energy output and the costs of the high-cost plants. We model this by saying that there are many curves of costs versus energy depending on this variation. The total system cost is the sum of the individual costs times the period of time.

A complete description of Dr. Booth's technique of probabilistic simulation is a subject for another time. However, it is documented in the reference included in this paper.[1]

Briefly the method is as follows. First, for whatever period we desire, say a week, let's describe the load by a diagram showing load level against the chance of it occurring (Figure 3). In other words, develop a distribution curve of probability versus load in megawatts. The area will equal unity since all possible loads are included. Such a curve will normally combine two features:

Figure 3

LOAD DISTRIBUTION

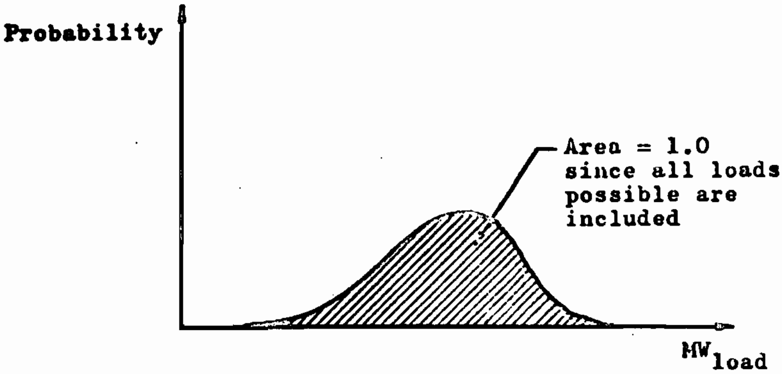
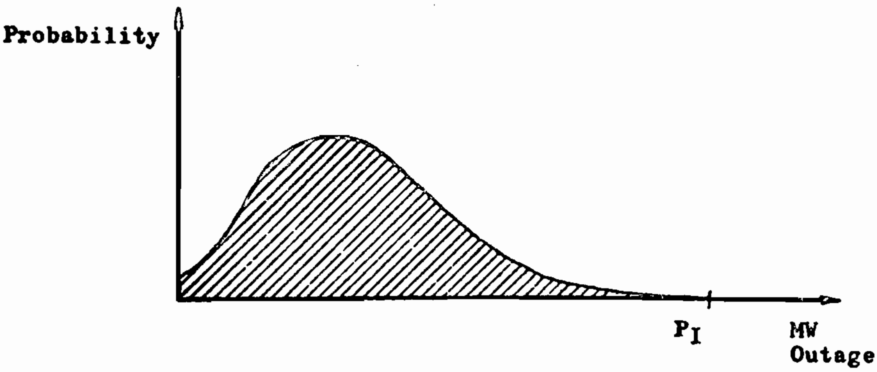


Figure 4

OUTAGE DISTRIBUTION



1. The variation of load level throughout the hours of the week, i.e., information normally given in load duration form.
2. The error in predicting the loads due to forecast error on weather variation or whatever else that has an effect. Thus, this technique applies load forecast error to production costing studies.

At the same time, we can build up systematically (and tear down, if necessary) the probability distribution for megawatt of plant on outage versus the probability of occurrence and obtain a second diagram (Figure 4).

One ordinarilly considers the load on a system as being served by the total installed capacity minus that capacity which is on outage.

An alternative but equally correct approach is to think of the machines on outage as supplying their rated capacity to a system but at the same time imposing a load exactly equal to their rated capacity. This approach allows us to define an equivalent load (Pe).

With this definition of load, all machines on the system whether on outage or not contribute to the supply. We now seek the probability of getting a given megawatt level of equivalent load. The formal process of calculating the form of the total probability distribution for the equivalent load is called convolution.

If we therefore convolve the distribution for load and for capacity on outage, we now obtain a new distribution for the equivalent load (Pe). It will stretch roughly to twice the capacity of the system. Thus, we have determined a graph which is essentially a distribution curve with megawatt of equivalent load versus probability of occurrence (Figure 5).

If we progressively sum the probabilities from the right to left in this diagram, we may develop still another diagram (Figure 6) depicting the probabilities of getting equivalent loads greater than this level (this is termed a cumulative probability distribution) and since the area under the original equivalent load distribution was one, the cumulative distribution looks like the conventional load duration curve with equivalent load versus the probability of occurrence.

This new curve represents the chance of getting a combination of loads plus capacity on outage greater than the installed capacity. Thus the curve is representative of the conventional probability of loss of load that has been used for reliability calculations for some time.

Also, the area underneath the distributions from the installed capacity upwards (Area A) is proportional to energy (MW x probability x hours in period) and represents the energy not served.

The real significance of this method developed by Dr. Booth and used by TVA is as follows. Visualize that in the system there is one plant which is perfectly reliable and that this plant is removed. The inclusion of that plant in the probability distribution for capacity on outage would not have altered the distribution at all. Thus the convolved distribution would be the same, and all that has been changed is that the installed capacity has been reduced by the capacity of the plant.

If the plant has an availability other than unity, the distribution of the plant on outage will be different (so will the convolved distribution), and we should really recalculate the model. Fortunately we do not have

Figure 5

EQUIVALENT LOAD DISTRIBUTION

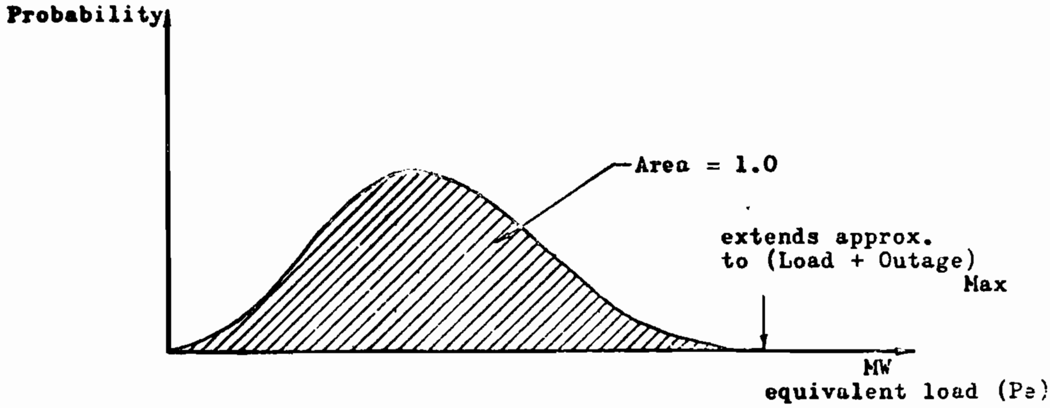
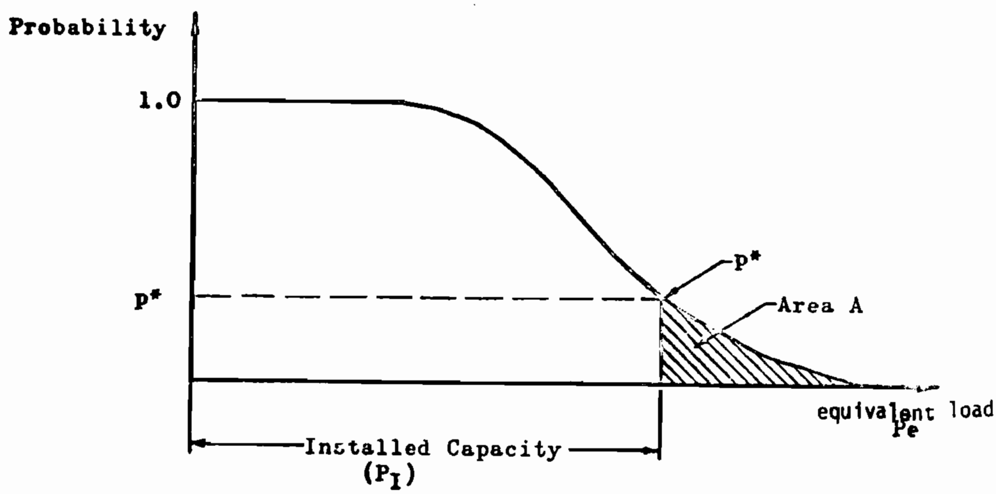


Figure 6

CUMULATIVE DISTRIBUTION



p* is the probability which represents the chance of getting a combination of loads plus capacity on outage greater than the installed capacity.

to do this. Since we built up the distribution for the capacity on outage, we can remove one plant simply by reversing the recursive process; thus we do not need to reconstruct the whole distribution, but only modify it.

In reality we have only scratched the surface in describing the probabilistic simulation technique to production costing on the TVA system, but in summary we can say that the probabilistic simulation can be used in production costing studies to consider the effects of forced outages and random variations in load curves in a consistent manner more effectively than any other method devised. Too, it is fast and economical of computer time and storage, respectively. The output of the production costing method is the expectation of the energy output from each plant (the variance of that energy output), the fuel requirements and cost of operation of each plant, and thence the total cost of operation. We are also provided with the loss of load probability and the expectation of energy that we are unable to supply, thus providing information on system reliability in addition to system cost and operation.

Also, the procedure is extremely flexible. Our only dependence upon time is a period over which the distribution of loads and plant availabilities remain valid. We can simulate any period of time that we desire--as small as 1 hour to as long as 10, 15, or 20 years in the future. The choice is ours.

Now there are some disadvantages to this technique. One of the things that we have given up is the ability to represent things that happen in sequence. The distribution of loads is quite impersonal and each load is not related to any other load. So we cannot explicitly represent unit startup and shutdown, minimum shutdown time restrictions, rates of loading, nor can we keep track of hydro and pumped-storage limits within each simulation. But the importance of things that we can represent far outweighs the importance of those that we cannot represent.

Additional Planning Program

The two models discussed thus far are TVA's generation planning models. However, there are several others that are used in production to supplement the basic planning programs or are being used in conjunction with the basic models to determine that the techniques are suitable for future use.

For example, TVA is now using a system analysis generation expansion model (SAGE) which essentially does the same as the previously described models. But the programs have not been used sufficiently to rely upon them as basic planning models at this time. This model was developed by TVA as a forerunner to the WASP package which was developed for the needs of the IAEA market survey for nuclear power in developing countries. Both of these models use Dr. Booth's probabilistic simulation techniques.

As it was stated earlier, one disadvantage of the probabilistic simulation production costing technique is that it does not indicate those events that occur in sequence. Thus, another model using the probabilistics simulation technique is currently in the early production testing period to be used in studies for weekly or monthly time periods taking the events in sequence as they occur.

Then, in addition to these generation expansion programs, there are the nuclear fuel planning models which also provide significant functions in the overall generation expansion programs in the TVA system.

One model, a Monte Carlo simulation, is used for studying contracting and pool strategies for enrichment services. This model includes provisions for treating economic penalties associated with cancellation, transactional tails assay adjustment, and carrying inventory. The model simulates the operation of the individual reactors over the study period and uses the result to test and evaluate various options.

Another model used in TVA's nuclear expansion represents the economics of a nuclear power reactor.

Too, we have found it necessary to develop a model to optimally schedule nuclear refueling outages while considering the total operating constraints.

Reference

1. R. R. Booth, "Optimal Generation Planning Considering Uncertainty," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-91, No. 1, pp. 70-77 (January-February 1972).

IIASA DISCUSSION PAPER

J. Gros

I was pleased to be asked to review this paper because of my previous and my present work on the siting of nuclear facilities. Also, it was a special pleasure because the TVA is a recognized leader of the electric utility industry of the United States.

I had one small disappointment, though, with the paper. The choice of what type of power generation additions is optimal depends on more than just monetary costs and reliability, but the described analysis does not include more than these two issues. For example fuel availability and security of supply, construction time and accuracy of predicting this time, public acceptance, whether sites are readily available for certain technologies, environmental factors, cost of borrowed money, all these are important issues in deciding on new additions types.

Let us look at some of these in more detail. The oil boycott of last year brought out very well the need for including the security of supply in decisions of large new generating additions. Here the question may be between domestic and foreign fuel, between domestic coal and imported oil. A lesson from that incident is that utilities should strive for a balance of fuels. As you brought out before, the inability to predict accurately the construction time of nuclear plants has been a problem plaguing the TVA system and other American electric systems. A unit whose construction time can be predicted accurately, is worth more than a unit whose construction time cannot be predicted as accurately. Has the TVA started using more advanced prediction techniques, such as forecasting a distribution of start up times instead of just one? And how are these construction delays priced?

Lack of public acceptance is another issue which can delay the commissioning of a power plant. Some technologies are much more acceptable than others, and this would have an impact on the case of obtaining regulatory approvals and building plants. I think the question of public acceptability must be included in a new additions model. The last issue, cost of borrowed money, may or may not have an effect on the TVA's choice decisions. For private utilities in the United States, the current interest rate certainly has an impact on the decision process. When interest rates are high, the private electric utilities favor the less capital intensive, higher operating cost choices. When interest rates are low, the opposite is true. My first question is how all these other issues are included in the optimal choice of generating technology decisions of the TVA.

I also have two technical questions. First, the equation for overall source reliability assumes an independence of probabilities of individual plant's forced outage rate when calculating overall source reliability. But this may not generally be the case, there may be dependencies between the probability. For instance, units with dry cooling towers are derated in warm weather. That means that all plants with such towers would be derated based on one common uncontrolled variable. A second common failure occurs when there are transients on the transmission networks. How are these dependencies included in your analysis?

A second technical question that I have concerns the basis of the index of reliability. Let me read from the text: "The significance of this index is that the TVA's planning is based on the criterion that one day in ten years the load will exceed the installed generating capacity. The selection of a satisfactory level of reliability or a corresponding index which will be appropriate to any method of measurement will require at some point the exercise of informed judgment." My question is, by what sort of analysis was the one day in 10 years criterion determined? One of the reasons for my question is that recent work has shown that this criterion may be too strict. For instance, a recent thesis by Mike Telson of the Massachusetts Institute of Technology has shown by a cost benefit analysis that one day in ten years should be made less severe.

I have two further questions:

1) How often are economically nonoptimum decisions made, for instance, for the reasons outlined above. In other words, if you do the analysis descirbed in the paper you end up with a clear cut decision. I suppose that often the actual decision is something different from that decision, and my question is how often and for what reasons are different decisions made?

2) How are experimental generating programs funded? For instance, the TVA is partially funding the LMFBR project, the liquid metal fast breeder reactor project. Is this funded as other generating projects would be, or is some special mechanism set up for this experimental program?

Now, I would like to take this opportunity to introduce you to the related work of the International Institute for Applied Systems Analysis. I am a member of a project that is interested in the problem of siting of nuclear facilities from a political decision-making viewpoint. Our analysis considers the several interest groups that influence the decision-making process. In the United States, these groups include electric utilities, regulatory agencies, environmentalists, local interest, and consumers. The type of analysis we will be doing is often referred to as Paretian environmental analysis. What we try to do is to find the set of decisions from which it is not possible to increase the benefits to one interest group without decreasing the benefits to another group.

As I mentioned before, the benefits from a siting decision involve several objectives. Therefore, in our analysis, we will have to find multiobjective functions which describe each group preferences. A major question is how to obtain such a function. Our solution is to assess a utility function for each interest group.

A third area in which we will be doing work is in the area of conflict resolution. Here the question is, if you are building a plant, how can the benefit be divided up with equity? Another project worth mentioning is the joint IAEA-IIASA project risk analysis. Here, the work is to determine the acceptability of risks of the nuclear fuel cycle.

TVA RESPONSE TO IIASA DISCUSSION PAPER

We agree that the choice of type of power generation additions that is optimal is dependent on more than economics and reliability. However, the paper presented by the TVA, "Power Generation Additions Model," was intended for discussion of two basic models used by TVA for generation planning. A discussion of all the models used by TVA in the total planning process would have been impractical in the time allotted. Because of the TVA's size, the various planning functions are performed by several respective organizational groups which effect close coordination in the overall development of an optimal decision for additional capacity. In this coordination, factors other than economics and reliability, such as money cost and effect on rates, transmission, social acceptability, environment, siting, and design are given the appropriate consideration. TVA now has a task force which has the responsibility for developing an integrated planning model for automating and updating the total planning process.

The comment that a unit whose construction time can be predicted more accurately is worth more than a unit whose construction time cannot be predicted would not, in general, be a sound criterion for the TVA system. However, accuracy of schedule prediction is a consideration. But there are other factors such as capital cost, system requirements, availability of fuel, type of fuel, social acceptability, environment, siting, and money and production cost that must be considered.

Historically, the TVA has an enviable record for meeting construction schedules for coal-fired generation. Unit delays of nuclear construction has not been as good. But it must be recognized that nuclear construction is a new technology with a multiplicity of other causes for delays such as regulatory, environmental, labor, and material.

Prediction techniques, such as forecasting a distribution of startup times would require a probability technique using some form of historical data base. Since a data base of other utilities would not necessarily apply to the TVA and since the TVA does not have such a data base, we believe that other means are more appropriate. For example, through standardization, more design and construction experience, and an increase in the planning cycle to allow for intervention and regulatory changes, we believe that the current nuclear unit delays on the TVA system can be overcome.

In answer to your first technical question concerning dependencies among outages, dependencies can be, and are included in our planning studies. For instance, SO_2 alerts in the TVA area sometimes result in reduced generation at several plants simultaneously. For these outages, a system-wide approach is necessary which removes the entire block of affected capacity rather than simply removing one unit from the system model independently of all other outages.

In regard to your second technical question, the TVA has several reasons for the use of a one day in ten years index of reliability. First, one day in ten years is the criterion generally accepted by the power industry. Second, this criterion results in a system which, from practical past experience, is known to be of about the proper reliability. Third, the TVA is bound by contractual obligation to make its best effort to carry a firm load; consequently, the legal implications of having a less reliable system could be very serious for the TVA. Finally, a one-day-in-ten-years criterion does not mean that the load will be dropped for one twenty-four hour period every ten years; the distribution of the twenty-four hours is totally unknown and, if known, would be different for every system. Consequently, generalized results of a study on one system are not applicable to another system.

With regard to your question as to how often economically nonoptimum decisions are made, we believe that the TVA's total planning and decision-making process is sound. As we have previously stated, the total planning for new generation does not end with the basic models described in the subject paper.

In response to the question as to how experimental generation programs are funded, the TVA participates in experimental generating projects in a variety of ways, each being decided on the basis of future potentials. For example the TVA jointly participates financially along with other utilities in the LMFBR program through payments to the Breeder Reactor Corporation as financial agent for the participating utilities. In other research programs such as fuel cell, fusion, and solar, TVA participates financially to EPRI. Another example of joint participation is through the Office of Coal Research.

We appreciate your discussion of related work (at the Institute.) In time, we would like to know more about the progress of the systems that you are developing.

Transmission System Planning Model

Before attempting to synthesize a planning model of the TVA electric transmission system, a brief review of conditions and constraints which faced early TVA planners would be in order.

In 1933 the electric energy requirements of the seven Tennessee Valley area states were supplied by numerous private power companies and municipal systems. As would be expected, early electric power facilities were concentrated in the most heavily populated areas along the Tennessee River and its tributaries where a few small hydro generating facilities were located. In those areas where hydro power was not available or developed, many small steam and some internal combustion power plants were in operation. By virtue of the extremely low distribution voltages utilized (2.4 and 4.1 kV), customer service seldom extended beyond city and township limits; so that in 1933 only 3 percent of the farms in the Tennessee Valley area had electric service.

Most of the electric transmission and distribution facilities in the Valley area were under control of nine separate power companies with very few transmission ties between major load areas. This resulted in numerous isolated and segmented systems often with different operating voltage levels. Even for those towns linked with transmission lines, the ties were relatively long with extremely limited power transfer capability.

Following approval of the Tennessee Valley Authority Act in 1933, all of the Government-owned properties in the Muscle Shoals, Alabama, area were turned over to TVA. These facilities included the U.S. Nitrate Plant, Wilson Dam and Hydro Plant (187,000 kW), a small steam plant on the Wilson Dam reservation, and approximately 8.5 miles (13.7 km.) of transmission line in the 154-kV and 110-kV class. These facilities were constructed primarily to supply the local nitrate plant loads. Two short transmission lines were included in the transfer which connected to neighboring private utility systems and were used to transmit the surplus energy then being generated at Wilson Dam. These power sales were covered under existing governmental contracts.

In transferring these facilities to TVA, the Authority was charged by Congress with responsibility to distribute and sell the surplus power generated at Muscle Shoals equitably to states, counties, municipalities, corporations, partnerships, and individuals. However, primary benefits from this sale of power were to accrue to the people of the area as a whole and particularly the domestic and rural consumers to whom such service could economically be made available. As such, sale to and use by industry and other profit motivated users was relegated to secondary importance with the intent that these customers would be used to secure a sufficiently high load factor and provide revenue returns to permit domestic and rural use at the lowest possible rates. To accomplish these broad objectives, the TVA was given authority to (1) acquire existing private-owned electric power company facilities and (2) construct transmission and distribution lines to those areas that were within reasonable transmission distance and were not otherwise being supplied.

With the initial directive to concentrate on improving rural electric services, TVA engineers surveyed existing distribution facilities and construction practices. They were quickly convinced that more consistent and economical methods for extending distribution system facilities were required if widespread rural electrification was to be successful. Therefore, they began a special study of construction standards for rural electric service lines with particular emphasis upon the reduction of construction costs through simplification of structures. In general, the result of this study was the adoption of

7200/12,500 volt single or three-phase lines with a common neutral for rural service, using wood poles and high strength conductors with average spans ranging between 350 and 500 feet (107 and 152 meters). Straight line construction of the lines was maintained as far as practicable, using long spans to take full advantage of the physical characteristics of the conductors.

In conjunction with the distribution construction activities and to avoid duplication of facilities, TVA initiated a program of orderly acquisition of private power properties in the Tennessee Valley watershed area. Initially this acquisition phase was concentrated in the north Alabama and northeast Mississippi areas adjacent to the Muscle Shoals facility and in east Tennessee where TVA started its first hydroelectric project (Norris Dam). Through these early electric program activities, TVA built rural lines in selected areas, sold power at retail and wholesale, and temporarily operated several small rural distribution systems until they could be turned over to organized local groups. In addition TVA loaned money to municipalities and rural electric cooperatives for the construction of distribution lines and generally assisted in establishing rural electric cooperatives.

This early formation of rural electric power associations in the Tennessee Valley and the initial work on construction standards for rural transmission lines helped guide the way for the national program of rural electrification which was established in 1935.

During the year 1934, TVA forces constructed and placed in service 63 miles of transmission lines and acquired 84 miles (135 km.) of 44-kV and 33-kV lines from the Mississippi Power Company. This brought the system total to 156 miles (251 km.) in operation by the end of 1934.

By the first of the year 1936, interest in TVA power was growing at a rapid pace with numerous municipalities, cooperatives, and industries seeking power contracts with the Authority for serving their particular requirements.

Quite a few of these applicants were too far removed from the then existing transmission system for their applications to be approved intially. However, loads of sufficient volume to justify system extensions were contracted for in the Mississippi, west Tennessee, and middle Tennessee areas, and some of the necessary facilities for serving them were already under construction.

The acquisition program continued at a moderate rate through 1938 with an accumulated total of 469 miles (755 km.) in addition to 1,480 miles (2,382 km.) of new construction. In these early years the expansion of existing systems to provide new rural services was seriously slow and was primarily hampered by restraining lawsuits entered in behalf of private power companies contesting the constitutionality of the TVA Act. However, with favorable court rulings in TVA's behalf in January 1939, acquisitions took a major upturn and 2,077 miles (3,343 km.) of lines were transferred to the Authority that year. This one year's activity accounted for approximately 65 percent of the entire acquisition program which was essentially complete in 1947, reaching a total of 3,186 miles (5,127 km.).

Aside from the initial problems of rural electrification, TVA engineers were further faced with the perplexities of designing a transmission system involving three multipurpose hydro plants then in service or authorized and under construction (Wilson - 187,000 kW; Norris 100,400 kW; and Wheeler - 259,200 kW). Although Wilson and Wheeler Dams were to be located within 20 miles (32 km.) of each other on the Tennessee River, there was a distance of over 200 miles (320 km.) between Norris on the Clinch River and the other hydro plants. Also, between Norris and Wheeler, with the exception of several large cities and towns with concentrated loads, the area was primarily undeveloped or rural in nature. Since existing private power companies were operating in this area, the question of TVA developing and operating either a unified or a segmented transmission system was of major concern. It was recognized that the segmented system development would require less initial capital expenditures for transmission but would over the long term tend to perpetuate the many duplications of facilities then in existence along with attendant poor utilization factors and lost efficiencies; the net result of which ultimately would transfer as penalties to the individual power consumers. Therefore, the approach adopted for planning purposes was that all power facilities in the area, regardless of ownership, should be considered as under unified control constituting a complete power system for the territory. In the large measure, this philosophical approach to the transmission system problem has been followed through and gradually brought all such facilities into one integrated system.

With the concentrated upsurge of dam construction beginning in 1933 for flood control and navigation purposes and with the assurance of an abundant supply of electric power for the Valley from these multipurpose hydro facilities, the transmission system engineers were challenged to provide suitable line connections and transformer stations that would fulfill short and long range territorial needs. Although an abundance of generation facilitated the short range planning efforts, long range planning was hampered by the uncertainties of legal delays in the acquisition of private power facilities in the area and the soaring but unpredictable area load growth patterns. As such, initial plans were fairly limited in scope and logically provided connections from generating sources to known load centers and sufficient interties between generating sources or adjacent private utility systems to guarantee a reasonable degree of generating unit operating stability. This led to the first high voltage (154 kV) intrasystem tie lines being constructed between 1934 and 36, extending from Wilson Dam to Pickwick Dam (located approximately 44 miles

(71 km.) downstream from Wilson) and from Wheeler Dam to Norris Dam, a distance of 216 miles (348 km.). The first official map of the TVA transmission system was published in 1935 and is included as figure 1.

From this meager beginning the TVA transmission system has grown to its present significance as an integrated electric network of over 16,683 miles (26,848 km.) of high voltage transmission lines and 589 substations (exclusive of generating plant switchyards). In this chain of progression, the once major transmission system voltage of 110 kV has for all practical purposes been phased out in favor of the higher capacity 161-kV system voltage. Figure 2 depicts the present transmission system.

During this time there was a gradual change in emphasis in system planning from plans for optimum utilization of existing facilities to long range needs. As an example, for three decades the 161-kV voltage level served as the backbone of the network for economical transmission of bulk power deliveries. However, in the early 1960's long range studies of higher transmission voltages were undertaken to meet the challenge of supplying a system load which at that time was projected to double every ten years. This study recommended the establishment of a 500-kV level of transmission to augment and ultimately replace the 161-kV system for bulk transmission purposes. Culmination of this study was realized in 1965 when the first 500-kV transmission line was placed in service between Johnsonville Steam Plant and Memphis, Tennessee. This line, in addition to supplying a portion of the large energy requirements of the Memphis Light and Water Division, also interconnected with the South Central Electric Companies to the west, providing an interchange vehicle for emergency assistance, scheduled power sales, and diversity power exchanges. Since 1965 the 500-kV network has been expanded and now includes 1,530 miles (2,462 km.) of transmission and ten area substations in addition to six generating plant switchyards.

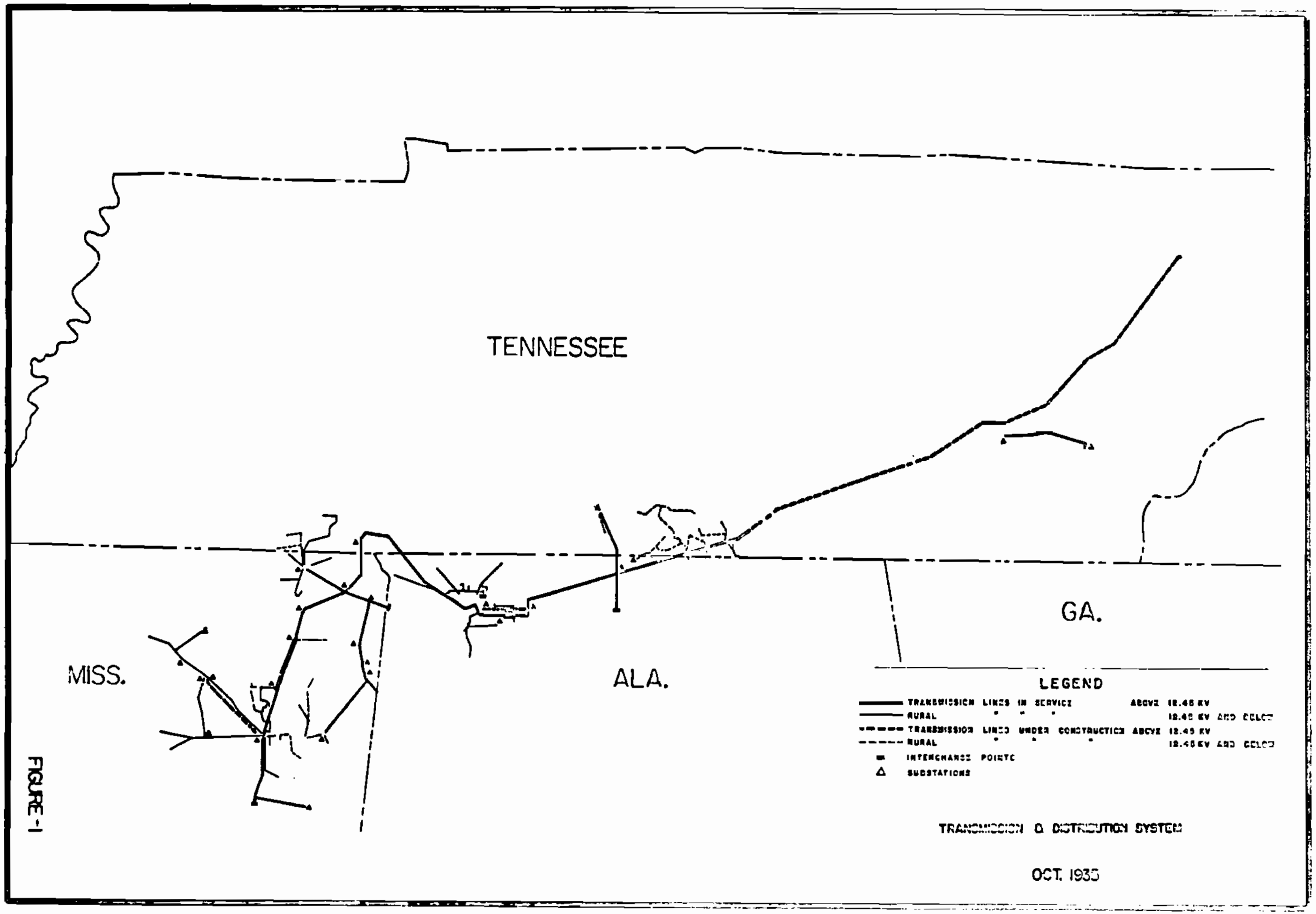
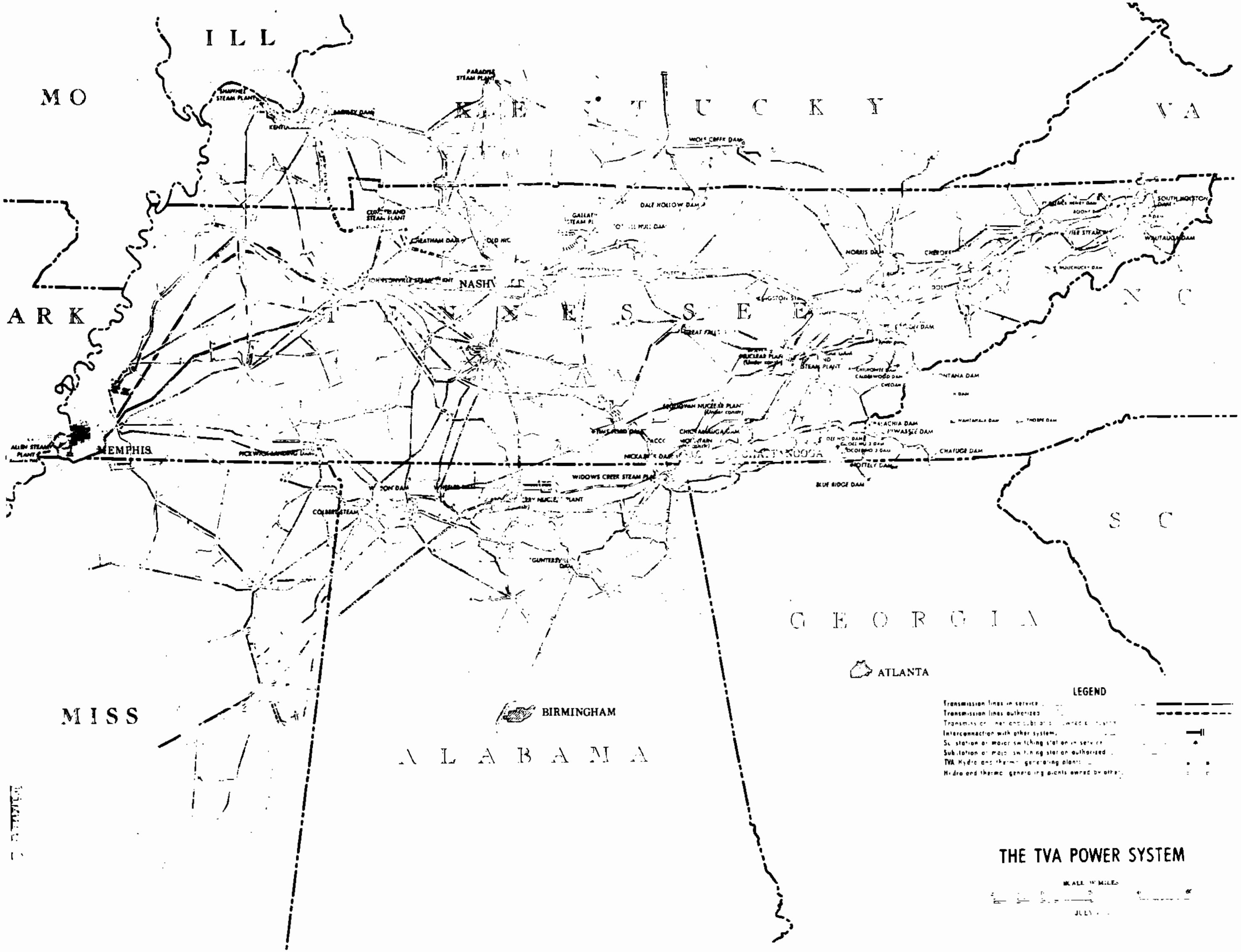

TENNESSEE
GA.
ALA.
MISS.
LEGEND
TRANSMISSION LINES IN SERVICE ABOVE
RURAL
TRANSMISSION LINES UNDER CONSTRUCTION ABOVE
RURAL
INTERCHANGE POINTS
SUBSTATIONS
TRANSMISSION & DISTRIBUTION SYSTEM
OCT. 1935

FIGURE-1


MO
ILL
KENTUCKY
VA
ARK
TENNESSEE
NC
SC
MISS
ALABAMA
GEORGIA
MEMPHIS
NASHVILLE
BIRMINGHAM
ATLANTA
ALLEN STEAM PLANT
SHAWNEE STEAM PLANT
PARADISE STEAM PLANT
KENTUCKY
CUMBERLAND STEAM PLANT
CHEATHAM DAM
OLD HICKORY
DALE HOLLOW DAM
WOLF CREEK DAM
NORRIS DAM
CHEROKEE
SOUTH HOLSTON DAM
WATAUGA DAM
BOONE
GREAT FALLS
PICKWICK LANDING DAM
WILSON DAM
WHEELER DAM
COLBERT STEAM
GUNTERSVILLE DAM
WIDOWS CREEK STEAM PLANT
NICKAJACK DAM
CHICKAMAUGA DAM
BLUE RIDGE DAM
CHATUGE DAM
HIWASSEE DAM
APALACHIA DAM
CALDERWOOD DAM
CHILHOWEE DAM
FONTANA DAM
LEGEND
Transmission lines in service
Transmission lines authorized
Interconnection with other systems
THE TVA POWER SYSTEM

Just as the 110-kV transmission voltage has been phased out, similar consolidation, conversion, and standardization has been introduced on the subtransmission and rural distribution systems. Standardization, at the highest level consistent with economic justification, resulted in the elimination of the acquired 33- and 22-kV subtransmission facilities by conversion to higher voltages or transfer to distribution use at a lower voltage. The result of these changes is a subtransmission system which presently utilizes only the 69- and 46-kV levels. Where feasible, only the 69-kV level is now being propagated for new construction to gain the advantages of its higher load transfer capability and longer transmission distances. Most transmission line conversions are made in conjunction with substation transformer replacements which are periodically replaced or upgraded to meet localized load growth.

Joint studies conducted with the distributors in the 1930's demonstrated in many cases that 12.45-kV distribution was considerably more economical than the 2.4 or 4.1 kV systems which had been economical at lower load levels. Also, efforts to standardize distribution system voltages have gradually resulted in the elimination and/or replacement of obsolete 2.4-, 4.1-, 11.0-, and 11.5-kV distribution systems.

More recently TVA has encouraged rural power distributors to consider a higher distribution level, 25 kV, which is more suited to serving increasing rural loads involving relative long supply distances. Changes to the higher distribution level have been made by some distributors where engineering studies have shown that the change is economical.

TVA is obligated by contract to continue existing distribution system voltages at any wholesale delivery point that the customer so desires. However, by coordinating the changes on both the distribution and subtransmission systems over a long time span, and in conjunction with capacity increases, practically no plant equipment has been sacrificed and reasonable standardization of voltages has been obtained.

The Planning Model

In developing the present electric system, the basic planning process utilized by TVA in itself is not unusual and follows generally accepted industry methods and practices. However, some uniqueness does exist because the TVA system is much larger than most other power systems in the United States. This scale factor becomes more apparent when it is realized that TVA electric energy production today accounts for approximately 10 percent of the nation's total, while at the same time the service area is confined to approximately 2.5 percent of the nation's continental land area (excluding Alaska) and represents 3 percent of the population. This heavy power usage has necessitated the development of a tightly integrated power system.

In the initial system planning process and while the number of transmission system elements were few, it was possible to establish partial or equivalent mathematicial models of the power system. From these unique models, constraints were studied and limiting conditions identified. However, as the number of transmission lines and substations increased and a more complex network evolved, hand obtained problem solutions in themselves became limiting factors in modeling. This led to the development of another modeling technique utilizing an AC network analyzer which basically made a miniature replica of the desired transmission system from linear circuit elements and controlled voltage sources. This provided a physical model which could be modified and examined to determine power system responses for different load conditions, altered generation schedules, proposed new transmission lines and/or substation equipment, and short circuit conditions. This tool greatly expanded the potential for long range planning studies and also provided a means for solving load distribution, relay, and transient stability problems.

The AC network analyzer was an indispensable planning tool in the TVA transmission system development program. But, by 1958 and despite the application of network reduction and equivalent circuit representation techniques, it was no longer practical to contain the long range modeling studies within the capacity of the analyzer. At that time, high speed electronic digital computers became available on the market and their potential for producing mathematical solutions for transmission load flow modeling problems was quickly recognized. Since then, computer programs have been developed which provide high speed solutions for a multiplicity of large dimension electrical engineering problems including short circuit and power circuit breaker application studies, steady-state and transient stability studies, switching surge studies, and a wide variety of load flow studies each of which is tailored to satisfy specialized study requirements.

Initially, in using the AC network analyzer and now with the digital computer, a procedural sequence has been established to provide long range planning directive for the near term transmission system construction program. This procedure entails the creation of a transmission system model significantly larger than the existing power system using base load projections, known industrial expansion plans, estimated industrial potential, generation requirements, desired system reliability factors, and interchange commitments with neighboring utilities. Usually a scale factor of 4:1 is used which provides a model representative of the system approximately 20 years in the future. Then a second model is prepared representing a 10-year system with a load approximately double the then existing system load. By manipulation, this system is optimized to determine the number and location of lines and major substations that will be required using only those facilities that will also satisfy the long range model requirements. At this juncture some rebalancing of the 20-year model is often made to incorporate or substitute a transmission facility needed in the midterm model that was not originally contemplated but would equally satisfy long term needs.

Using this intermediate system model, optimization studies are performed for the immediate system requirements in which only those lines and major substations useful in the 10-year model are proposed for construction. Often when immediate system needs indicate that a power facility should be constructed but would have only short term usefulness, it is rejected in favor of advancing or substituting other power facilities that would better fit the 10-year model. In some instances, network overloadings which entail only minor risks are allowed in lieu of constructing the new facility with limited usefulness. Every three to four years the 10- and 20-year models are revised. However, the optimization phase of this planning sequence is a continuing function. To date, operational models have been developed which are representative of the system expansion required to supply future load levels of 50,000 and 60,000 MW.

It should be recognized that development of a transmission system planning model is in itself a complex undertaking requiring an intimate knowledge of power system characteristics, marketing trends affecting electric power demands, system operating standards and limitations, power plant operating modes and schedules, and general transmission design and reliability planning criteria. Many of these factors are continually changing to keep pace with equipment improvements, larger generating unit sizes, customer demands, and availability of more sophisticated control and protection equipment. Companion papers will discuss the obvious factors translatable to planning criteria in the areas of power production, system operations, and marketing. Some of the other guidelines and general criteria used in transmission system modeling follow.

General Reliability Criteria for the Bulk Power Transmission System

The TVA bulk power transmission system is planned and constructed to withstand the following unscheduled contingencies.

A. Those contingencies most likely to occur which will be sustained without loss of load:

1. Loss of any one transmission line or any one generator.
2. Loss of any two transmission lines which are on the same double-circuit towers for at least one-fourth of the length of the shorter line.
3. Loss of any one transmission line or generator with any line out of service for maintenance during spring and fall periods or during summer and winter offpeak periods. It is recognized that outages for routine maintenance will not normally be taken on heavily loaded transmission lines.
4. Loss of any one transmission line or generator while any generator is out of service for scheduled routine maintenance.
5. Loss of a transformer bank or major bus at a generating plant or bulk transmission substation.

Following the contingency listed in 1 or 2 above, all equipment should be loaded within its normal rating and all voltages should be reasonably normal. Following contingencies 3, 4, and 5, all equipment should be loaded within emergency ratings applicable for the probable duration of the outages, and voltages should be within the tolerable range.

B. Those contingencies having a reasonable chance of occurrence which involve possible loss of some bulk load and/or instability of some localized generation but not resulting in uncontrolled cascading interruptions:

1. Sudden loss of any generating unit or transmission line with any other generating unit or transmission line out of service for any reason.
2. Loss of transmission lines and/or generation resulting from failure of one pole of a power circuit breaker to properly clear a fault for those installations with independent pole operation of circuit breakers. A three-phase fault and stuck breaker will be otherwise assumed.
3. Sudden loss of a generator with any two units out of service for any reason. (It is recognized that such contingency may result in insufficient generation to satisfy the load requirements, but the bulk transmission system should be sufficiently firm to avoid uncontrolled cascading.)

C. Those Contingencies Having the Lowest Probability of Occurrence Which Could Produce Widespread System Disturbances

As a practical means of determining transmission system responses for contingencies beyond those which can be reasonably expected, studies of extreme conditions are made. The following examples serve as a means of measuring the ability to withstand disruption of a portion of the system without resulting in an uncontrolled cascading interruption. These may result in loss of some load, instability of some generating units, and some islanding within TVA's system and possible neighboring utilities.

1. Sudden loss of an entire generating plant and all associated transmission lines from relay operations in which a fault is properly isolated in normal relay time.
2. Sudden loss of all transmission lines on a common right of way.
3. Sudden loss of a very large industrial load or major load center.

4. The forced outage of the most critical transmission line during outage of any other critical transmission line. For study purposes, a three-phase fault shall be assumed as the cause of the forced outage.

5. Loss of transmission lines and/or generation resulting from slow clearing of all three phases of a three-phase fault as a consequence of relay or power circuit breaker malfunction.

Transmission Interconnections with Other Utility Systems

The TVA transmission system is interconnected with neighboring utilities to the north, south, east, and west at 28 separate locations. These free-flowing power interconnections have been established to provide benefits to the respective parties which include:

1. Reciprocal emergency assistance.
2. Short-term power and energy sales.
3. Economy and diversity interchange.
4. Energy assistance for replacement power when generator units are out of service for maintenance.
5. Access to other (remote) power systems in the interconnected grid for regional exchange and emergency assistance.

Through these interconnections the TVA system operates as an integral part of a huge power network covering most of the Continental United States and parts of Canada. Therefore, the importance of the TVA system is by no means limited to serving electric power consumers in the Tennessee Valley area. In times of power emergencies, operation of TVA's system can contribute significantly to power supply conditions from the Great Lakes to the Gulf of Mexico, and from New England to Oklahoma and Texas.

This has required a new look at the system planning process--a much broader view than previously taken. Particularly with the establishment of extra high voltage intertie lines, the system planning and operating functions of TVA and neighboring utility companies have become interdependent. To ensure that operating and planning functions are properly coordinated, TVA and these other utility systems have joined together as a regional reliability council to exchange system data and determine the effectiveness and reliability of the interconnected transmission systems. On an annual basis load flow study models of the interconnected systems are established and joint studies are made to investigate (1) the performance of the interconnected systems under normal conditions for the next summer and winter peak loads, (2) the capability of the systems to interchange power in amounts above the firm transfers scheduled for this same period, and (3) the effects of various possible single contingencies and a limited number of multiple contingencies on the individual and combined transmission systems performance. Also system models for as far as 10 years in the future are made to investigate the broad implications of individual system plans upon the interconnected group. The effectiveness and accuracy of TVA's continuing long range system modeling program has been greatly improved by having access to representative models of neighboring systems which can be reduced to meaningful equivalents and be made a part of the TVA models.

Environmental Planning

TVA recognized that the construction and maintenance of transmission facilities can have an impact on the environment and that sizeable amounts of land will be required for transmission line easements and substation sites. In keeping with the National Environmental Policy Act of 1970, evaluations of all proposed actions are now made to minimize negative effects of line routings and substation site locations. At each significant point where a decision must be made in the planning process, environmental impacts are evaluated and weighed against each alternative so that finalized plans are developed to mitigate environmental losses and increase benefits.

To minimize land requirements for lines and substations, facilities of the highest voltages and capacity consistent with sound engineering practice are employed by TVA. Approximately 25,000 acres (101 sq. km.) of land will be required for substation sites and transmission line rights of way for the 5-year period 1974 through 1978. Similar requirements for land use will exist for some time thereafter. However, it is expected that the amount of land required in proportion to the added transmission capacity will diminish from year to year through continuing efforts to use transmission facilities more effectively. This will include the greater use of extra-high voltage lines, the parallel construction of lines on existing rights of way, increasing capacity by replacing or rebuilding existing lines, the joint use of rights of way with other utilities (electric, gas, and oil), and by employing multi-circuit lines on common structures.

Through continuing system studies, TVA determines the general location, capacity, and voltage levels of transmission lines and substations which best meet load growth on its system. After determining the terminals of a line, and weighing the economics and the environmental impacts of alternatives, TVA chooses a preliminary route. In so doing, care is taken to minimize land use conflicts of the facilities with residential properties and other sensitive areas.

After preliminary studies are completed, selected transmission line route and substation site locations are coordinated with municipal, county, and state planning authorities and federal agencies.

For the 1974-78 construction program, specific plans have been developed to provide the required transmission system changes. These changes which will be made at an estimated cost of $415,000,000 will be concentrated in the bulk supply, 500-kV and 161-kV networks. A quantitative listing of these planned facilities appears on page 17.

Projecting transmission system development further through the year 1990 shows that a substantial 500-kV transmission system construction program will have to continue. Preliminary studies for the bulk power supply network indicate that between 1978 and 1990 as many as 14 additional 500-kV substations, in addition to generating plant switchyards, and approximately 1,580 miles of 500-kV transmission lines will be required. Similarly, 60 additional 161-kV substations and approximately 600 miles of 161-kV transmission lines will be constructed. It is anticipated that many existing 46- or 69-kV substations which are dedicated to the supply of localized area loads will be converted to 161-kV operation and will continue in their present local supply function.

In proportion to projected load growth, note should be taken that fewer miles of 161-kV transmission lines will be required from 1978 to 1990 than in the 1974-78 period. This can be accounted for in part by TVA's present use of extra-high voltage facilities for primary bulk power transfer functions as opposed to previous dependence on 161-kV lines for this purpose. Also by selective placement of 500-161-kV bulk supply substations over the system in the future, very few long 161-kV lines will be required to connect load stations to these supply sources.

This paper traces the changing requirements of transmission system planning through the 40 years of development of the TVA transmission system. The planning function is more complex today and is subject to more constraints than every before. The large capital expenditures needed for transmission

Transmission Facilities To Be Added

FY 1974-78

Transmission Lines	Circuit Miles	Estimated Cost ($ Million)
500 kV	363	$ 61
161 kV	816	65
69 kV	214	13
46 kV	190	8
Subtotal	1,583	$147

Substations*	Number	Estimated Cost ($ Million)
500 kV	5	$ 61
161 kV	45	40
69 kV	17	6
46 kV	19	6
Subtotal	86	$113
Communication Facilities		21
Other**		134
Total		$415

*Excludes generating plant switchyards.

**Includes capacity increases at existing substations, conversion and rehabilitation of existing transmission lines, the installation of capacitors, voltage regulating equipment, and circuit breakers and miscellaneous minor construction activities.

system development require that planning be done as accurately as possible so that no money is spent on facilities having only short-term usefulness. At the same time the system must be planned with due regard to its role as an integral part of the bulk power transmission system of the whole southeastern United States. While the complexity of planning is increasing because of this need to include larger and larger areas in modeling studies, the constraints imposed by environmental considerations in the location of the transmission lines, substations, and generating facilities are increasing in severity. System planning has always been done in an environment of constant change, and even though the present problems are formidable, TVA is confident of its ability to plan an adequate and reliable transmission system to meet the requirements of the future.

IIASA DISCUSSION PAPER

N. Weyss

The main point of this conference is to learn, in a retrospective way, from the large treasure of experiences of the TVA history until the present. In your first steps you have been convinced that the system you propose will stay for, say, 10 to 20 years. In reality, sooner or later a changing demand, the changing progress of technology, even a new ruling management will enforce changes or at least an unforeseen addition of system details, and this occured even during your first systems period of 10 years. For the sake of flexibility we want to know if it is possible to get your unforeseen TVA cases, especially regarding the transmission job in an average, say, quantified grip, for our common future use.

As I have the privilege to guide the discussion I want to classify all questions into two groups economic and technological. First, let us go to the economic questions.

1) Can you give us figures for such additional costs in your transmission system that were unforeseen beforehand?

2) You have, to be certain, some links and interconnections between utility companies in your area. This was mentioned in part by Mr. Seeber yesterday. Is there a realized or planned supergrid in the States, one to eventually include Canada, similar to what we have in Europe? Your geographic difficulties are bigger, but your political unification is an advantage. A chief aim might be the proper use of non-synchronous consumption of more than one or two time sectors: The USA has 60 meridian degrees, and with Canada there are 90 degrees; this makes a 6 hour difference. Why not use that? Besides this policy, are there also technological impediments to a supergrid for well used load distribution?

   Another question involves a link between economic and technological categories.

3) If you plan a new power station, nuclear or perhaps solar or whatever, do you perfer a site close to an old station to use all the infrastructure? Or is there constraint against this?

4) Now let me ask questions concerned purely with technology.

   You have shown us slides of steel poles and tower types. Is there a US standard type pole, and has it followed your own primary design? European towers--we call them masts--seem to be lighter, perhaps owing to a more cost-effective, optimized static construction.

5) Where did the kilovoltage standards of 46, 69, and 161 come from? Was that a matter of calculating the optimum copper solution for it at this time, given load and distances? Or was it a consequence of technology say of the breakers and other switchgears?

6) Are there any constraints to the erection of new overhead transmission lines in America as there are in Europe, for instance, between closely situated villages or in other agglomerations? Do you voluntarily get the siting area necessary for the tower from the ground proprietors? What do you pay for one square meter on the average? What do you pay for the right of way for suspending your wires over private land?

7) My last question regards the cost divergence of transmission systems. After my own observation, transmission costs per kilometer differ highly by time, by geographic features, by construction qualities; your average figures have certainly a wide-spread dispersion. Can you give us maximum and minimum figures of dollars per kilometer for a given highvoltage or extra-high voltage? Are there considerations for the transition toward cable-transmission systems? What are the maximum average, and minimum costs per kilometer that you insert in your option comparison? Are you thinking about even more sophisticated systems as sodium, cryo and superconducting lines, or, as an extreme example, hydrogen pipe lines?

TVA COMMENTS ON IIASA DISCUSSION PAPER

1) What are the economic consequences of changes to transmission system plans as a result of changing demand, technology, etc?

It is recognized that projecting a master transmission system plan that will survive without alteration as a basis for 10 to 20 years of system development is highly theoretical. In practice, estimates of power demand trends, anticipated generation siting patterns, and the entire list of influencing factors are constantly being replaced with new estimates based on currently available facts. As such, the transmission system models are extremely evolutionary and are in a constant state of change. However, the long-range models, in spite of their shortcomings, do provide insights to transmission system trends, needs and responses and serve as the framework against which relative economic study comparisons can be made of alternative plans for system additions.

Because of the increasing frequency of changes with respect to time, we have found that it is highly impractical to project expenditures for more than five years in the future. This has led to the establishment of a five year working budget document which is revised annually.

To illustrate the relative economic effect of changing plans and altering construction schedules, Table 1 gives a running list of five year budget projections for a 20 year period beginning in 1955. The projected expenditures for a given fiscal year are tabulated in vertical columns and reflect the progressive changes. The bottom number in each column represents the actual expenditures for that year.

In retrospect, the most significant unanticipated cost increase experienced for transmission facilities during this 20 year span resulted from the technical decision in 1962 to establish a 500-kV transmission voltage level to facilitate system bulk power transfers. The first of these EHV projects was identified in the 1962 budget with major expenditures scheduled for 1965. This first large expenditure is included in the $67,850,000 total budget figure for 1965 (underlined value), which reflects a 42.6% increase over 1964.

It should be noted that although there was a relatively large budget increase in 1965, the decision to move to a higher transmission voltage produced offsetting lower voltage expenditure in later years for system bulk power transfers. The actual expenditure for 1965 reflects the refinement of plans to delete portions of the lower voltage network expansion plans. The 1966 budget includes the second significant expenditure for 500-kV facilities.

2) Is there a supergrid planned in the States, eventually to include Canada?

There is presently no formal plan to establish a specific supergrid for the continental United States and Canada. However, the many EHV and lower voltage interconnections linking practically all electric utility systems do provide an effective network for significant power transfers. Figure 1 depicts the integrated EHV transmission network for the eastern two-thirds of the US. Topography and low-population density in the western plains and the Rocky Mountains has resulted in relatively few low-capacity interconnecting ties between the eastern systems shown in Figure 1 and the balance of the country. Therefore, extension of the concept of time displacement of energy is practically limited for the present to the eastern two-thirds of the country.

All interconnected companies which effectively operate as a national grid accept responsibility for maintaining reasonable transmission and generation facilities to extend emergency assistance, when required, to neighboring systems and to accommodate scheduled and inadvertent power transfers through their systems. These companies through regional council agreements annually conduct system studies to ensure the adequacy of the respective systems to reliably meet the demands of the interconnected systems. These studies usually include simulation modeling of planned system additions for all years over an eight to ten year period. Copies of regional study reports are available from TVA and will be discussed during the IIASA visit to the TVA. These reports list the interconnecting line capacities, system transfer limits and identify the limiting system elements for hypothetical scheduled and emergency transfers between systems. Similar studies are conducted by representatives of all other regional reliability councils.

When viewed on a national basis, many power companies or councils can and do draw on reserves from other regions because of time and/or temperature variations. Such transfers are arranged seasonally or on shorter daily and hourly schedules by individual power system operators. However, if all regions were to maximize their load/capacity situation through all time periods, their interregional emergency support could be significantly weakened.

3) Does the TVA seek locations of new power stations in proximity to existing stations to utilize existing infrastructure?

In general, the TVA retains options for placing new power stations on existing plant sites where feasible. Normally, however, land commitments at existing plant sites and/or other environmental loadings reduce many of the viable options. From a transmission standpoint, we investigate all possibilities of using existing switchyard and area lines to provide connections for new generating plants. A situation such as this has recently been investigated for the siting of a two-unit nuclear plant in east Tennessee, and plans are being developed to provide four direct heavy duty 161-kV line connections to a nearby steam plant switchyard where sufficient other area lines exist for distribution of the new generating capacity.

4) Standard Transmission Towers

There is no one standard steel tower design that has widespread use in the US. At first glance, however, many towers used across the US appear to be similar. As a rule, most individual companies utilize specific designs tailored to meet their individual needs, such as 1) unusual weather loadings, 2) irregular terrain necessitating major elevation changes, numerous large angles or short spans, 3) difficult footing or foundation conditions, 4) land-use restrictions such as metropolitan areas necessitating vertical phase spacing in lieu of horizontal, and 5) aesthetic appearance to satisfy special interest groups, etc. The TVA currently has approximately 250 separate steel tower designs for many different purposes. Although many of these towers, like some structures used by other US companies, appear to be similar in shape, there are many differences in individual member strengths and sizes to carry unusual design loadings.

5) Transmission System Voltage Standards

The US kilovolt standards of 46, 69 and 161 kV basically evolved from a progression of utilization practice compromises, rather than from strict equipment technological constraints. Of course, user practices were derived from a variety of optimized system regulating solutions for a range of given loads and transmission distances. These solutions initially led to the standardization of apparatus which produced, rather than a single coordinated system voltage level, several standardizations for utilization and generator apparatus. The standardization process which eventually led to present preferred system ratings was guided by desires to improve equipment interchangeability and reduce unwarranted manufacturing costs associated with designing and producing an excessive product line of special rated apparatus.

6) Transmission Line Siting Constraints

In the US, transmission line siting is effected by many individual zoning ordinances and land-use restrictions peculiar to each state, county, and township; economic alternatives dictated by land values; environmental restrictions; air traffic glide path restrictions; etc. Probably the most restrictive element in recent years has been the many potential environmental constraints which are difficult to define or evaluate quantitatively.

As a Federal agency, the TVA has the right of eminent domain giving the agency the authority to condemn property for public utility use. Currently, we are negotiating 93% of our easement agreements without having to institute condemnation proceedings. This easement document gives the TVA the right of way to clear the land and to erect and maintain transmission line facilities. Our practice is to reimburse the property owner on the basis of locally appraised area land values which range from $200-$1,000/ acre (5-25 cents/sq. meter) and average $430/acre (11 cents/sq. meter).

7) Transmission Construction Costs

The TVA is currently experiencing the following overhead transmission line construction costs (including right of way) as shown in table 2.

Table 2.

Line Type	$/Kilometer MAX	$/Kilometer MIN
500 kV steel	$162,800	$144,200
161 kV steel	108,100	67,700 (wood)
69-46 kV wood pole	69,000	49,000

We are not anticipating any commitments for underground cable systems in the near future and certainly will not expend the extremely high cost for high-voltage cable systems until zoning, land-use, or aesthetic restrictions become significantly more restrictive than now. TVA line construction is still basically being sited in rural and open areas.

It is anticipated that in the future more sophisticated gas-insulated pipe systems may have utility in some isolated situations. To ensure that a technology is advancing in this area, the TVA provides financial support to the Electric Power Research Institute for basic research and prototype testing of such systems. For comparative studies we are estimating that 500-kV gas-insulated pipe will have an installation cost range of 15-20 times overhead system construction costs.

TABLE 1. TOTAL (EXCL. OVERHEADS) ORGANIZATIONAL, BUDGET COST BY FISCAL YEAR (THOUSANDS).

BUDGET PUBLICATION DATE AUG	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1955	19,254*	16,790	13,985	29,058	42,413	10,674																			
1956		12,222*	23,124	26,769	34,101	34,482	29,944																		
1957			22,374*	24,700	28,000	35,225	44,100	15,850																	
1958				23,995*	19,750	28,750	35,600	38,500	12,900																
1959					18,456*	25,440	26,150	44,125	53,275	28,925															
1960						22,989*	26,400	31,600	37,675	33,750	27,400														
1961							22,364*	28,915	32,435	38,545	38,510	13,625													
1962								29,545*	33,125	45,075	$\boxed{67,850}$	67,980	35,880												
1963									27,873*	38,705	59,750	66,600	40,900	43,225											
1964										35,275*	48,063	54,035	54,465	44,500	9,290										
1965											50,318	61,975	60,755	59,770	29,140	10,645									
1966												66,279*	56,825	59,675	53,680	35,865	20,405								
1967													58,419*	61,525	54,350	65,565	22,145	17,345							
1968														71,451*	51,775	59,600	48,730	66,775	38,610						
1969															59,299*	66,025	66,175	72,625	50,795	21,570					
1970																54,359*	67,425	70,800	74,155	75,555	56,820				
1971																	66,121*	74,070	77,400	86,225	89,995	70,855			
1972																		67,190*	72,425	67,375	85,045	94,000	98,000		
1973																			55,149*	63,135	63,250	75,000	95,000	87,145	
1974																				46,489*	58,000	73,000	88,000	98,000	80,000
1975																									

* Actual Cost

Figure in Box: First year of budgeted 500 kV facilities

COMPUTER APPLICATIONS TO ACHIEVE OPTIMUM ECONOMIC LOADING OF GENERATING PLANTS

INTRODUCTION

The scheduling of generation in an optimum manner is a complex problem for all power systems. Moreover, this complexity increases with the number and type of generating plants.

The principal considerations in scheduling generation for power systems with only thermal plants are the optimization of maintenance schedules, the daily unit selections, and the continuous division of generation among plants and units in order to minimize costs. For power systems with only hydro plants, perhaps the principal consideration is the maintenance of adequate storage margins for use in the event of extreme droughts. For hydro-thermal systems an important additional consideration is the optimization of the use and distribution of storage, reflecting both streamflow probabilities and the values of stored or storable water as replacement of thermal power.

Other involved considerations are required in scheduling the use of pumped storage plants and combustion turbines with limited fuel supplies. Transmission interconnections with other electric utilities are very beneficial; but they, too, add more considerations to the complex problem of generation scheduling.

The TVA system has all of these types of generation except a conventional pumped storage plant, which will be added in 1975. There are also 28 transmission interconnections with several adjacent utilities which permit large exchanges of power.

Generation scheduling by TVA involves the use of several computer applications. Two of these are used directly in scheduling generation by plants, and several others are indirectly involved.

INDIRECTLY INVOLVED COMPUTER APPLICATIONS

The computer applications indirectly involved with generation scheduling are:

1. Monthly Load Forecasts
2. Basic Rule Curves
3. System Economy Rule Curves
4. Values of Project Storage

Monthly Load Forecasts

The primary prerequisite for a monthly load forecast is the historical record for the past several years. The monthly peak loads of the residential, commercial, and small industrial consumers of TVA power are shown on figure 1. These loads are very sensitive to weather factors, especially temperatures and winds, due to extensive use of electricity for both heating and air conditioning. At present these peak loads vary about 120 MW per degree Fahrenheit during winter months and about 210 MW per degree Fahrenheit during summer months. Since the temperatures in this area are quite variable from year to year, this load-temperature sensitivity results in rather erratic load growth.

The TVA peak load forecasts are based on extreme temperatures, which have a 50-percent probability of being exceeded one day each month. The next chart (figure 2) shows the historical peak loads adjusted to reflect these temperatures. This removes much of the erratic annual variations in load growth. A rather simple but useful computer program is utilized to project this historical record into the future. This program determines the trend line which is rather easily extended for the next several months or years. The program also provides monthly factors which enable one to determine quickly the monthly peak forecasts. The program is also used in forecasting average monthly loads.

Load forecasts are essential in determining maintenance schedules and in preparing broad plans for use of hydro power. The other three computer applications indirectly involved with generation scheduling by TVA are used for this latter purpose.

Basic Rule Curves

In planning the use of hydro power, it is often satisfactory to consider the energy equivalent of the storage in all reservoirs as a total. Examples of this are the TVA basic rule curves and the system economy rule curves, which are shown on the next chart (figure 3). The bottom curve on this chart is a basic rule curve and the upper curves are system economy rule curves. You will note that the coordinates of all curves are total storage and time.

The basic rule curve indicates the necessary total storage in the system reservoirs throughout the year to ensure the delivery of firm power commitments in the event of an extreme drought. To determine this curve, several historical droughts must be examined in detail.

The top portion of the next chart (figure 4) indicates the rather extreme variability in streamflows in this area in terms of system power from unregulated streamflows. The line labeled 1929 is the power obtainable from the present hydro plants with a repetition of streamflows in 1929, which was a very wet year. The other lines indicate power obtainable in an average streamflow year like 1924 and in two extremely dry streamflow years like 1925 and 1939.

This chart indicates a simplified method for the determination of basic rule curves. As a first step, the minimum system hydro requirements must be calculated. This is equal to the forecasted average load minus the maximum usable thermal power. It is determined for each week of the next two years and is quite variable. It is shown here as a constant amount merely to simplify the illustration. Even this minimum hydro load cannot be supplied during portions of dry years without withdrawal of water from storage. With the two extremely dry years above, the energy deficits are the requirements from stored water for portions of a year. The basic rule curves for the streamflow years 1939 and 1925 are merely cumulations of the energy deficits. The basic rule curve for use in current operation is the envelope of all such derived curves. The computer program determines such curves for both one- and two-year dry periods. Perhaps the most complicated part of this program is the computation of thermal power that cannot be used during night hours and on weekends.

System Economy Rule Curves

The system economy rule curves (figure 3) indicate the average values of top increments of storage in the storage-time diagram considering the uncertainty of streamflows that may be expected in the future. Comparisons can be made of the value (or cost) of hydro generation from an increment of storage and the incremental costs of generation from the various thermal power sources. The curves are useful in day-to-day operation as guides in evaluating the desirability of running or shutting down thermal units not otherwise required in supplying peak loads. They also provide some indication of the desirability of operating certain thermal units below full capacity.

The determination of these system economy rule curves requires extensive computations and analyses. The approximate ideal operation of the hydro system as a whole, along with the thermal plants, is determined for each of a representative sample of possible streamflow years beginning at each of several storage levels. For each of the initial storage levels the value of the top increment is calculated based on the use of the increment as a replacement of thermal power, the probabilities of spillage of the increment, and the energy benefits from increased head if the increment is retained for future use. Several computer programs are involved in this application in addition to considerable manual efforts.

Values of Project Storage

In addition to the determination of values of incremental system storage, similar values are computed for individual hydro storage projects. Using the basic and economy rule curves previously described as inputs, a computer program simulates the operation of the power system by projects for several months into the future. Moreover, this simulation is repeated for each of a large sample of possible hydrological and weather years in order to evaluate the effects of streamflow and temperature variations upon the future operation. As in the case of the system economy guide curves, the final results are the average values of incremental storage. The values of the individual projects are determined weekly in order to reflect the effect of the current total storage and the current distribution of this storage. They provide general guidelines for establishing priorities in the daily use of stored, or storable, water.

DIRECTLY INVOLVED COMPUTER APPLICATIONS

Two computer applications are more directly involved in the optimum economic loading of individual generating plants. These are:

1. Daily Preschedules of Generation
2. Economic Dispatch Each Half Hour

The preschedule program provides an approximate advance schedule of generation by plants for each hour of the following day. The economic dispatch program provides two schedules of generation each half hour--one 15 minutes ahead and another 45 minutes ahead.

The scheduling of daily and hourly generation by plants in an optimum manner requires several detailed considerations. The next chart (figure 5) illustrates some of them. It shows the hourly power supply for the TVA loads during a hot day in August 1973. You will note that the principal power supply sources are steam power and hydro power, but smaller amounts of power purchased from adjacent utilities and power from gas turbines are indicated. Also, during the peak hours some industrial loads were curtailed. Note that during the night hours only steam and hydro power were used and the latter to a very limited extent.

The next chart (figure 6) provides some general information about these sources of power. The full capability of the steam power sources and the power that can be purchased are normally available for the full 24-hour period. It was the relatively high cost that limited the use of the purchased power to peak hours of the hot day just mentioned. The hydro and gas turbine power are limited-use resources. The hydro energy available during a day is a function of the uncontrolled streamflows and the planned use of storage. This available energy is determined each day for use during the following day. Large changes in any planned hourly use of this energy are possible for a few hours, but sustained changes normally are not possible during the day in question. The TVA gas turbines now burn oil exclusively, and both limited supplies and high costs reduce the use of this power to the peak hours of days with abnormal power requirements.

Certain industrial loads can be curtailed, or peak shaved, for up to 12 hours per day on limited occasions as provided for in contracts with these customers.

The power supply for a more typical day is shown on the next chart (figure 7). On such days the principal economic problem is the determination of the optimum distribution of the hydro and steam energy. The two computer programs last mentioned are used for this purpose.

Daily Preschedules of Generation

The basic principles involved in distributing generation among operating steam units are those of economic dispatch. For power systems in a very small geographic area with short transmission lines the distribution of generation on the basis of equal incremental generating costs is a satisfactory method. The next chart (figure 8) illustrates this method. For most power systems the distribution should be based on equal incremental costs of delivered power. This latter method is rather complicated, since it involves the determination of incremental transmission losses. The next charts (figures 9a and 9b) present a simplified summary of the method.

TVA uses this latter method for both steam and hydro plants in prescheduling generation. The primary difficulty in applying economic dispatch principles to hydro plants is in the determination of proper incremental cost functions for these plants. The next chart (figure 10) indicates the nature of this difficulty. For a steam plant there is a single incremental heat rate curve and a single incremental generating cost curve for several hours, days, or weeks until there is a change in the selection of units for operation. Therefore, for any economic dispatch calculation of justifiable incremental generating cost there is a specific level of plant generation. On the other hand, for a hydro plant there are multiple answers since the operating units can be changed very easily and quickly. In effect, there are as many levels of indicated generation as there are units in the plant.

The TVA solution of this problem is indicated on the next chart (figure 11). A single incremental discharge and incremental generating cost function is determined for each plant so that specific generating levels can be determined. These functions force a generation selection that is obtainable by operating units at best turbine efficiencies unless a very high plant generation level is economically justified. This method avoids possible large losses in turbine efficiencies at a sacrifice of very small improvements in incremental transmission losses. For systems with distantly located hydro plants some refinement in the cost functions might be justified.

The incremental water cost, γ , for each hydro project is essentially a mathematical constant selected to force the use of a predetermined quantity of water during the entire day. The proper γ's and generation schedules are determined in a rather massive iterative solution. This is illustrated on the next chart (figure 12).

In the first loop of this flow diagram the incremental transmission losses associated with the various generating plants are determined. The determination for each plant requires calculations involving a 132 x 132 B-constant matrix, the estimated load at each load bus, the estimated generation at each generating plant bus, and the power flows at all transmission interconnections with other utilities. A modified generation is determined for each plant using the economic dispatch equations and incremental generating cost functions. Modified generation for any plant results in modified incremental transmission losses for all plants. Therefore, iterative calculations are required in this loop.

The second loop involves an increase or decrease in the system lambda, or justifiable incremental cost of delivered power. This is the method used to increase or decrease system generation in order that the total system generation equals the forecasted system requirement. This is also an iterative process and involves the first loop.

The third loop involves getting a generation schedule for each of the 24 hours of the next day. The first two loops are involved in the computations for each hour.

After the third loop, plant-by-plant generation schedules have been obtained for 24 hours that equal the 24-forecasted system requirements. Then a check is made to determine how closely the energy computed for the day at each hydro plant compares with specified energy quantities. In the fourth loop adjustments are made to the incremental water costs which will force increases or decreases in water use at individual plants, as required.

Economic Dispatch

Due to the inability to forecast precisely the total loads, load distribution, and availability of thermal units, it is necessary to modify the preschedules of generation. The economic dispatch application serves this purpose.

The current economic dispatch system utilizes an IBM 370 general-purpose computer located about one-half mile from the load dispatching office. Certain real time load and interchange power data are converted from analog to digital quantities in the load dispatching office. This information is automatically transmitted to the computer over telephone lines each half hour for use in the economic dispatch calculations. Other current information regarding industrial loads and the availability of generating units is entered into a data entry keyboard by load dispatching personnel and also transmitted to the computer over telephone lines. This current information is used in the economic dispatch computer program, as indicated in the first two loops of the previous chart (Figure 12). The resulting generation schedules are transmitted to the load dispatching office over telephone lines and printed by an automatic printer.

PROGRAMS FOR NEW POWER SYSTEM CONTROL CENTER

TVA plans to have a new direct-digital data acquisition and control system in operation by the end of this year. This will be a closed-loop system as contrasted with the present open-loop system. A large process control computer will be dedicated to this operation along with three mini-computers. This new system will require the conversion of several existing programs for operation in a new environment and the development of many new programs. The programs required can be grouped into the following general subsystems shown on the next chart.

1. Automatic Generation Control
2. Console Displays and Inputs
3. Logging
4. Alarms
5. System Security
6. Data Acquisition
7. Background Programs
8. Backup Programs

Automatic Generation Control

This subsystem provides direct digital load-frequency control for thermal and hydro units on an economic basis. Economic dispatch and automatic interchange scheduling are included.

Console Displays and Inputs

This subsystem provides man-machine interface processing, utilizing light pen, keyboard, and pushbutton inputs. Video displays include single line diagram for substations and tabular information.

Logging

The logging subsystem provides processing for power interchange, generation, water records, and other miscellaneous logs. Both video displays and printed logs are included.

Alarms

The alarm subsystem provides centralized message processing and routing for unusual conditions on the power system or the computer system.

System Security

This subsystem will perform load flow and contingency analyses as required for continual power system monitoring.

Data Acquisition

This subsystem controls the gathering and processing of analog and digital information from local sources and from terminals at 13 thermal plants. Information exchange with remote computers is also planned.

Background Programs

Programs operating in a background portion of computer memory will include generation prescheduling, B-constant calculations, and miscellaneous analyses.

Backup Programs and Facilities

Backup facilities will provide load-frequency control and minimal logging during outages of the primary computer. The backup system consists of an analog load-frequency control system and a mini-computer which performs interchange schedule processing for this analog system and interchange MWh processing.

CONCLUSIONS

The economical scheduling of generation was one of the primary justifications for TVA's first general-purpose computer in 1958. The use of computers for this function has expanded since that time; and as you can see, further expansions are expected in the future.

TVA WEATHER-SENSITIVE LOADS

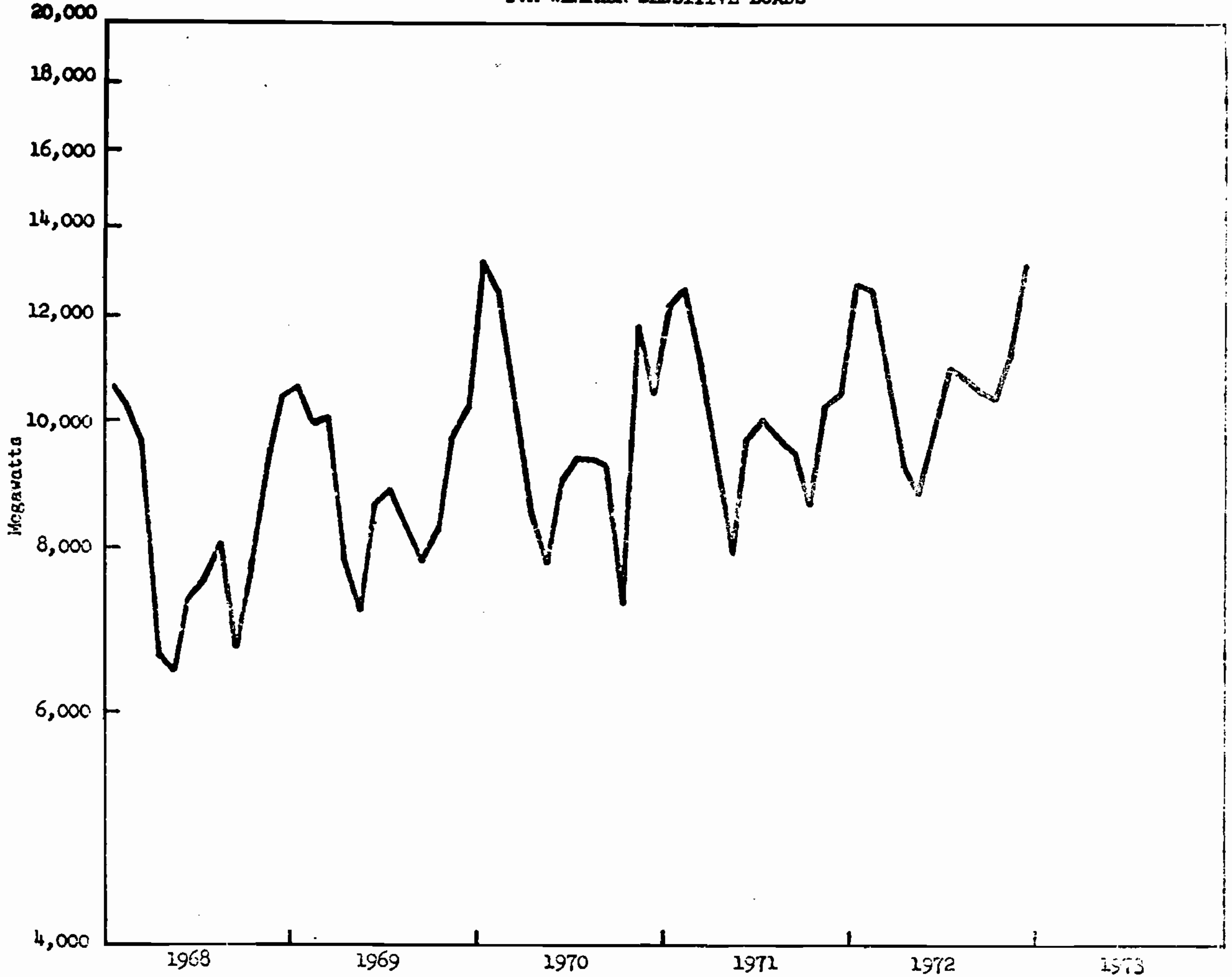


Figure 1

TVA WEATHER-SENSITIVE LOADS

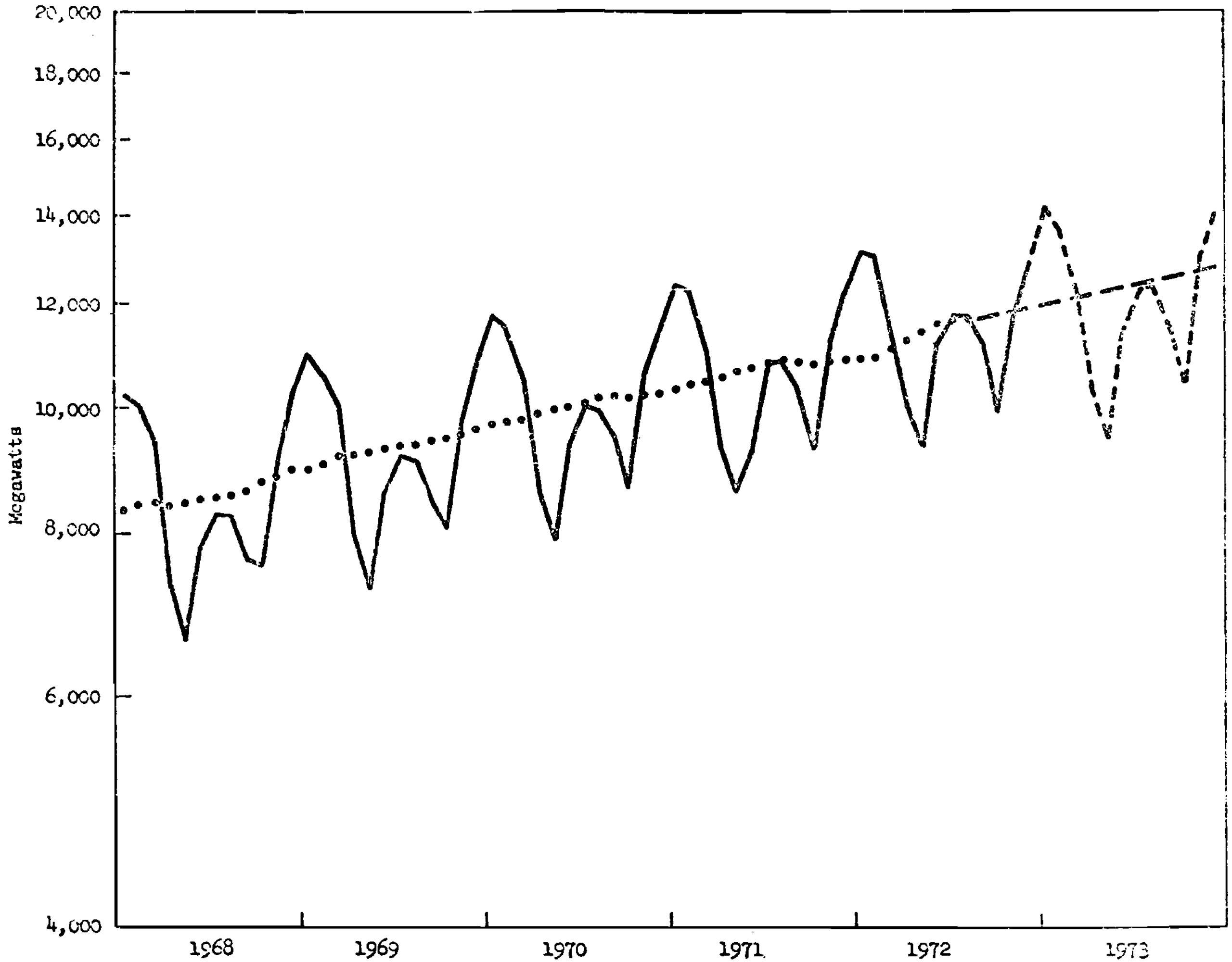
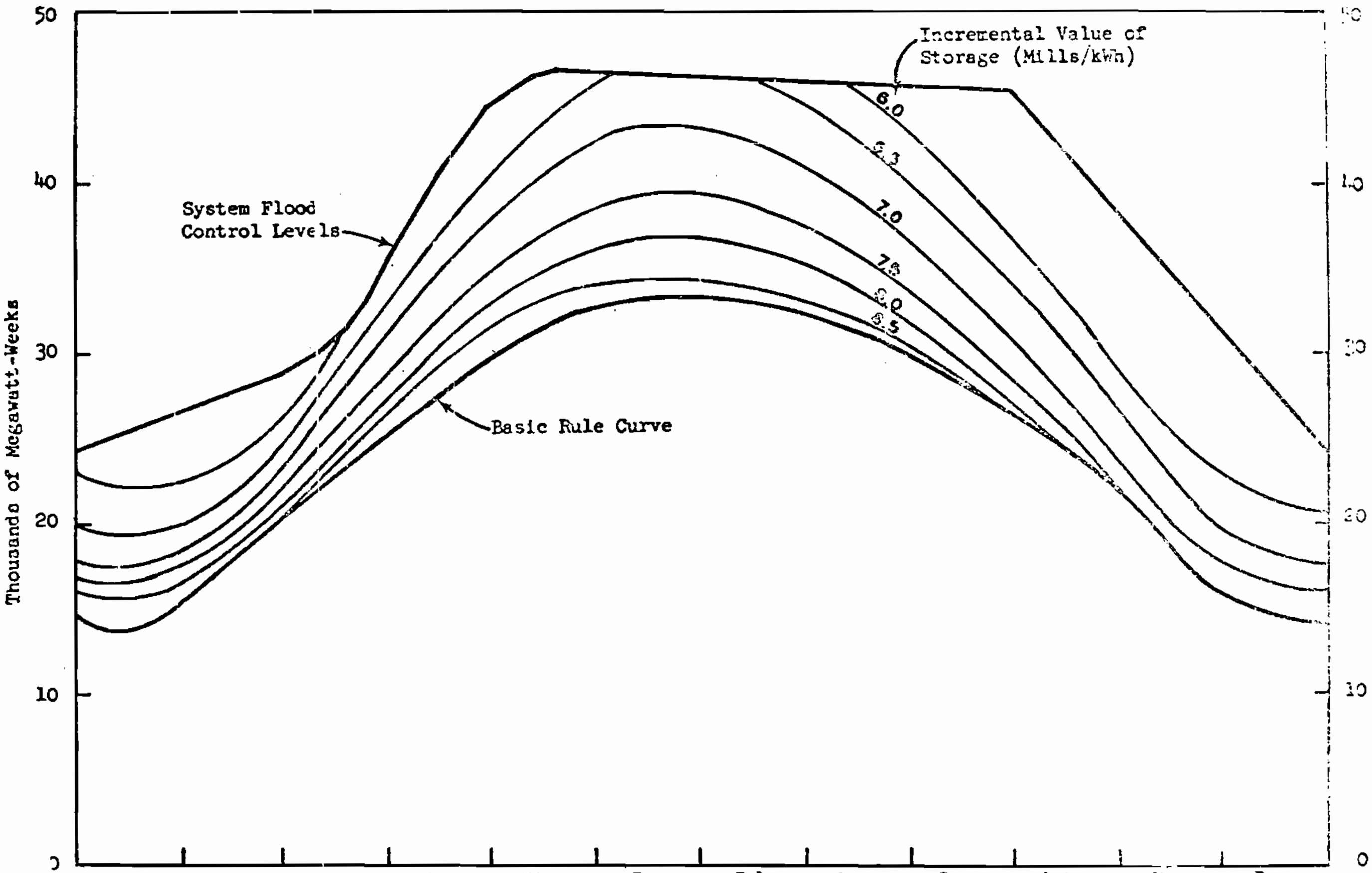


Figure 2



SYSTEM ECONOMY GUIDES

Figure 3

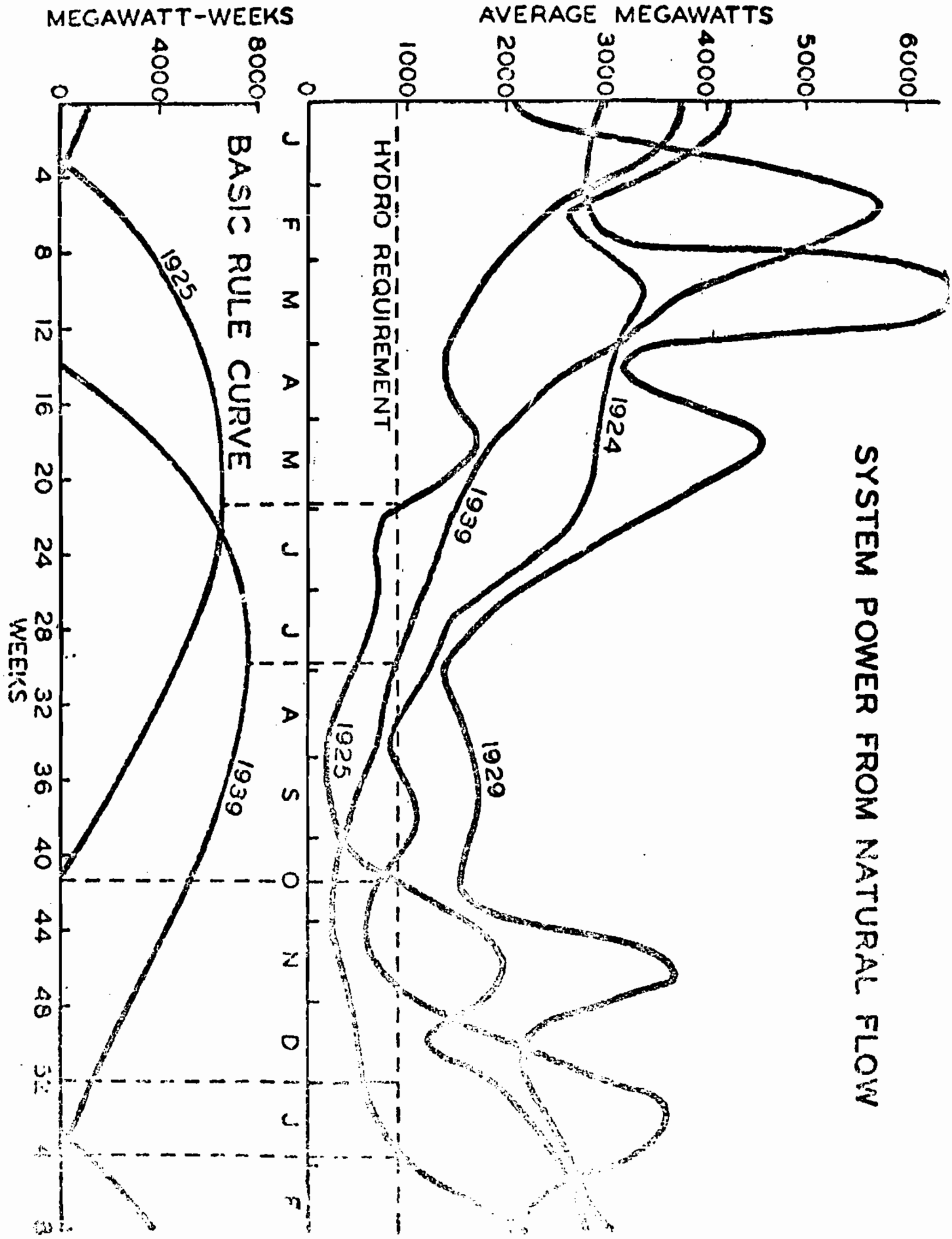

SYSTEM POWER FROM NATURAL FLOW
AVERAGE MEGAWATTS
0
1000
2000
3000
4000
5000
6000
HYDRO REQUIREMENT
1924
1939
1929
1925
J F M A M J J A S O N D J F
BASIC RULE CURVE
MEGAWATT-WEEKS
0
4000
8000
1925
1939
4 8 12 16 20 24 28 32 36 40 44 48
WEEKS

Figure 4

LOAD AND SUPPLY
Hot Day, August 1973

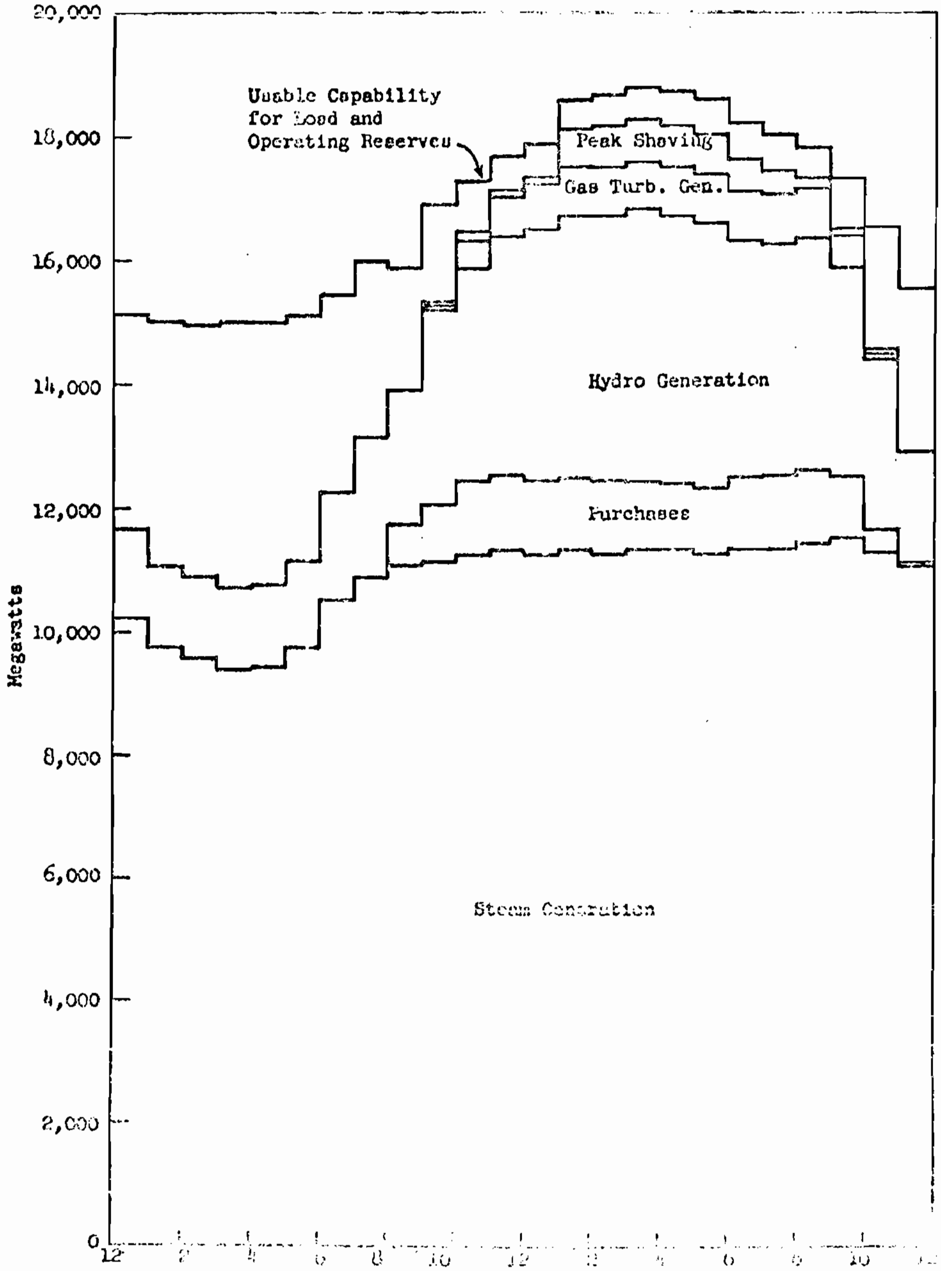


Figure 5

TVA POWER SUPPLY SOURCES

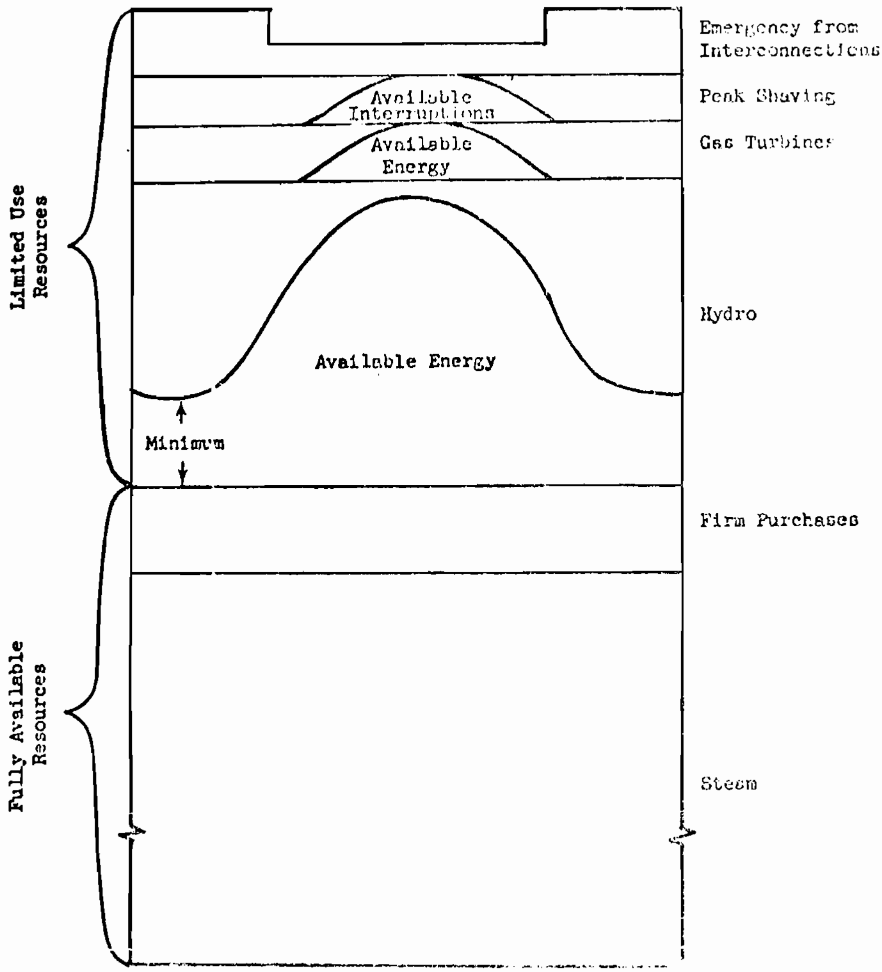
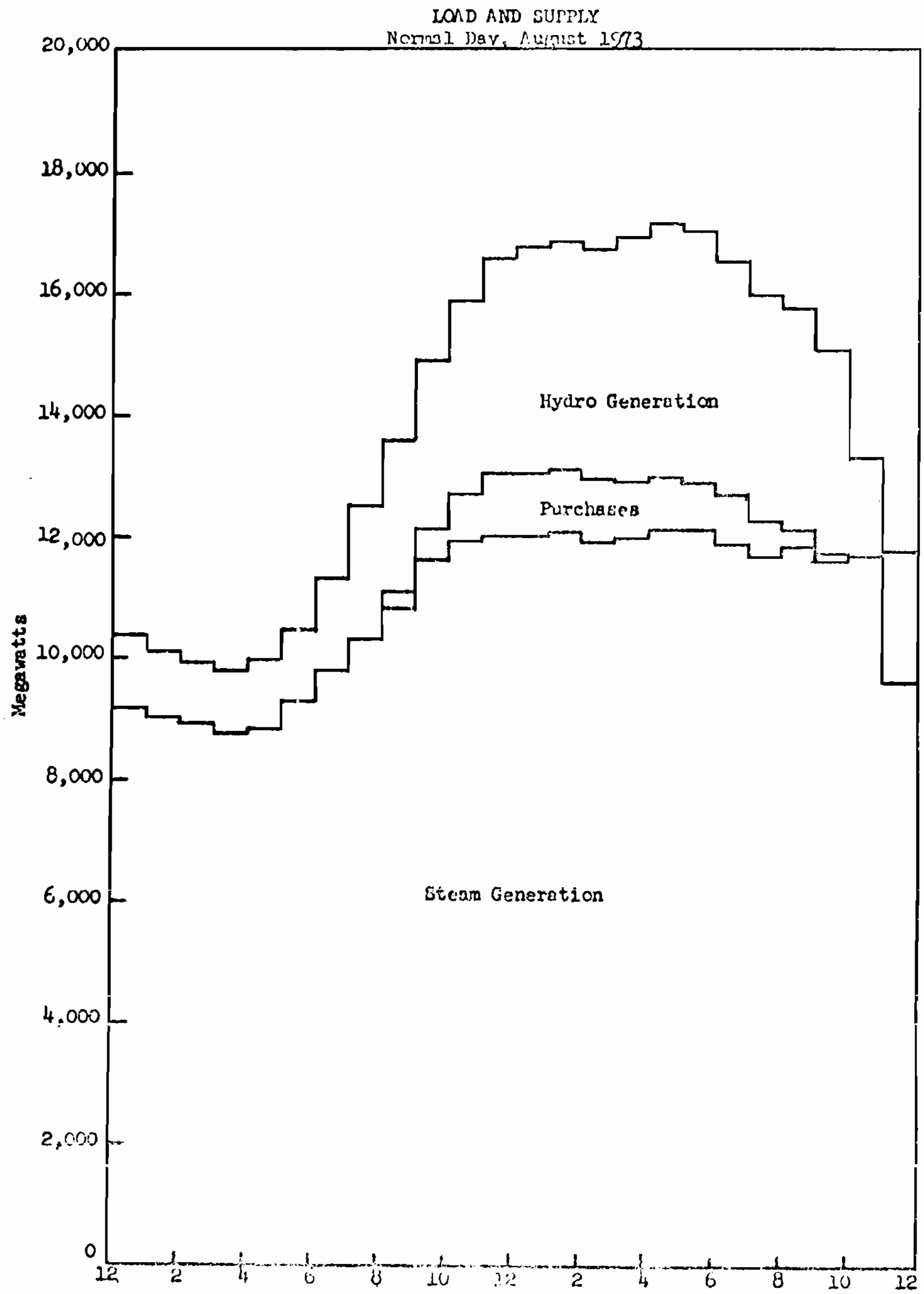
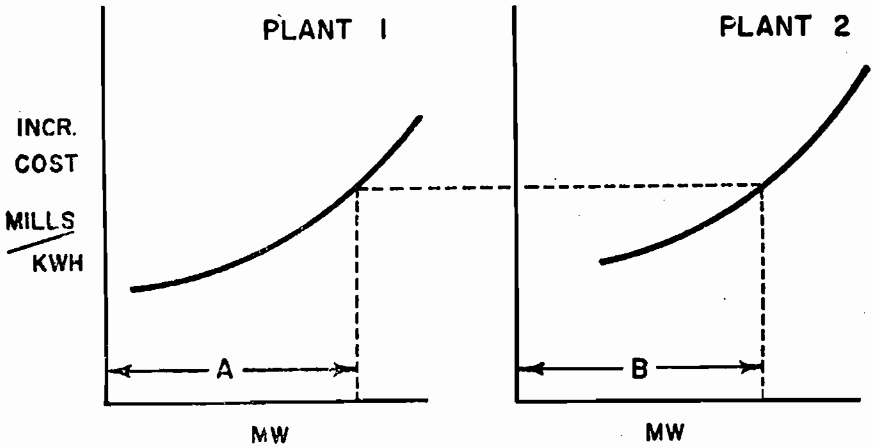


Figure 6



LOAD AND SUPPLY
Normal Day, August 1973
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Megawatts
Hydro Generation
Purchases
Steam Generation
12
2
4
6
8
10
12
2
4
6
8
10
12

Figure 7



LOAD + LOSSES = A + B

ECONOMY LOADING
(NEGLECTING INCREMENTAL LOSSES)

Note: The justifiable incremental cost of generation is the same for all plants. In operation, this cost is changed as required to provide more or less total generation.

Figure 8

INCREMENTAL COST OF DELIVERED POWER

(PLANTS IN ECONOMIC BALANCE)

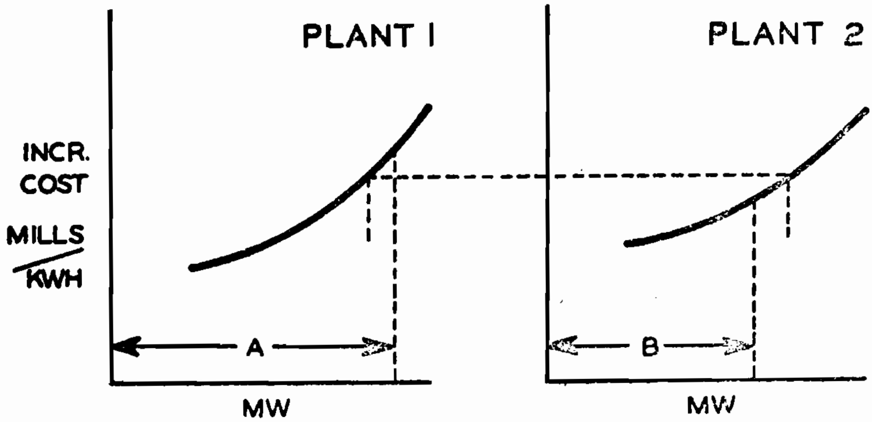
	GENERATION	LOSSES	DELIVERED POWER		LOSSES	GENERATION
	100	3	97	190	10	200
	101	3.06	97.94	190.90	10.10	201
INCREMENT	1	.06	.94	.90	.10	1

INCREMENTAL GENERATING COST	2.00	1.92

INCREMENTAL DELIVERED COST $= \lambda = \quad \frac{2.00}{1-.06} = 2.13 \qquad 2.13 = \frac{1.92}{1-.10}$

$$\lambda = \frac{\frac{dC}{dP_n}}{1-\frac{\partial L}{\partial P_n}} \qquad\qquad \frac{dC}{dP_n} = \lambda\left(1-\frac{\partial L}{\partial P_n}\right)$$

Figure 9a



LOAD + LOSSES = A + B

$$\text{JUSTIFIABLE INCR. COST} = \frac{dC}{dP_n} = \lambda\left(1 - \frac{\partial L^*}{\partial P_n}\right)$$

*Incremental transmission losses.

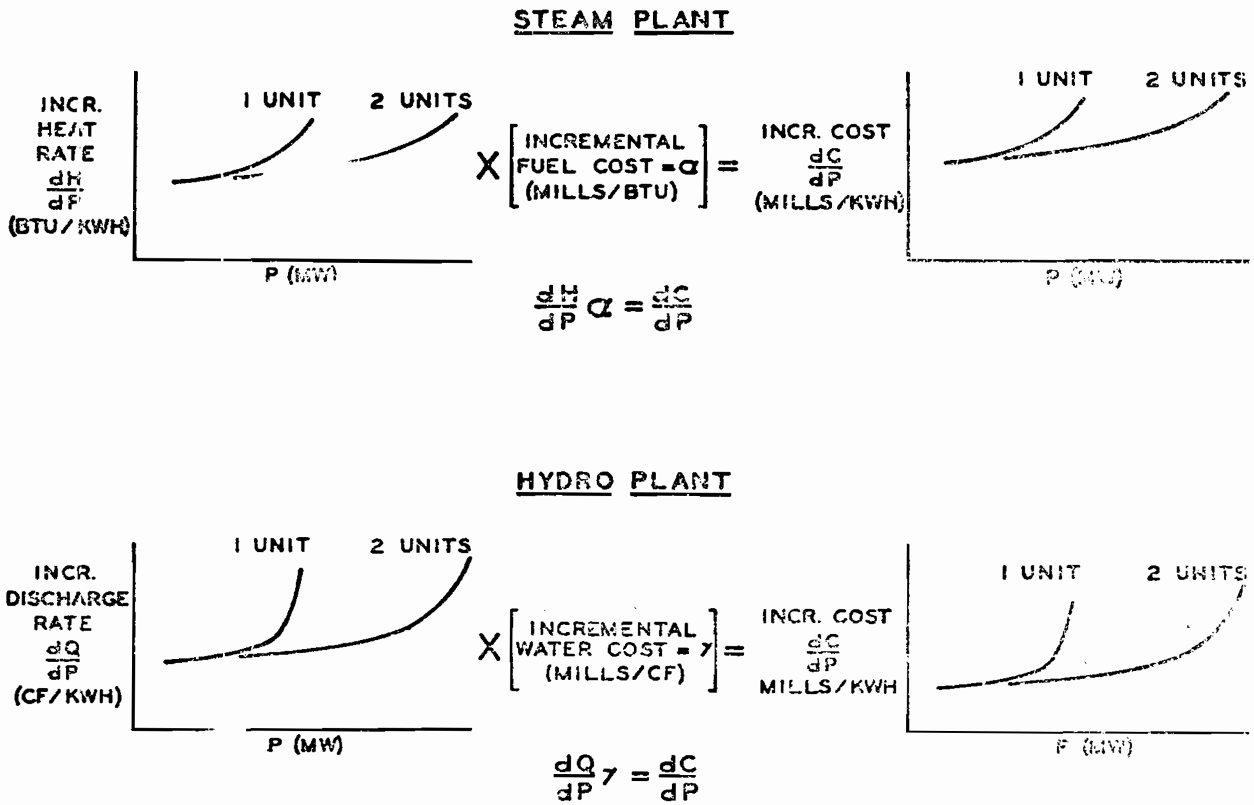
OR

$$\text{INCR. DELIVERED COST} = \lambda_n = \frac{\frac{dC}{dP_n}}{\left(1 - \frac{\partial L}{\partial P_n}\right)}$$

BASIC ECONOMIC DISPATCH PRINCIPLES

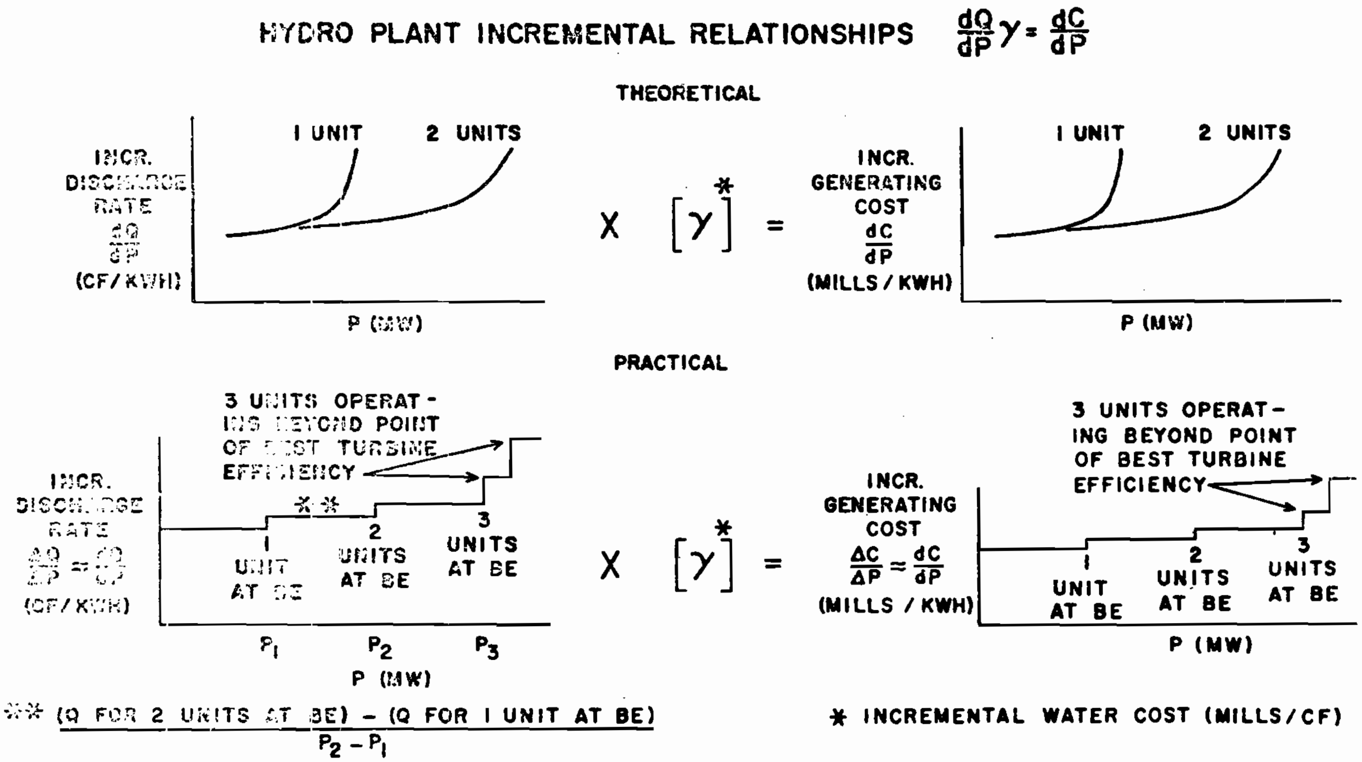
Note: When operating in economic balance, the incremental delivered cost (λ) is the same for all plants. This cost is changed as required to provide changes in the justifiable incremental costs and related changes in total generation.

Figure 95



Typical incremental generating cost curves

Figure 10



Typical incremental discharge and cost functions for hydro plants

Figure 11

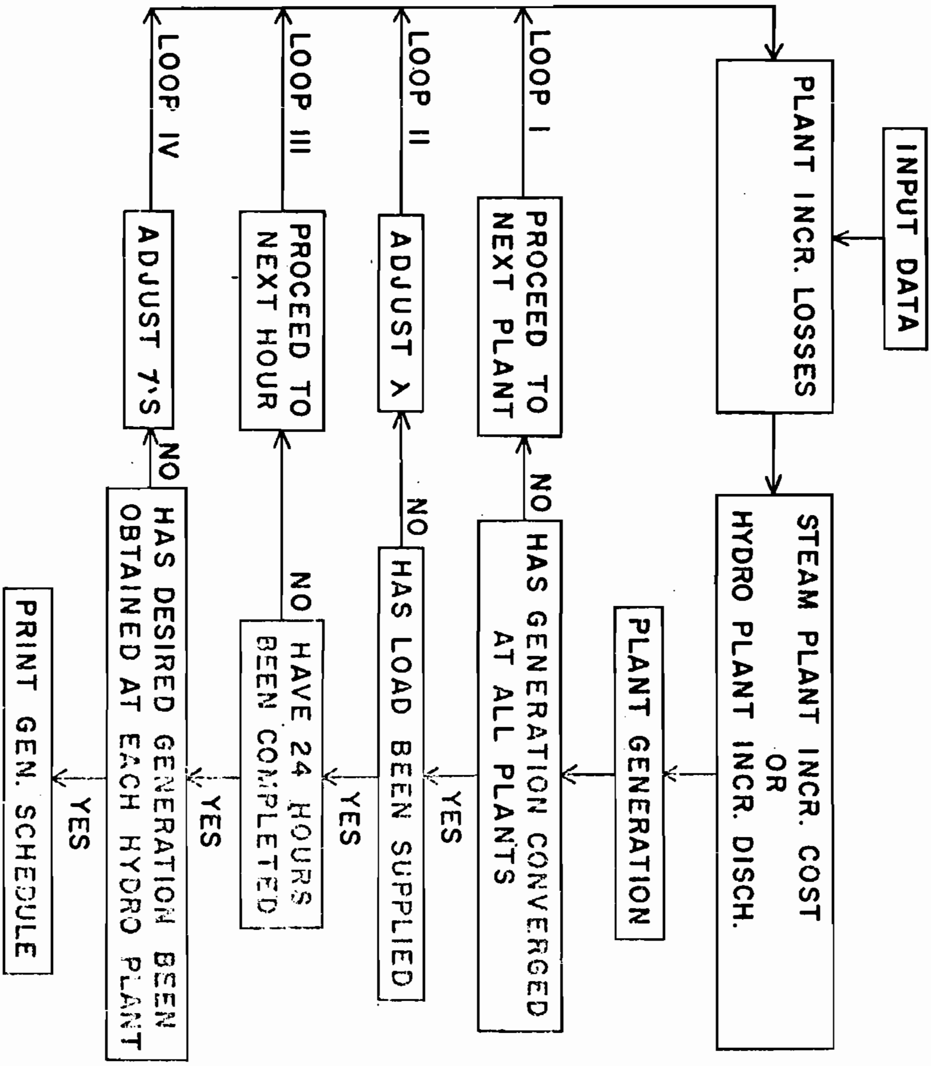

INPUT DATA
PLANT INCR. LOSSES
STEAM PLANT INCR. COST
OR
HYDRO PLANT INCR. DISCH.
PLANT GENERATION
HAS GENERATION CONVERGED AT ALL PLANTS
NO
PROCEED TO NEXT PLANT
LOOP I
YES
HAS LOAD BEEN SUPPLIED
NO
ADJUST λ
LOOP II
YES
HAVE 24 HOURS BEEN COMPLETED
NO
PROCEED TO NEXT HOUR
LOOP III
YES
HAS DESIRED GENERATION BEEN OBTAINED AT EACH HYDRO PLANT
NO
ADJUST γ'S
LOOP IV
YES
PRINT GEN. SCHEDULE

Figure 12

IIASA DISCUSSION PAPER

J. Gros

It was good to find out yesterday about system planning and the inputs to the decision process for planning generation additions. Now we are concerned about operation. The paper describes the cost and limitation routine but other considerations are important. What for instance, is the role of government in operative decisions? Let us look at two hypothetical examples which may illustrate what I am talking about. We have two identical fossil fuel power plants side by side, identical because the generation of electricity is the same but with different air pollution control equipment on them. The one with the better equipment and lower pollution passage has a high cost. Now if one performed the usual cost utilization routine, one would use the environmentally more damaging plant more than the less damaging plant. This may not be permitted, which would be unfortunate from the viewpoint of a utility.

Once again with two plants with cooling--one on a river with spawning fish and the other with a cooling corridor. The plant with river cooling is the cheaper plant though the environmental hazards are greater with such a plant. Again, if one performed a cost utilization routine looking only at the monetary cost, you would load the power plant with one step cooling more heavily because it is cheaper. I believe it is clear that environmental costs should be included. The question is how, since there are no monetary transfers involved. I believe that whatever method is used must include the present conditions, such as whether there is a thermal inversion at either power plant site, the ambient water conditions, and whether fish spawning season in a particular river is affected by the plant.

A related question goes back to another session held this morning where the monitoring systems of TVA for water quality and air quality and fossil fuel plants were discussed. How were the results of the monitoring systems integrated into your operating decision process? I think that other considerations must be included in the action process. Some of these considerations, such as the availability and present stockpile of fuels and preventive maintenance, were not mentioned in the paper.

For other operating problems the question is who should be the actual decision maker? For example, two areas of controversy in the US are voltage cutbacks and load shedding. Voltage cutbacks could reduce the voltage levels from 117 volts AC to some other level, say 100 volts AC. Load shedding for

for most utilities is an interruption of power supply to either certain users or to a region. I would suppose that, when the TVA would interrupt service, you mean service to noninterruptible loads. I believe you call it firm loads. Who should determine the criteria which you use for cutting back the voltage or cutting back service? What cirteria are used? Who should be the actual decision maker? How could guidelines be drawn up in advance to handle these situations?

Another far more ticklish problem in the US is the problem each utility faces of whether to reduce voltage in its own service area or to cut back service to its own consumers in order to aid a utility in an adjacent area.

My final question concerns the trade-offs between flood control and navigation. How is that viewed from an administrative viewpoint, since flood control and navigation are in one department of the TVA and generation of electricity is in a separate department?

TVA COMMENTS ON IIASA DISCUSSION PAPER AND RELATED QUESTIONS ON POWER SYSTEM OPERATION BY J. GROS

What is the role of government in operative decision?

In the United States, both the national and state governments establish standards relating to permitted pollution of the atmosphere and rivers by power plants. For future plants, the national standards shall be controlling, except in those indivudual states with more rigid standards, which shall then apply. For existing plants, the individual state standards are controlling. However, the national government can disapprove of the standards for an individual state, and thereby require that state to establish more rigid standards.

In general, these pollution control standards result in rigid constraints upon the operation of the affected plants. The TVA is not permitted to violate the standards at one plant in order to reduce generation from a plant with higher generation costs which is not violating the standards. As a last resort, loads will be interrupted in order to reduce generation at any TVA plant that would otherwise violate specified pollution limits.

In regard to the two hypothetical examples, the TVA's plants are separated to the extent that two plants do not pollute the same geographical area. If there were such cases, preference in generation supply would be given to the plant with lower generation costs when pollution limits were not exceeded. When the pollution limits for the area would otherwise be exceeded, preference in generation supply would be given the plant with the best pollution control equipment to the extent necessary.

How are the results of the monitoring systems integrated into operating decisions?

The TVA's monitoring and forecasting system associated with the SDEL program results in two types of alerts to system operating personnel. One of these alerts is a warning indicating the probabilities of pollution control action. The second alert is a request for a specified reduction in generation at a particular plant. Such reductions are begun immediately. Investigations are being made of methods for substituting low sulfur coal as an alternative to reductions in generation. The use of divided bunkers with low sulfur coal readily available in half of each bunker is an interesting possibility.

Water quality monitoring systems include both temperatures and dissolved oxygen content. Operating decisions on the use of cooling towers are based on the maximum river temperature below a plant and the temperature rise due to the plant operation.

Such decisions are currently being made at one large coal-fired steam plant and are planned for the Browns Ferry Nuclear Plant and other future plants. The dissolved oxygen monitoring systems affect generation schedules at hydro plants on occasions.

Questions regarding load interruptions and voltage reductions

The TVA has contracts with the several power systems with which it is connected which provide for assistance in times of emergencies and temporary shortages of power. This assistance reduces the occasions for load interruptions and voltage reductions. Also, the interconnected utilities in the entire country have established guidelines for seeking and providing additional assistance. These guidelines, along with other guidelines established by the TVA's Division of Power System Operations, provide for several actions before either reducing voltage or interrupting firm load. These include the peaking of steam plants, running combustion turbines, interrupting loads contractually permitted, and obtaining available power from other utilities. Voltage reductions are indicated before firm load interruptions. Also, the TVA and other utilities will interrupt loads contractually permitted and reduce voltage to prevent the interruption of firm loads of an interconnected utility.

Question regarding trade-offs among power, flood control, and navigation

The law creating the TVA required that flood control and navigation be considered as priority requirements in the design and operation of the various dams. Rather rigid constraints were established to accomplish this. Within these constraints the reservoirs have been used in as near an optimal manner as possible for power purposes. Based on operating experience there have been some trade-offs involved in modifying basic operating guidelines for certain reservoirs, but normally constraints rather than trade-offs have been involved in operating decisions. Current investigations which were reviewed at this conference may result in more frequent consideration of trade-offs in future operating decisions. To assure an unbiased consideration of all water uses by the investigating group, advisors with primary interest and expertise in water use for single purposes were selected.

SUMMARY OF DISCUSSION TOPICS

PART 4

In the discussions which followed the presentations the following people took part:

T. Koopmans	IIASA
D. Kelley	IIASA
J.-P. Charpentier	IIASA
I. Lefkowitz	IIASA
W. Haefele	IIASA
E. Minajev	USSR
K. Hoenigman	Austria
L. Gramotejeva	USSR
U. Daeunert	FRG
H. Kikkawa	JPN
B. Milner	USSR
W. Haetscher	GDR
J. Krutilla	US
G. Marquis	FRG
T. Vasko	CSSR
G. Kolb	FRG
A. Makarov	USSR
H. Wagner	US
C. Zwicker	Canada
G. Bespachotnyi	USSR

The main problem topics discussed were:

- Use of high power transmission lines.
- Future power demands should be met.
- R & D activities of TVA and other power companies.
- Operating reserve provided by TVA to meet contingencies.
- Mechanism by which contingency analysis is brought to bear in determining optimum loading, scheduling, etc.
- Power cost trends.
- Safety measures taken by TVA with respect to nuclear waste disposal.
- Mechanism for coordinating TVA power development programs and the power consuming industry development programs.
- Growth of industry in region with abundant energy.
- Role of nuclear power in the next 10 years.

- Development of fossil fuel in view of its multiple purpose utilization.
- Rate structure in TVA.
- Financing of new plants.
- Economy of scale - capacity of thermal units now in the planning phase and proposed capacities.
- Distribution of costs for 1 kWh.
- Percentage of error in long term forecasting.
- Shaping load curve by encouraging use of power in off peak periods.
- Use of optimization model for capacity and location decisions.
- Possible retrospective study of decisions in view of reduction in power production during past years.
- Nuclear Parks.
- Outage rates.

PART 5

INTEGRATED WATER CONTROL SYSTEM OF THE TVA

The Water Control System and Changes in Multipurpose Use

Introduction

Unified multiple-purpose development of an entire river system was a new and exciting concept when TVA was created by Congress 41 years ago. The agency was directed to provide the maximum amount of flood control, the maximum development of the Tennessee River for navigation purposes, and the maximum generation of electric power consistent with flood control and navigation. These basic development activities--flood control, navigation, and power production--were not new in themselves; but this was the first time these related parts of resource development had been brought together in one comprehensive effort for a major region.

There was mixed reaction to this plan for multiple-purpose development of the Tennessee River system. Some were enthusiastic over the concept. But there were others, some qualifying as experts, who said it was a wild dream. They pointed to the large lakes planned to form a 650-mile (1046 km) inland navigation channel as hazardous to commercial barge traffic--high waves would swamp tows. They argued vigorously that flood control and power could not be partners. "Reservoirs must be full for power and empty for flood control," they said. Obviously, these functions could not be performed by one multiple-purpose system.

Today, there is no question that the development of multiple-purpose reservoirs with their associated benefits has helped make tremendous changes in the quality of life in the Tennessee Valley region. From a predominantly agricultural region, the Valley has evolved into a predominantly commercial and manufacturing region. Flood control has made the shoreline safe for industries and jobs. New opportunities for a secure and productive future in the region have all but halted the tide of migration which in the past swelled the populous northern urban centers. Even in a day when some voices are being raised against more man-made lakes, and multiple-purpose reservoirs, the evidence of the beneficial results of such lakes and reservoirs is overwhelmingly in their favor.

Multiple-Purpose Project Development in the United States

Expansion in America, as elsewhere, occurred along the lines of the waterways, and those waterways were developed as the pressure of expansion increased. The mouths of the rivers afforded many of the best ocean harbors, and from the earliest days great cities developed in such locations. River valleys determined the lines of the first migrations westward, and the locations of many inland settlements were fixed by their geography. From earliest times, therefore, the use and control of America's rivers have been a major concern of the Federal Government.

Multiple-purpose planning and development were recognized in the United States as far back as 1879 in an act creating the Mississippi River Commission to deal with the related problems of flood control and navigation improvement. Since then, legislation covering multiple-purpose projects has been enacted frequently, or Presidential vetoes have blocked legislation which did not reckon with Government interest in multiple-purpose objectives. Court decisions have had an important part in confirming the ever-broadening Governmental interest. Special commissions, Congressional committees, and public agencies have issued report after report, emphasizing policies affecting planning and regulation.

The occurrence of droughts and floods during the period 1925-1940 had a decided impact on national affairs and were contributing factors to the accelerated progress in multiple-purpose planning by the Government. Between 1889 and 1940 there were 11 well-recognized drought years in the United States, five of which occurred during the 1930-1940 decade. Nearly 50 percent of the recorded large floods prior to October 1938 occurred during the eight-year period ending in 1938. The 1927 and 1937 floods in the Mississippi Valley and 1936 floods in the eastern seaboard area, in particular, strongly influenced new and extensive legislation and Government activities.

The rapid increase in water conservation activities during the 1930 decade, culminating in the implementation of the TVA Act of 1933, may be ascribed to several factors: (1) a long-established trend toward increased governmental responsibilities and corresponding expansion in Federal public works; (2) the then current abnormality of climatic and hydrologic conditions; (3) a public awakening to the need for wise utilization of water and soil resources on a scale impossible by private developments; and (4) the requirements of national defense.

The advantages of a Government corporation, such as TVA, for the effective administration and development of multiple-purpose projects furnished further reasons for active Federal participation in the development of local natural resources. Another factor was the tremendous advance made in the theories, methods, and art of manufacture of machinery, equipment, and tools required for economy of development. The TVA Act carried forward the broadening principles of Government interest in the development of the river system.

Unified Development of the Tennessee Valley

For many years, the idea of a unified development of an entire river basin was a great challenge to engineering planners. For the first time in history, the opportunity was afforded in the Tennessee Valley to develop all of the resources of a large region for all of the purposes and potentialities of which it was capable. This development was unique in several other ways.

For the first time a complete river basin was used as a planning unit, overlapping the boundaries of seven states. Also, for the first time the potentialities of the river and its tributaries could be developed for the benefit of the entire region and not just for the benefit of a small area or for a single purpose. And, for the first time all of the purposes for which the river was to be developed were under the administration of a single grass-roots agency instead of a branch of the central Government in Washington.

Moreover, there was a challenge in planning the development of the Tennessee Valley due to its very size as the fifth largest river with regard to discharge in the United States. Certainly the problem of its development was too great to be undertaken by any existing agency and had not TVA been created, progress would have been delayed for many years, and the river would have undoubtedly been developed piecemeal instead of in a unified manner.

This can be illustrated by comparison with the development of other rivers in the United States. The Ohio River had been improved for many years for navigation only and the dams along its main stem, built by the U.S. Army Corps of Engineers, were low dams providing an adequate navigation channel but no flood control or hydroelectric power benefits. The five dams built by the Miami Conservancy District in Ohio were built for flood control only and, while they have served this purpose economically and adequately, they provide no navigation or hydroelectric power benefits. In fact, bronze plaques placed in the bases of these dams warn future generations that the structures should never be used for the generation of hydroelectric power since to do so would destroy their value for flood protection and endanger lives and property below the dams.

On the Coosa River in Alabama, most of the head was developed for hydroelectric power by a private utility, the Alabama Power Company. The dams on this river provide no navigation nor flood control benefits although they have been in operation for hydroelectric power for many years. Proposals have been made to add locks to these dams to make the river navigable--a much greater expense than if locks had been included in the original plan.

Legislative and Policy Background and Policy Adopted

Water control developments on the Tennessee River were few when TVA was established in 1933 with its mandate from Congress to develop the full resources of the river. All earlier efforts were disconnected, isolated attempts primarily to improve navigation at some of the worst rapids and shoals without proper integration for uniformity of development.

A review of the situation in 1933 showed that the existing navigation improvements on the 650-mile-long (1046 km) main stem of the river consisted of four rather widely separated lateral canals with locks, one navigation dam, one Federally owned power-navigation dam (Wilson), one privately owned power-navigation dam (Hales Bar), and numerous lateral dikes and dredged cuts. From the mouth of the river to Florence, Alabama, controlling depth was only 4 feet (1.2 m), and to Knoxville, Tennessee, only 1-1/2 feet (0.5 m). The results were disappointing in terms of either physically improved navigation or economic benefits because the nature and scope of the improvement projects invariably failed to keep pace with the advances in water transportation techniques and the needs of commerce.

Although physical development of the Tennessee was totally inadequate in 1933, the river and its tributaries had for several years been the subject of a detailed engineering study conducted by the Corps of Engineers. This study, authorized by Congress in 1926 and reported upon in a comprehensive manner in 1930, presented alternative plans for the development of the river for the purposes of navigation, flood control, and power.

The "308 Report" was the first such report prepared for many rivers in the United States, and it marked a change in Federal policy on the Tennessee River with respect to multiple-purpose development--one that was eventually to effect the policy on all major streams in the United States. Moreover, it provided a sound basis for the future legislation that established the Tennessee Valley Authority as well as a comprehensive outline for work that was to follow, providing invaluable basic data for detailed planning.

The report proposed two alternative plans for the creation of a nine-foot (2.7 m) channel on the Tennessee's main stem from the mouth of the river to Knoxville. It also recommended that no new project be constructed on the tributaries at that time, but presented preliminary plans for a considerable number of flood control and power dams on all of the principal tributaries.

The two plans for obtaining the necessary minimum depth throughout the river varied in the number and character of the dams required. One alternative contemplated the construction of 32 low-lift navigation dams that would provide a narrow navigable channel of nine feet (2.7 m), but would have no value for flood control purposes, would leave river terminals subject to great fluctuations of water levels, and would not be adapted to the generation of electric power.

The other plan contemplated the construction of seven high dams at selected sites in the main stream. These dams, together with the existing structures, would provide the required minimum depth and more advantageous navigation facilities. In addition, they would provide an effective measure of flood control and would be of such character as to permit the conversion of water power into electricity. This plan, as set forth in the report, was contingent on the cooperation and joint contribution between state or local governments or private power companies on the one hand and the Federal Government on the other.

As a result of the "308 Report," Congress included in the River and Harbor Act of 1930 an authorization for a nine-foot (2.7 m) navigation project from the mouth of the Tennessee at Paducah, Kentucky, to Knoxville. When it became evident that cooperation from utilities or public bodies in the building of high dams could not be anticipated in the near future, the Corps recommended in 1931 the construction of low navigation dams between Wilson and Hales Bar Dams.

The only important unit constructed under the Congressional authorization of 1930 was the Wheeler Lock, which was commenced by the Army Engineers with funds appropriated under the Emergency Relief and Construction Act of 1932.

The site of the lock had been selected and work was under way before the Tennessee Valley Authority Act of 1933 was passed. No funds were made available for the construction of the dam.

The TVA Act

Two sections of the TVA Act provided the early planners with considerable guidance in establishing the framework for TVA engineering activities. In defining the powers of the Corporation (TVA), Section 4(j) provides:

> (The Corporation) shall have power to construct such dams, and reservoirs, in the Tennessee River and its tributaries, as in conjunction with Wilson Dam, and Norris, Wheeler, and Pickwick Landing Dams, now under construction, will provide a nine-foot (2.7 m) channel in the said river and maintain a water supply for the same, from Knoxville to its mouth, and will best serve to promote navigation on the Tennessee River and its tributaries and control destructive flood waters in the Tennessee and Mississippi River drainage basins; and shall have power to acquire or construct power houses, power structures, transmission lines, navigation projects, and incidental works in the Tennessee River and its tributaries, and to unite the various power installations into one or more systems by transmission lines.

Section 9a is an explicit directive concerning the operation of the projects in the system and provides:

> The board is hereby directed in the operation of any dam or reservoir in its possession and control to regulate the stream flow primarily for the purposes of promoting navigation and controlling floods. So far as may be consistent with such purposes, the board is authorized to provide and operate facilities for the generation of electric energy at any such dam for the use of the Corporation and for the use of the United States or any agency thereof, and the board is further authorized, whenever an opportunity is afforded, to provide and operate facilities for the generation of electric energy in order to avoid the waste of water power, to transmit and market such power as in this act provided, and thereby, so far as may be practicable, to assist in liquidating the cost or aid in the maintenance of the projects of the Authority.

These directives were of great assistance in planning and operating the system. Without them, the purposes involved and the priority of one over another would probably have been determined by minority pressure groups, not by application of law to the physical situation. No multiple-purpose projec involving naturally conflicting purposes can permanently succeed without such directives. This is not to say that conflicts can be resolved by passing a law, but the existence of a law as explicit as the TVA Act should leave no doubt as to the purposes which should receive priority in event of conflict.

Interpretation and Implementation

One of the first problems faced by TVA after its formal organization was interpretation and implementation of the statute which created it. It was clear from a perusal of the statute that a river control system, composed largely of multiple-purpose projects, was the intent of the authors of the Act. It was also clear that separate systems of single-purpose projects for all three purposes--navigation, flood control, and power--could not be superimposed on each other, and that an attempt to develop the river for any one purpose alone would forestall development of the other two.

Initial studies by TVA developed a number of conclusions that established the policy for future planning of its water control projects. The series of 32 low navigation dams proposed in the Corps' "308 Report" held a number of disadvantages. Low dams would provide only navigation. The sailing line would follow the original channel and would require boats to stop for locking more than three times as would the system resulting from the construction of seven high dams. Operation and maintenance costs would be high. The power potential of the river could not be developed and, in fact, would be permanently forfeited except at the headwaters. Finally, a navigation only plan would provide no reservoir capacity for flood control and other means would have to be employed if that were to be achieved.

Detailed studies of costs and benefits for several low- and high-dam schemes revealed that a system of high, multipurpose projects on the main stem offered the most economical solution with better facilities for water control. The shortage of good dam sites on the Tennessee River was a dominant factor in expediting the decision to build few but higher dams. This type of main stem development also made possible a fully effective system for hydro generation and flood control, together with a capability for the reduction of flood stages on the lower Ohio and Mississippi Rivers.

Due to the confinement of major floods on the main river to a definite December to April flood season, it seemed entirely feasible to provide for both navigation and flood control without sacrifice of either or without duplication of storage. The seasonal drawdown to provide additional storage for flood control would not encroach on the navigable depths in the pools. At the same time, this drawdown would supplement low flows for power production and help sustain navigable depths on the lower Ohio and Mississippi Rivers. Such drawdown would reduce the power head on the main river only by a small amount.

It would also be physically feasible to superimpose flood control storage on top of power storage in tributary reservoirs in somewhat the same fashion as on the navigation pools on the main river. With higher heads possible at tributary projects, regulation of flow to a more uniform rate by storage, and the use of this water through some 500 feet (152 m) of head at plants downstream, the combined storage could be used for generating power during summer and fall, thus lowering the reservoirs by the beginning of the flood season. The combined storage volume then would be reserved for flood control until near the end of the flood season, when filling would be permitted until drawdown for power was needed. Adherence to the TVA Act would resolve any possible conflict between flood control and power in favor of flood control.

System Planning and Development

As stated earlier, a multiple-purpose system consisting of relatively few projects on the main river and large storage projects on the principal tributaries was ideally suited to carry out the TVA Act and to meet the physical situation. Many studies were required, however, to show that this type of development was the most economical.

In order to determine the relative economics of various schemes of development involving low dams or high dams, comparative costs for three plans were estimated: (1) the 32-dam navigation only plan; (2) an 18-dam navigation plan; and (3) a multiple-purpose 10-dam plan. The latter plan called for an allocation of costs to the specific purposes so that comparisons could be made with the other single-purpose schemes.

This analysis showed that the multiple-purpose scheme of development consisting of eight dams on the main river and two dams on the tributaries would provide navigation, flood control, and power facilities at about three-quarters the combined cost of three single-purpose systems supplying the same facilities. It was also shown that multipurpose structures would provide a superior navigation scheme at well below the cost of the 32- and 18-dam navigation plans while a high degree of flood control and power generation could be obtained. This, together with the clear implication of the statute, was the basis of the decision to build high, multipurpose dams on the main river rather than a system of lower dams for navigation alone.

Report to Congress--1936

Pursuant to Section 4(j) of the TVA Act, the Board of Directors submitted to Congress on March 31, 1936, a report entitled The Unified Development of the Tennessee River System. This report clearly states TVA's policy with regard to the multiple-purpose system of projects:

> A unified plan for the development of the Tennessee River calls for the integration of the primary requirements in the regulation of stream flow for navigation and flood control with the needs for power generation.
>
> The plan for a definite cycle of reservoir operation is being set up in such a way that it will serve best the purposes for which the projects were constructed--navigation and flood control. To a considerable degree, operation for flood control and navigation are consistent with the best operation for the generation of power. For example, the release of flood waters during the period of low flow will increase the prime power capacity of the generating plants on the system, and this increase will be cumulative as the water flows through the successive plants below the point where the water stored in the reservoir is discharged into the main stream.

This policy, established after careful studies of the river, has been scrupulously observed in planning the system.

The 1936 report also pointed out to Congress the great need for flood protection at Chattanooga, Tennessee. Portions of Chattanooga, nestling in a low plain and nearly surrounded by mountains, had been flooded many times. Records show that the most serious flood at this mid-point of the Valley occurred in March 1867, discharging a peak flow of about 459,000 cubic feet per second (13 000m^3/s). It is said a steamboat pushed down the city's main street during the crest of the flood.

The report recommended the construction of three tributary storage dams above Chattanooga to bring flood protection within the limits of possible local protective works. Thus, from TVA's very beginnings, flood control at

Chattanooga has been inseparably tied up with the unified development of the Tennessee River.

Sequence of Project Construction

Once the multipurpose type of development had been decided upon, the order of construction of the various projects to accomplish the purposes enumerated in the TVA Act had to be determined.

Since navigation was the primary purpose involved on the main river, the first concern was to increase the depth in various sections. It appeared logical to improve the least navigable sections progressively from the lower end upstream in order to make streams accessible to other parts of the national inland waterway system as early as possible.

The problem was to select a project which would give a substantial increase in depth over a considerable distance and, at the same time, make a contribution to other purposes. However, the first project to be built, Norris Dam on the Clinch River, was specified by Congress in the TVA Act. This project, completed in 1936, would increase the minimum depth on the main river below the mouth of the Clinch River by one foot (0.3m) through low-water releases during the dry season. It also afforded 1,600,000 acre-feet (2,000 hm^3) of flood control storage, as well as increasing the streamflow at Wilson Dam, acquired in 1933, and Hales Bar, acquired in 1939, for power production.

The lock at Wheeler Dam site was under construction before TVA's inception and this fact made it the next most logical project for construction. Wheeler Dam went into service in 1936 and added 74 miles (119 km) of nine-foot (2.7 m) channel, 350,000 acre-feet (432 hm^3) of flood control storage, and ultimately increased power capacity by 356,000 kilowatts. Pickwick Landing and Guntersville, completed in 1938 and 1939, respectively, added 129 miles (208 km) of nine-foot (2.7 m) channel as well as 590,000 acre-feet (728 hm^3) of flood control storage and, ultimately, 317,000 kilowatts of power capacity to the system.

Chickamauga was completed in 1940, Watts Bar in 1941, and Fort Loudoun in 1943. These three projects provided 837,000 acre-feet (1032 hm^3) of flood storage, 397,000 kilowatts of power, and a navigation channel to Knoxville. With the completion of Kentucky Dam in 1944 near the mount of the river, the nine-foot (2.7m) navigation channel was completed, 160,000 kilowatts of power capacity was added, and over four million acre-feet (4932 hm^3) of flood control storage was provided which could be effectively used for reduction of flood peaks on the lower Ohio and Mississippi Rivers.

The completion of Norris Dam on the Clinch River in 1936 was followed on the tributaries by Hiwassee on the Hiwassee River (1940), adding an effective unit for flood control above Chattanooga. This was followed by Cherokee on the Holston River (1941), Douglas on the French Broad River (1943), and Fontana on the Little Tennessee River (1944). Four other smaller tributary projects with combined flood control and power provisions were started in the 1940's.

Effect of World War II

World War II had a marked effect on the sequence of construction of several of the projects. Generating units were placed in all empty stalls at existing power plants and construction of other projects which had been started was stopped in favor of projects that would provide power capacity sooner for war production.

Kentucky Dam was started in 1938 because it would make available a great length of the 9-foot (2.7m) navigation channel and would also provide a large amount of flood control storage. However, Kentucky would require six years before the first unit would come on line; Fort Loudoun, Cherokee, and Douglas construction schedules ranged from three years to 13 months. Cost estimates made at the time indicated that Kentucky would cost about $16 million more than the other three projects. Moreover, Kentucky, with all five units installed, would have a generating capacity of 160,000 kilowatts, while the combined capacity of the other three projects would total 360,000 kilowatts. For these reasons, it was decided to delay the construction of Kentucky in favor of the other three dams.

25 Years Later--The System in 1958

The period of TVA's activities from 1933 to 1958 saw the virtual completion of the river control system. The system on the Tennessee River and its tributaries consisted of 31 major dams, of which 17 were multiple-purpose structures embracing flood control, navigation, and power. These 31 included 20 dams constructed by TVA, Wilson Dam built by the Government during World War I, and four dams purchased by TVA from private interests. Linked with these by agreement as an integral part of the system were six major hydro projects owned by the Aluminum Company of America.

The system provided a total of nearly 14,600,000 acre-feet (18,000 hm^3) of useful, controlled storage. The navigation channel created by the system extended 650 miles (1046 km) and had become an important link in the 10,000 mile (16 100 km) inland waterway system of the United States. Beside the main channel, the reservoirs provided 225 miles (362 km) of feeder channels, some of them used by commercial as well as recreation craft. The system hydroelectric capacity had grown from 184,000 kilowatts to over 3,700,000 kilowatts.

The TVA river control system in 1958 reflected the wisdom of the early TVA planners as expressed in their 1936 report to Congress which contained their recommendations for the unified development of the Tennessee River system. The 650-mile (1046 km) navigation channel was developed essentially as envisioned in 1936. While the early recommendation called for three tributary storage dams above Chattanooga, it recognized the possible future need for "dams to provide substantial storage on the Holston and French Broad Rivers . . . when their construction is justified." Thus, the construction of Cherokee and Douglas Dams to provide additional flood protection for Chattanooga followed the thinking of the early planners.

The situation with respect to power was difficult to appraise in 1936 because of pending litigation, but it was recommended that provision at dams be made for possible installation of somewhat less than 2 million kilowatts, including the two existing dams. This was approximately 54 percent of the system power actually provided by 1958.

<u>41 Years Later--The Developed System Today</u>

Subsequent to 1958, three major projects have been added to the TVA reservoir system and three other units are presently under construction--Tellico Dam on the Little Tennessee River and Columbia and Normandy Dams on the Duck River.

Melton Hill Dam on the Clinch River was completed in 1964. A dual-purpose project, Melton Hill extended barge traffic some 40 miles (64 km) up the Clinch River to Clinton, Tennessee, and added some 72,000 kilowatts of generating capacity to the hydro system. It was the first TVA lake where state and local planning agencies completed a full land-use plan in advance for the entire shoreline.

Nickajack Dam was completed in 1968 on the Tennessee River as a replacement for Hales Bar, which had been plagued by foundation leakage problems since its completion in 1914. Nickajack added a generating capacity of 97,200 kilowatts to the hydro system, virtually the same as Hales Bar.

Tims Ford Dam, completed in 1970 on the Elk River in middle Tennessee, is the first major dam built by TVA as part of a comprehensive tributary area development program. Tims Ford has a generating capacity of 45,000 kilowatts and the reservoir provides a flood storage capacity of over 220,000 acre-feet (271 hm^3). Operation of the dam has resulted in substantial flood control benefits for the town of Fayetteville, Tennessee, located 43 miles (70 km) downstream. The project is planned to provide opportunities for recreation development, sport fishing, waterfowl hunting, commercial fishing, water supply, and water quality control.

Tellico Dam on the Little Tennessee River is scheduled for completion in 1977 and will provide additional flood storage space for control of floods at Chattanooga. The project includes construction of a 1,000-foot-long (305 m) canal through which the waters of the Little Tennessee will be diverted into Fort Loudoun Reservoir, thereby enabling them to pass through the hydroelectric units in Fort Loudoun powerhouse. The canal will also open Tellico Reservoir to commercial navigation.

As part of a comprehensive plan for the development of the Upper Duck River basin in Middle Tennessee, TVA is constructing two dams on the Duck River--Normandy and Columbia. The dams, which will be operated as a unit, will provide substantial flood protection for the area as well as a new and reliable water source for five major cities and rural users. Normandy is expected to be completed in 1976 and Columbia in 1979.

Today, 34 major dams regulate the Tennessee River and its tributaries. The dams are located in the states of Tennessee, Georgia, Kentucky, North Carolina, and Alabama.

The nine dams on the main river provide a continuous chain of pools which afford a minimum navigable depth of 9 feet (2.7 m) from Kentucky Dam to Knoxville, even at their lowest levels. Capacity above this level is provided in eight of these reservoirs for regulation of flood peaks. Kentucky Reservoir has flood detention capacity of 4 million acre-feet (4932 hm^3) during the winter and early spring. Due to restrictive land rights from late spring to late fall, this capacity is reduced to slightly under 2 million acre-feet (2466 hm^3). The other main river reservoirs upstream from Kentucky provide flood detention capacity totaling about 2 million acre-feet (2466 hm^3).

The tributary reservoirs range in size from 3,800 to 1,920,000 acre-feet (5 to 2367 hm^3) of useful storage capacity and from 480 to 39,800 acres (194 to 16 100 hm^2) of surface area when at full levels. Collectively, they furnish 7,637,000 acre-feet (9416 hm^3) of storage capacity for flood control and power generation, and their total surface area amounts to 186,000 acres (75 270 hm^2). The combined tributary and main river generating capacity totals 4,473,000 kilowatts, or about 19 percent of the total installed capacity of TVA's combined hydro- and steam-electric generating plant system.

<u>Changes in Multipurpose Use</u>

Over the years, TVA has had a variety of occasions to consider operating changes. Some of these have been generated from internal considerations and a great number have been urged upon TVA by the people who live, work, and play around the multiple-purpose reservoir system.

By the late 1940's it was clear that future demand for power on the TVA system would soon exceed the generating capacity of the Tennessee River system. Very little hydroelectric capacity remained to be developed. Consequently, TVA began building large steam plants and stepped up this activity substantially during the Korean War. Today, about four-fifths of TVA electricity is produced in steam plants.

The addition of steam-electric generating plants to the power system has greatly affected the operation of the hydroelectric power system. Steam plants now carry the base power load with hydro carrying the peak power demands during various times of the day, dependent upon the season of the year and streamflow conditions. The effect of this type of operation at hydro plants is a greater variation in flows during the day, with much higher flows during the peak hours and more decided cutback during off-peak hours.

One universal conflict involves the use of water impounded for flood control and power generation on the one hand and water-based recreation on the other. Recreational interests can tolerate fluctuating water levels if those fluctuations are modest. The larger changes necessary to impound and release water for seasonal regulation are considered incompatible with most recreation uses.

In recently conceived multiple-use projects, recreation has been considered in initial planning and the establishment of operating plans. Earlier TVA projects were planned with recreational use strictly as a bonus by-product. Recently, operating guide curves for nine tributary reservoirs were modified after study and evaluation to produce lake levels generally more favorable for recreation use.

When a river is turned into a lake, ripples of change spread among living and growing things. To deal with these changes, TVA maintains a staff of ecological scientists at Muscle Shoals, Alabama. They are supported by an environmental research laboratory, where experiments and studies related to water and air quality are carried out.

One of the first environmental challenges that faced TVA involved malaria, the mosquito-borne disease that affected a third of the population near some of the swampy areas along the original Tennessee River. At the time TVA began building dams on the Tennessee, it was known that some earlier man-made lakes had created new mosquito-breeding habitats and had increased the malaria problem, so there was concern that all possible steps be taken to prevent or minimize such a problem.

The program that evolved is based on control of the mosquito vector. Emphasis is placed on providing an ecological environment unsuitable for its propagation. Mosquito control also is integrated with other program needs and is virtually built into the design and operation of the dams and reservoirs.

Prior to impoundage, reservoir basins were cleared of all debris. Drainage ditches were constructed so that no water would be left stranded in pools along the reservoir margin when lakes were drawn down. In instances involving shallow flats where plant life, and hence mosquito production, would be difficult to control, the mosquito-breeding problem was "built out" by deepening and filling or by diking and dewatering.

The most important postimpoundage measure for the continuing control of mosquitoes on TVA reservoirs is water level management. This control is accomplished at most main river projects by a weekly fluctuation of reservoir levels during the breeding seasons within a zone of about one foot (0.3m) and a gradual recession later in the year. Control measures employed by TVA to supplement water level management include drainage maintenance, plant growth control, and larviciding. Collectively, these measures have just about eliminated malaria in the Tennessee Valley.

Another problem area is that of low levels of dissolved oxygen in the releases from deep reservoirs. Many deep impoundments, including those of the TVA system, were built without providing ways to withdraw water selectively from the reservoir strata having the higher dissolved oxygen content. The benefits of providing such facilities at a later date will have to be substantial to justify the cost. Other methods (such as upstream dams or barriers of some kind or the introduction of air or oxygen into the reservoir) would also be costly and are currently under study. Eventually, however, the demands may be such as to require that the most feasible methods available be applied in some instances.

One of the major concerns for water quality confronting TVA today is the matter of eutrophication, nutrient enrichment of the water and the bottom of lakes. Although eutrophication as a natural process has been going on for millions of years, the question now is whether man is speeding this process and in so doing speeding the growth of nuisance weeds. TVA is actively pursuing its investigation into the unknowns of nutrient pollution. Several small watersheds are being carefully examined for the runoff of chemical fertilizers to the streams through both groundwater and silt carried off by rainwater.

The greatest weed nuisance in TVA lakes is Eurasian watermilfoil, a lacy water plant sometimes used to adorn fishbowls or aquariums. It grows so dense that it clogs coves and blocks boating and swimming. It chokes water intakes and creates an ideal breeding place for mosquitoes. In the Tennessee Valley, watermilfoil first became established on one of TVA's mainstream lakes in the late 1950's (perhaps dumped from a fishbowl). For several years TVA has been battling watermilfoil with chemicals as well as reservoir manipulation. It has been checked but it has not yet been eradicated completely.

Warm water discharges from thermal electric generating plants introduce another major potential for change in water quality and reservoir operations. So-called "thermal pollution" did not pose a serious problem at early TVA steam plants, which were built on rivers large enough to dissipate the heat readily. In fact, the most obvious effect has been the popular winter fishing at steam plant discharge basins, where the warm water attracts fish. But as growing power demands require ever larger plants across the United States, both nuclear and conventionally fueled, there is increasing concern about what effects these heated water discharges may have on fish and other aquatic life.

At the site of TVA's Browns Ferry Nuclear Plant in northern Alabama, large underwater pipes will carry the heated water from the condensers out across the main river channel and release it through thousands of small holes to mix with the streamflow. Mechanical draft cooling towers are also being constructed to provide additional cooling capacity. In addition, studies of reservoir operations are being presently conducted to ensure that ample water flow will be maintained to ensure the diffusion of heated water into the reservoir. At the site of TVA's Cumberland Steam Plant, now under construction, the temperature rise will be held down by large, uniquely designed condensers and by regulation of flows past the facility.

Water quality control for sustenance of fish life or the development of new fisheries is becoming increasingly significant. Although a secondary objective in reservoir system operations, there are times when regulation of releases from the reservoirs can effectively improve downstream conditions. Most of the time these cases can be adequately accomplished by scheduling special turbine releases.

Streamflow management for fish spawning in reservoirs also is given consideration. Fish biologists know that spawning of most game and pan fish in TVA lakes takes place when water temperatures rise in the spring. During the spawning period, the changes in water level must be limited so that the eggs are not left high and dry by a falling lake or covered too deeply by a rising lake. Fortunately, all lakes do not usually reach the critical spawning temperatures at the same time and thus stabilization of several reservoirs can be staggered so as to avoid substantial effect on power system operations.

TVA storage reservoirs have an equalizing or smoothing effect on mineral quality in general. Peaks and valleys of concentrations are smoothed out so that water of more uniform mineral quality results downstream. The equalizing effects of a reservoir on general water quality are quite beneficial to downstream municipal and industrial water supplies because the range of variation and the rate of change in almost all water characteristics are significantly reduced, thus facilitating water treatment.

Development of Economic Evaluations

Four main sets of criteria have influenced TVA's evaluation of water resource projects at various times. Each set has come from a different source and represents differences in planning objectives and evaluation approaches. The sources of the four in chronological order are:

1. Tennessee Valley Authority Act of 1933 (May 18, 1933)
2. Bureau of the Budget Circular A-47 (December 31, 1952)
3. Senate Document 97 (May 15, 1962)
4. Water Resources Council's Principles and Standards (October 25, 1973).

Under the provisions of the TVA Act, Congress assigned TVA the task of making the main river navigable from its mouth to Knoxville. It also provided for maximizing flood control and associated power generation on the main river and tributaries. A set of objectives like this is best approached by examining various alternatives in terms of their cost effectiveness and most of TVA's system of dams and reservoirs were selected on that basis.

A 1950 interagency report, commonly known as the "Green Book," provided the first systematic treatment of the benefit-cost practices then in use. Although this report never became part of the official procedures, it provided a basis for much of the criteria contained in Budget Circular A-47. Under the A-47 criteria, projects were evaluated on the basis of "primary benefits" for functions such as flood control, navigation and hydropower. Recreational types of benefits were considered to be incidental, and Federal hydro-power was to be valued in terms of the cost of the cheapest alternative means of production.

When Senate Document 97 replaced A-47, the general objectives of water resources planning were expanded to national and regional development, preservation of the environment, and well-being of the people. However, the absence of accepted procedures for many of these effects limited implementation. Review criteria used by the Bureau of the Budget discouraged consideration of other effects by emphasizing national income effects. Nevertheless, recreation, water supply, water quality control, and fish and wildlife soon became coequal with the older primary benefits of flood control, power, and navigation. And employment of previously underutilized labor in areas characterized by chronic under-employment was considered a "redevelopment" benefit.

"Principles and Standards," developed by the Water Resources Council, replaced Senate Document 97 and provides the criteria Federal agencies are shifting to in their evaluation of water and related land resource projects. These guidelines provide for the consideration of two objectives, national economic development and environmental quality, and for display of project effects in four information accounts which include national economic development and environmental quality plus regional development and social well-being. Much effort is being expended to develop procedures which will make the multiobjective planning system operational. Section 80 of the Water Resources Development Act of 1974 calls for future consideration of additional objectives and for development of Federal-local cost-sharing criteria.

Although many issues remain unsettled and the practicality of the latest set of criteria is sometimes questioned, it is clear that water resources planning leads other types of public investments in techniques developed to estimate program effects. Each succeeding generation of guidelines has attempted to account for an ever widening range of factors.

Implications for the Future

The resolution of operation problems that will undoubtedly arise in the future of any presently planned system will require new or sharper tools than are now available for evaluation, both economic and social, of the various functions of water control systems. The techniques used today to evaluate some individual functions are reasonably adequate; others are not. In a system designed to serve only one purpose over its useful life, this is not a critical problem, but in a multiple-purpose system it probably will be at some point in time.

Special tools and new methods are needed as TVA seeks refinement of its planning techniques and its methods of operation. A study in this direction is now underway. It is aimed at developing a comprehensive TVA water resources management program. The methods to be developed will consist of several mathematical component models that would interrelate all factors affecting our water resource management. An optimization procedure would also be devised to determine the system design or operations required for best use of the region's water resources.

Experience in multiple-use river development and operation in the Tennessee Valley has attracted the interest of individuals and nations on a worldwide basis. Although this experience cannot be used as a model to be transferred intact to any location, it can be drawn on as man attempts to find adequate methods of approach to problems of making full and balanced use of his natural resources. Trends in water control and water use problems show that only the fullest research and development will meet future needs.

IIASA DISCUSSION PAPER

I. Gouevsky

In my opinion all TVA experience, as far as water resources is concerned, shows that very good results have been obtained under two major types of conditions:

1) objective conditions including:

   a) some extreme abnormalty in climatic, hydrologic and economic conditions, i.e. flood, drought, unemployment, etc.,

   b) increasing needs of complex use of water (and other) resources throughout the region,

   c) tremendous advances made in the theories, methods, and art of manufacture of tools required for economic development and for control; and,

2) subjective conditions including:

   a) a public awakening to the need for wise utilization of water and soil resources on a scale impossible by private developments,

   b) existence of an authority (or an individual group) who can look at the future with current methods and techniques and who is able to implement his ideas whatever happens,

   c) existence of an authority to create the laws and to support investigation and construction throughout the system's development.

Fortunately when the TVA was initiated, all of these conditions were present. This is one of the reasons for its success. But nevertheless when one reads the presented paper some questions arise. These questions are concerned with the following:

1) What are the connections and main influences between the investigated region and all neighbouring regions. Are these influences negligible, e.g., as far as electrical energy and environment are concerned?

2) The paper mentions that four main sets of criteria have influenced the TVA's evaluation of water resource projects at various times. These criteria were set up

by appropriate acts. But from a methodological point of view it is more interesting how these criteria were created. For example, if we consider the last set of criteria called "Water Resource Council's Principles and Standards" we can see these guidelines provide for consideration of two objectives, national economic development and environmental quality. Are these objectives sufficient for satisfaction of the near futures' needs?

It seems to me that before creating any law, such as these principles, we should do some kind of simulation procedure. This procedure will roughly describe the main inputs, outputs and processes of the investigated system under different conditions determined by goals, resources needed for achievement of the goals, etc. After such a procedure has been completed, we could say more definitely that <u>these</u> are our main objectives and create a law for their attainment.

3) The next two questions, I suppose, are more interesting and useful for the nations and organizations just starting to develop similar models for their water resources in the future.

   a) Did the experience of TVA show that we could determine the structure of the system if we know the goals and available resources? (The structure means the number and size of the reservoirs and canals, different kinds of equipment, connections between each other and so on.)

   b) Have any mistakes been made in either planning or in control of the water resource system from a retrospective point of view?

4) One of the most valuable chapters of the paper deals with the problems arising from multipurpose use, e.g., influence of steam-electric generating plants on the operation of the hydroelectric power system, conflict between use of water for flood control and power generation on the one hand and recreational use on the other, control of water level during the breeding seasons to prevent malaria, eutrophication, warm water discharges, water quality control for both sustenance of fish and fish spawning, low levels of dissolved oxygen in the releases from deep reservoirs, smoothing effect on mineral quality. The paper mentioned that these problems are under extensive investigation, and the models have been developed for some of them.

   My questions about these matters are:

   a) Does a planning or operation model exist encompassing all mentioned activities?

b) Suppose for every activity a criterion is prescribed. Could these criteria be ordered? If not, could they be divided into two or more groups and the groups be ordered?

c) Have any measures been developed for the evaluation of the new criteria (national economic development and environmental quality), proposed in "Principles and Standards"?

d) How will TVA models be developed in the future? By refinement where the models are developed to involve more detailed description of all elements and processes in the system, or will you develop a new model for greater use of all resources located in the region?

e) When the TVA was created had the necessity arisen to develop planning and control systems for a given sub-region aimed at:

   i) examining certain principles and techniques prior to their implementation in a large-scale system,

   ii) overcoming so-called "psychological barriers" arising when people do not believe in the success of such innovations.

As far as the IIASA Water Project is concerned, we are now trying to develop a methodology for the control and planning of large-scale water resources systems. After that this methodology will be implemented by National Member Organizations in different river basins taking into consideration physical, economical, social and environmental processes. In keeping with this, we are very interested in the establishment of close relations for exchange of information with TVA's scientists concerning: for example, multiobjective techniques, water quality control, risk evaluation, and conflict resolution. Some of these matters I think will be the subject of other, more specific, papers.

TVA COMMENTS ON DISCUSSION BY I. GOUEVSKY

Most of the major benefits arising from the unified development of the Tennessee Valley's water resources have influences that go outside the region. Flood control operations on the Tennessee River make substantial contributions to the reduction of flood stages on the lower Ohio and Mississippi Rivers. The electric power generated by TVA dams, as a part of the total TVA power system, is interchanged with other power systems outside the region. The Tennessee River is also a part of the interconnected Inland Waterway System of the United States which extends from the Great Lakes to the Gulf of Mexico and serves a trade area from the Rocky Mountains to the Atlantic Coast.

In terms of the TVA, the objectives of national economic development and environmental quality as developed by the US Water Resources Council do not appear to be a sufficient limit on meeting the Tennessee Valley's near future needs. The Council began its review of Principles and Standards for planning water and related land resources in 1968 to carry out the Water Resources Planning Act. After a preliminary report was issued in 1969, it was reviewed by numerous organizations and individuals both within and outside the Federal Government. As a part of this process, the proposals contained in the report were subjected to extensive analytical testing--tests which indicated that the multiobjective approach to planning was practical.

It has been the TVA's experience, primarily because of the specificity of goals for water resource development in the region, that the structure of the system can be determined if the goals and available resources are known. In retrospect, two specific areas come to mind where improvements could have been made in the planning and construction of early TVA Hydroelectric projects: 1) more flexible outlet arrangements for water withdrawal from the dams as an aid to water quality; and 2) provisions for additional generating capacity to be added to hydroelectric plants at later dates and when needed.

The TVA is currently undertaking a project which will develop for the Tennessee River water control system comprehensive procedures which will allow simultaneous consideration and evaluation of all operation objectives in day-to-day water resource management. These procedures will provide guidance for optimizing the total public benefit derived from the region's abundant water supply while operating the system within statutory and environmental constraints. The project will expand presently used decision-making procedures utilizing currently available advanced technical skills and methods in a systems analysis framework.

The activities are aimed at the development of four mathematical models considered essential for day-to-day water resource management: a) weekly planning model; b) daily planning model; and c) daily operation model. All proposed models are primarily designed for operation planning and as decision aids in day-to-day real-time system operation. However, the "operation planning" models also will be useful tools for project planning and design studies in a total system context of new additional water resource and/or related projects. Indirectly, the models will be able to assess the two objectives proposed in the US Water Resources Council's Principles and Standards.

DEVELOPMENT OF A COMPREHENSIVE TVA WATER RESOURCE MANAGEMENT PROGRAM

1. INTRODUCTION

In recent years water management has become more complicated due to increased water quantity and quality demands, more diversified and often conflicting interests in water use and a growing public concern about environmental quality. As a consequence more and sometimes severely limiting constraints have been imposed by which the water resource system must be operated. In response to these developments, TVA has initiated a program to improve the capability of presently used planning and operation methods for the river and reservoir system. This program is planned to produce a set of mathematical models which will be used as decision aids for planning and real-time operation of the reservoir system. The models must be sensitive to all essential operation objectives and will enable the system operator to rapidly evaluate management alternatives and the tradeoffs resulting from management decisions. Also included in the program are the measures necessary to implement the models.

The program consists of three steps each of which will yield results of practical significance over a period of about 10 years. The first two steps will be completed by the end of 1974. Step 1 is an application of existing systems methodology to evaluate the impact of a large nuclear plant on economy, water quantity and water quality characteristics of the system. The second step assesses the applicability of modern systems analysis techniques to system operation planning and management. The third step will comprise the principal program to develop for the TVA reservoir system comprehensive procedures which will allow current evaluation and consideration of all essential operation objectives such as flood control navigation, power production, water quality maintenance, water supply and recreation in day-to-day water resource management.

In chapter 2 the system operation objectives are defined and examples are given of present and future operation problems facing the system manager. Chapter 3 is a summary of methods used and results obtained of the Browns Ferry impact study illustrating the complex interactions in the system. In chapter 4 results are discussed dealing with a comparative study of several optimization methods potentially useful for release scheduling. Chapter 5 describes the development of a long-range planning model for reservoir system operations using dynamic programing by successive approximation. Also the development of a multiple purpose objective function for hydropower and flood control used in conjunction with this model is described. In chapter 6 future model development plans are outlined. Chapter 7 contains the conclusions and an outlook for the future.

2. SITUATION

The present day-to-day operation of the TVA system must achieve among others the statutory objectives of "maximum amount of flood control, maximum development for navigation purposes and maximum generation of electric power consistent with flood control and navigation and bring about the social and economic well being of the people living in the basin."

A few specific problems, some already encountered in present day-to-day operations, others expected to arise or to become more accentuated in the future, are used to illustrate the water management situation.

TVA operates a large hydrothermal power system consisting of 34 major hydro projects. Also nine hydro projects on the Cumberland River are coordinated with TVA operations, see figure 2.1. Of TVA's present 12 steam plants nine are located on the Tennessee River and its tributaries or on the Cumberland River using the water resource mostly for condenser cooling purposes. In the near future two large nuclear plants with river cooling capabilities will be added. These plants may require specific hydro operations for condenser heated discharge dissipation when operated on the river. Comprehensive system operation planning can produce a balanced schedule such that most beneficial use is made of available system capabilities within all system constraints (see chapter 3).

Considerable impacts on the reservoir operations result from unscheduled outages of large thermal units when the hydropower resource is usually used to compensate at least temporarily for sudden capacity losses, sometimes causing considerable tributary reservoir drawdown. Planning for such events compatible with flood control requirements is needed.

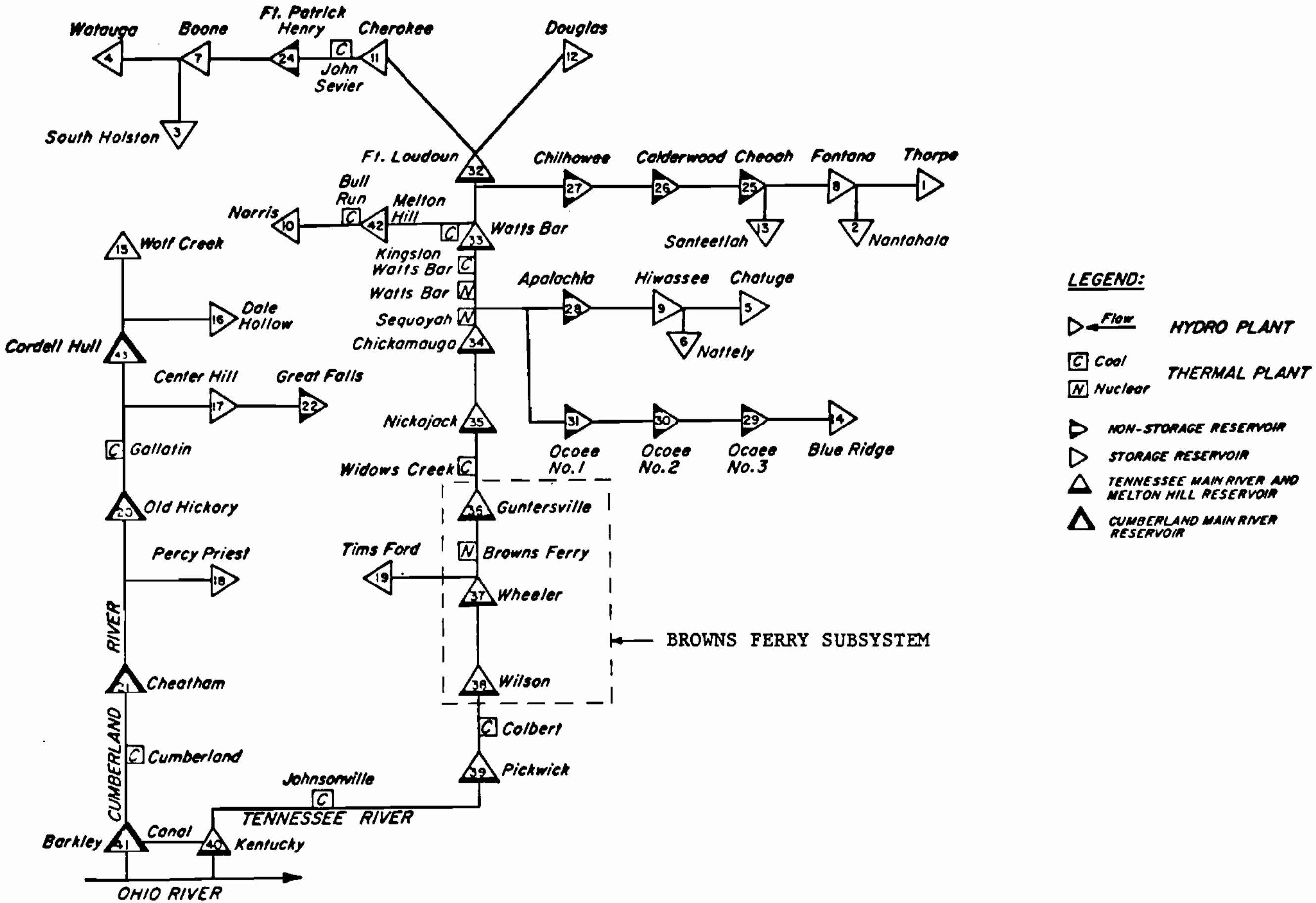


FIGURE 2.1 TVA RESERVOIR SYSTEM (CUMBERLAND RIVER INCLUDED)

Frequent and fast release schedule adjustments are required in the combined Tennessee and Cumberland reservoir systems because of the transient character of hydrologic and meteorologic input data, thermal unit schedules and electrical loads. Presently, optimal scheduling for all objectives is beyond the capability of existing methods.

Reservoir operations are still essentially based on so-called "rule curves" which were developed by multiple objective considerations yet without the benefit of modern system analysis techniques and high speed digital computers. There are indications that significant improvements in water resource management can be achieved by more comprehensive planning and operation procedures using optimization techniques. The annual benefits derived from such improved methodology may easily amount to several million dollars.

It is recognized that the impoundment of water in large and deep reservoirs is producing in some instances deleterious effects on water quality. The interrelationships between reservoir system operation and system water quality regime are very complex. For example, it has been found that the large and deep storage reservoirs can respond to operation and inflow events early in the year by development of particular water quality patterns within the reservoir and downstream many weeks or months later. Some predictive tools for water quality development in rivers and reservoirs already exist. However more modeling capability is needed. Especially lacking is a scheme tying together the various component models in a system-wide water quality transport model.

Some of the more severe impacts of flow control on water quality occur during periods of low or zero releases from reservoirs. Future stream flow requirements for water quality maintenance in the affected river reaches may require changes in the release schedules of controlling dams and thereby produce considerable changes of the present water quantity and quality regime in parts of the system. The benefits from such water quality management operations remain to be determined.

Cold water releases from reservoirs are important for industrial and municipal water supply and for cold water fisheries. Any change in reservoir operations which would change present cold water supply capabilities could generate numerous repercussions.

Steadily increasing recreational demands on the system could best be served by high and constant water levels over long periods or over the entire year. Recreational demands require emphasis on water quality maintenance within and downstream from reservoirs as well as fish and wildlife enhancement. Competing with these objectives for storage especially in the tributary reservoirs are flood control, stream flow augmentation and hydropower production.

Fish and wildlife management and water quality improvement are requiring various operational restraints such as reduction of reservoir level fluctuations during the fish spawning season and release reductions during time of low outflow dissolved oxygen concentrations thus interferring with hydro peaking use.

Increasingly complicated decisions arising from such diversified interests in reservoir use have to be made by the system manager. Knowledge of the tradeoffs resulting from such decisions will be helpful in the decision-making process.

The great challenge for the proposed program is to tackle this variety of problems by proper allocation of the water resource to the various interests to achieve overall optimal results in terms of a "best solution for the social and economic welfare of the people." Admittedly, not all the answers are available at the present time.

3. SYSTEM SIMULATION FOR WATER RELEASE SCHEDULING

3.1 Purpose

The addition of Browns Ferry Nuclear Plant (3 units with a total capacity of 3,400 MW) to the TVA hydrothermal power system raised the question of how such a large component would interact with the system and what assistance could be provided by the water system to operate the plant most efficiently within all current system constraints. More specifically, the study was to examine the effects of various plant operation modes on economy, water quantity and water quality parameters of the system. In principle, this type of investigation would have required the availability of models proposed by the methodology development program described in this report. However, the time frame of this study required the use and adaptation of available systems methodology.

The plant has three possible ways of condenser cooling: by river, by towers, and by river and towers combined (helper). Also considered was the possibility that river and helper cooling can be used with or without upstream water scheduling. It was assumed that when cooling with the river alone the plant capacity would be reduced as required to stay within the legal water temperature limits (5°F maximum rise above ambient water temperature; 86°F maximum temperature) in the mixing zone of heated water discharge (1450 ft^3/s per unit) and river flow. After reaching a minimum power level (25% of nominal capacity) total plant shutdown would occur. It should be emphasized that this case is hypothetical since cooling towers are under construction at Browns Ferry. With towers, no such capacity reduction is required; but capacity losses are incurred due to efficiency reduction by less efficient steam condensing. Combination of cooling facility use and system scheduling led to the definition of four cooling modes to be tried in the study: river alone (mode 0)*; closed towers alone (mode 3); any of the three cooling facilities with upstream release scheduling for river and helper use (mode 1) and any of the three cooling facilities without upstream scheduling (mode 2). All operations had to be compatible with existing system constraints and guided by system economy.

The impact of these operations on system economy was represented by power economy parameters, such as total system generation cost, Browns Ferry plant capacity and cooling facility use. Water control was represented by river flow at the plant site and water levels in the major tributary reservoirs Fontana, Cherokee, Douglas and Norris. Water quality was represented by the resulting river temperatures at the plant site and outflow temperatures from the same four reservoirs. Emphasis was placed more on highlighting the complex system interactions than on a complete analysis of all possible methods of operation.

Four principal mathematical models were used:

- a system scheduling model by weekly time steps
- an hourly scheduling model for a subsystem consisting of Browns Ferry Nuclear Plant and Guntersville, Wheeler and Wilson hydro plants, see figure 2.1
- a water temperature generation model for weekly average water temperatures at the steam plant site, and
- a deep reservoir water temperature prediction model.

---

*this mode is hypothetical since cooling towers will be available.

Brief descriptions of the models are given in the following sections.

3.2 Weekly Scheduling Model

The basic concept of scheduling the TVA hydrothermal system has been described by Brudenell and Gilbreath (1959). A weekly scheduling model originally developed by TVA's System Loading Branch was modified and expanded for the purposes of the Browns Ferry impact study (TVA, 1973a). The model simulates weekly steam unit selection and division of generation between hydro plants and steam plants to achieve most economic power production to meet the load of a given project year and to maintain adequate storage levels in the reservoirs for multipurpose uses. The program starts with reading the week's flow and temperature data for a selected historic flow year, the steam unit availability and cost table, the values of hydro storage and other system configuration data and proceeds with checking various multipurpose use rules. It then enters the hydro scheduling routine to compute a first hydro generation schedule for 41 hydro projects and determines a feasible Browns Ferry operation dependent upon the resulting flow and the given (or externally generated) water temperature at the plant site. All steam units are then selected from a list of available units for 11 steam plants up to a predetermined cost level. After secondary adjustments a new steam unit selection is made by balancing steam and hydro costs. After this first pass through the iterative process of balancing steam and hydro costs, the program returns to Browns Ferry capacity selection and then again adjusts the necessary hydro generation and so on. When the steam-hydro cost balancing is completed by reaching equal steam and hydro costs within a given tolerance, the final capacities, costs and resulting water temperatures are computed and the next week's computation is initiated. The program is entirely TVA system oriented.

Its scheduling procedure is economically guided by use of externally computed average values of hydro energy in storage for balancing steam and hydro use. For this reason the program strictly speaking can only produce averages based on several flow years. Only three selected years were investigated, the choice being based on the flow and its annual distribution at the plant site: a wet year 1950; a dry year 1954 and an average year 1955.

3.3 Hourly Scheduling Model

A more detailed analysis of Browns Ferry operations and cooling facility use than could be provided by the weekly model was made by an hourly scheduling model (TVA, 1974a). The weekly averages or totals produced by the weekly model were disaggregated into hourly distributions such that the total system was approximately scheduled by hours. The hourly schedules for Guntersville and Wheeler were then iteratively adjusted to equalize the hourly incremental value of water between periods with storage at a limit. The adjustment consisted of rescheduling all hours in a chronological order to make all hourly values equal to the average of the last iteration between periods with storage at a limit. Wilson was scheduled the same as Wheeler because it was assumed that the small Wilson Reservoir capacity would not allow it to be operated independently. Only the Browns Ferry subsystem, consisting of Browns Ferry, Guntersville and Wheeler-Wilson, was iteratively rescheduled. The remaining system was held constant except for net steam load, steam cost, Browns Ferry flow and cooling water value which were updated for each schedule change. The value of hydro use included steam costs saved by hydro use and by the improvement of Browns Ferry.

efficiency over the tower mode if either river mode or helper mode could be used. The year 1969 was selected for analysis since it was the first year with almost complete hourly records of water temperature and meteorological data at the Browns Ferry site.

The scheduling problem was complicated by the need to relate the flow at the Browns Ferry site to discharge four hours and one hour earlier, respectively, at Guntersville and Wheeler which precluded the use of other scheduling methods, such as dynamic programing.

The scheduling method used was not entirely successful in monotonically decreasing the weekly steam generation costs, but time and resource limitations precluded the development of a better method.

3.4 Deep Reservoir Temperature Prediction Model

The water quality impact was simulated by a deep reservoir temperature prediction model (TVA, 1973b). The model is a simulation solution of the complex equation system describing the unsteady flow-density interactions in a warming and cooling water body over a yearly cycle. In the model the reservoir is viewed as homogeneous in temperature in the horizontal plane at all times with temperature variations only occurring in the vertical direction. For this reason the model is termed "one-dimensional." Water movements into and out of the reservoir are affected by vertical density variations caused by nonhomogeneous temperature distributions. The resulting complex water movements are simulated in a simplified manner by the model. In context with the Browns Ferry study only outflow temperatures were considered. Therefore, in order to simplify the use of the model the same inflow temperatures and heat transfer data were used for all years. This simplification can be justified by the fact that inflow, outflow and reservoir levels have a dominant influence on water temperature development in deep reservoirs.

3.5 Weekly Water Temperature Generation Model

In the TVA region certain types of data records are available over many years while others are not. Flow and air temperature data belong to the first type, water temperatures to the second. The need arose in context with the Browns Ferry study to extend the record of water temperatures by using a common short period of water and air temperatures as base. The data generation model consists of a seasonal component extracted from the limited water temperature record (12 years of weekly averages) to which a residual component is added obtained by correlation of water and air temperature residuals (TVA, 1973c). A similar method was used on Ohio River data by Kothandaraman and Evans (1972).

The data generation model is

$$TW(t) = FW(t) + RW(t) \qquad (3.1)$$

where TW(t) is the generated water temperature; FW(t) is the seasonal component of water temperature and RW(t) is the residual water temperature. It was found that a one-harmonic Fourier approximation adequately reflected the weekly averages of Browns Ferry water temperature:

$$FW(t) = 64.40 + 19.97 \sin((2\pi/52)\, t + 4.17) \qquad (3.2)$$

with FW(t) being in ^{o}F and t the week number from 1 to 52. The residual water temperature was computed by linear multiple regression

$$RW(t) = A + \sum_{j=o}^{k} B_j\, RA(t-j) + E(t) \qquad (3.3)$$

with A and B_j regression coefficients, RA the residual air temperature at time t-j and E(t) a random component. The residuals were computed by

$$RW(t) = TW_o(t) - FW(t)$$

and $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (3.4)

$$RA(t-j) = TA_o(t-j) - FA(t-j)$$

with TA being the air temperature; index o meaning "observed" and FA being the seasonal air-temperature component. Tests revealed that the serial correlation coefficient rapidly decreased after j=2. Therefore, only j=0, 1 and 2 were used.

Also it was found that only a slight reduction (10 percent) in the standard deviation of the generated data resulted when the random term was omitted. Therefore, the final regression on the residuals was

$$FW(t) = 0.179\ RA(t) + 0.228\ RA(t-1) + 0.145\ RA(t-2) \qquad (3.5)$$

The procedure was tested by comparing generated and observed data for all years of record. A sample of this comparison is shown in figure 3.1. Most of the years showed a remarkable agreement between observed and generated data. A similar procedure was used to generate time series of inflow temperatures for reservoirs used in water temperature predictions.

3.6 Results and Conclusions

Results are discussed on various aspects of the interaction between Browns Ferry operations and the remainder of the TVA system as well as some effects of present system operation constraints:

1. By considering the annual totals of system electrical energy generation costs, system peak energy shaved and Browns Ferry capacity reduction and cooling tower use, it was concluded that

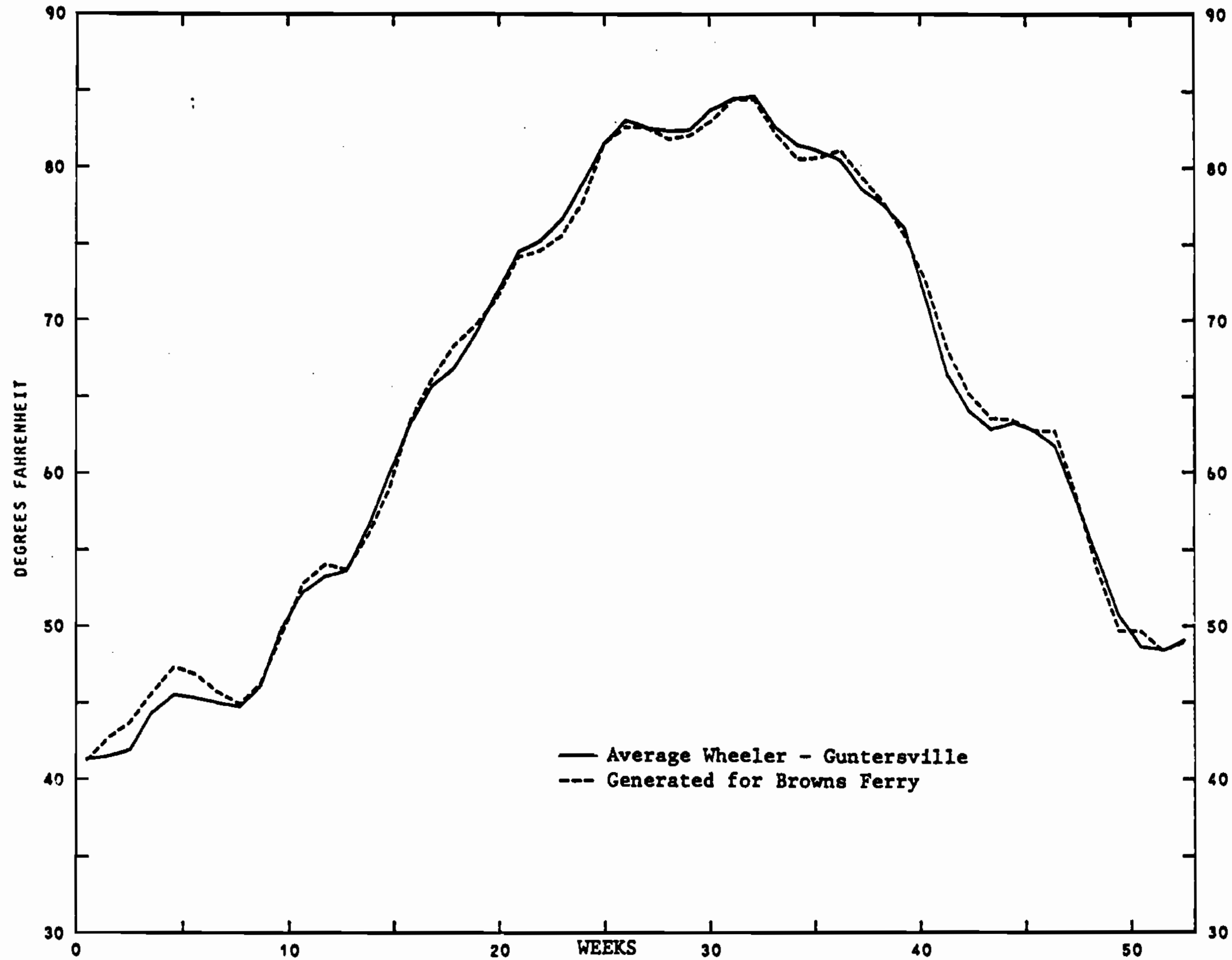


FIGURE 3.1 COMPARISON BETWEEN DATA AND GENERATED WATER TEMPERATURES FOR THE BROWNS FERRY SITE, 1964

mode 1 was most economic closely followed by mode 2. The river mode 0 was least economic due to shutdown periods forced upon the plant during periods of water temperatures at or above the limit set by the standard. Using all available system capabilities and still operating in compliance with all system constraints (mode 1) indicated savings of about 2 million dollars over exclusive tower use and the salvage of 50 MW (for 2 units) installed capacity at Browns Ferry which otherwise would have to be dissipated as additional waste heat through the towers. This capacity represents an investment of about 15 million dollars and a 3 million dollar annual power revenue.

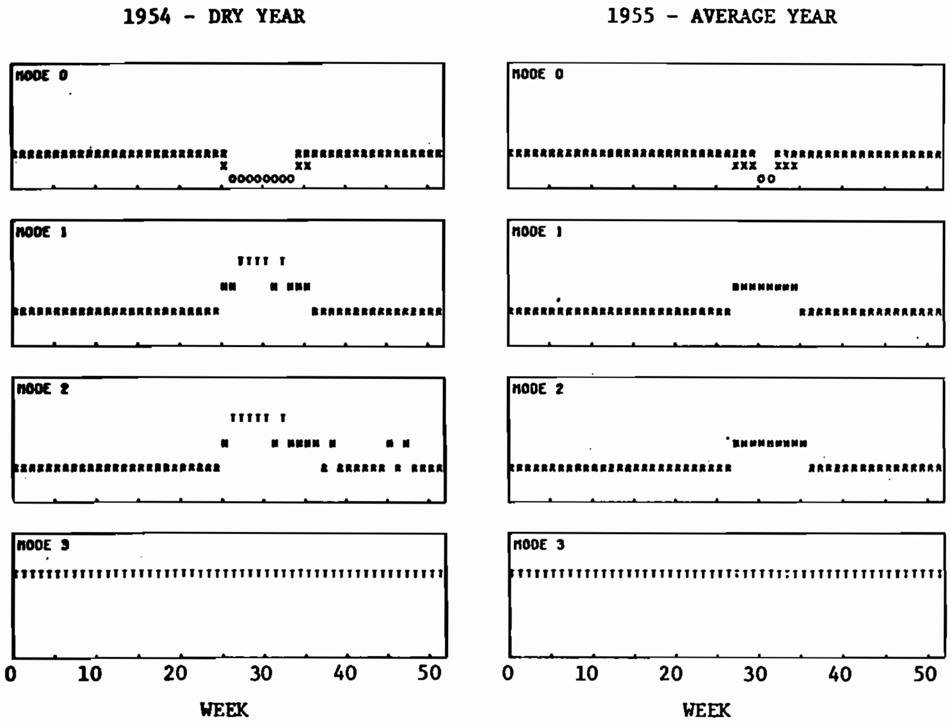
2. Mode 0 was found to be impractical under current temperature standards due to an average 3-week shutdown period per year when river temperatures are at or above 86^{o}F. During the shutdown period power would have to be compensated to the extent possible by more expensive units by increased hydro production and by purchases, the rest being peak shaved. Use of more expensive units would result in an average 5 million dollar annual power generation cost increase over mode 1.

3. The total value of the water passing the plant site based on efficiency improvement of Browns Ferry when using the river was estimated at 2 million dollars annually or about one-half percent of total system generating costs. It was also found that hydro peaking at the upstream and downstream project was sometimes more economic than providing more balanced flow for Browns Ferry cooling purposes. This is to a great extent due to the fact

that Browns Ferry is located directly upstream of the two largest TVA hydro projects, Wheeler and Wilson with a combined capacity of about 1000 MW, which are generally operated in tandem because of the small Wilson storage capacity.

4. Examples of cooling facility use in all modes for 1954 and 1955 as scheduled by the weekly model are shown in figure 3.2. For the wet year 1950, river cooling was possible throughout the year in modes 0, 1 and 2. A comparison of weekly and hourly predictions of tower use showed that the weekly prediction was in good agreement with the hourly schedule (98 percent of time) when there was a full $5^{\circ}F$ rise available and the weekly model scheduled river or when closed tower cooling was required. When the temperature rise was less than $5^{\circ}F$ and the weekly model predicted helper use, the hourly model scheduled helper about 65 percent of the time and the rest mostly closed tower cooling.

5. A comparison of cooling tower usage was made based on observed past river flows and temperatures (before existence of Browns Ferry) and simulated flows obtained by the scheduling models. Since the flow at the site can be controlled upstream and downstream by hydro projects major differences in release patterns at these projects were expected and confirmed by the results. While the study based on historic data predicted tower use 30 percent of the year, the simulation results predicted only 15 percent, the difference being caused by a change in flow regime in Wheeler Reservoir due to consideration given to economic water scheduling.



R = river
H = helper
T = tower
X = reduced operation
O = plant shutdown

FIGURE 3.2 ANNUAL DISTRIBUTION OF COOLING FACILITY USE AT BROWNS FERRY - 1954 AND 1955

6. The maximum temperature limit of 86°F was found to have more effect on cooling facility use than the 5°F maximum rise. The 86°F limit causes plant shutdown in mode 0 during periods of high river temperatures and precludes any use for cooling of the considerable flow at the site during the same periods caused by increased hydro project use on the upstream tributaries. During the year 1969 which was investigated on a weekly as well as on an hourly basis, only 7 percent of the time the full 5°F rise was used; 80 percent of the time the rise was 3.2°F and less, see figure 3.3. The annual temperature regime at the Browns Ferry site and the resulting temperature rise for the various modes is shown in figure 3.4. In the dry and warm year 1954, the natural temperature rises above the limit of 86°F and precludes any use of the river for heat dissipation.

7. Due to the scheduling method used, in all investigated years only a very minor impact on tributary reservoir levels resulted from scheduling upstream hydro projects to provide dilution flow at the Browns Ferry site in mode 1. Also the impact of mode 0 on reservcir levels was small in all years except when Browns Ferry shutdown became necessary due to high water temperatures at the site, a situation which cannot be influenced by upstream scheduling. Thus, in the dry year considerable drawdown occurred by increased hydro use as shown in figure 3.5.

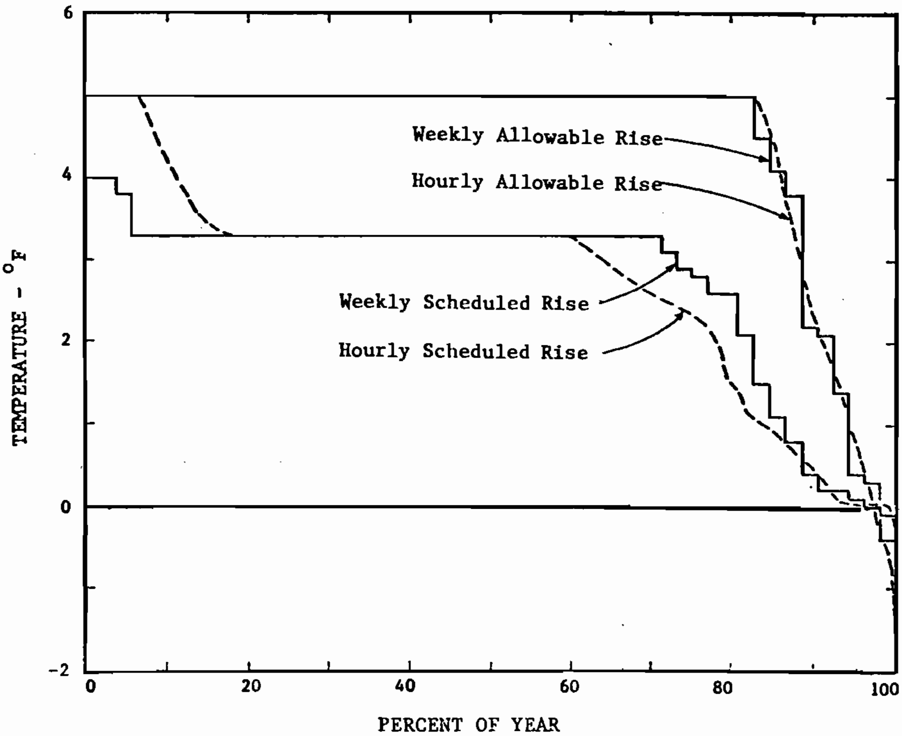


FIGURE 3.3 FREQUENCY OF OCCURRENCE OF ALLOWABLE AND SCHEDULED TEMPERATURE RISE AT THE BROWNS FERRY SITE FOR WEEKLY AND HOURLY TIME STEPS - 1969

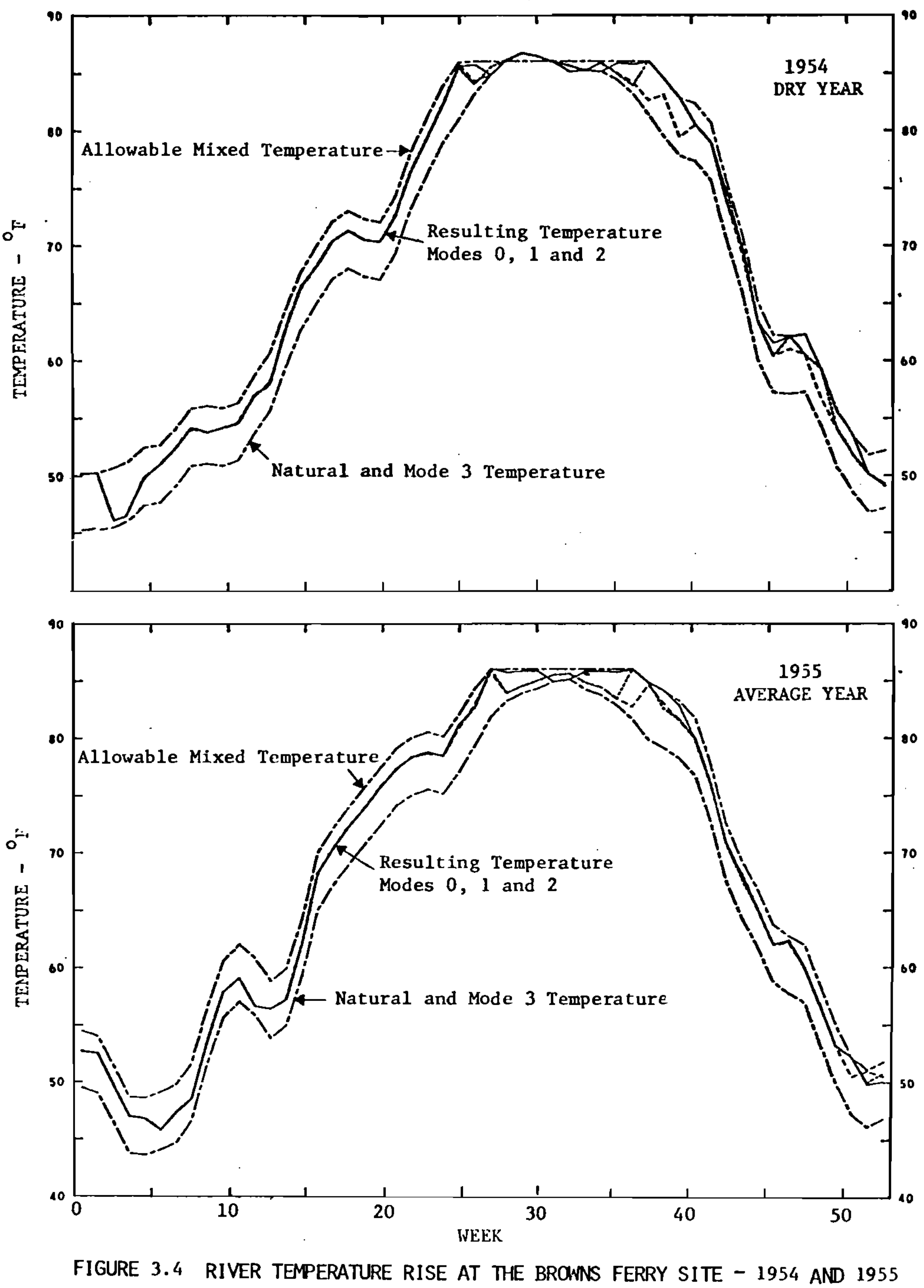


FIGURE 3.4 RIVER TEMPERATURE RISE AT THE BROWNS FERRY SITE - 1954 AND 1955

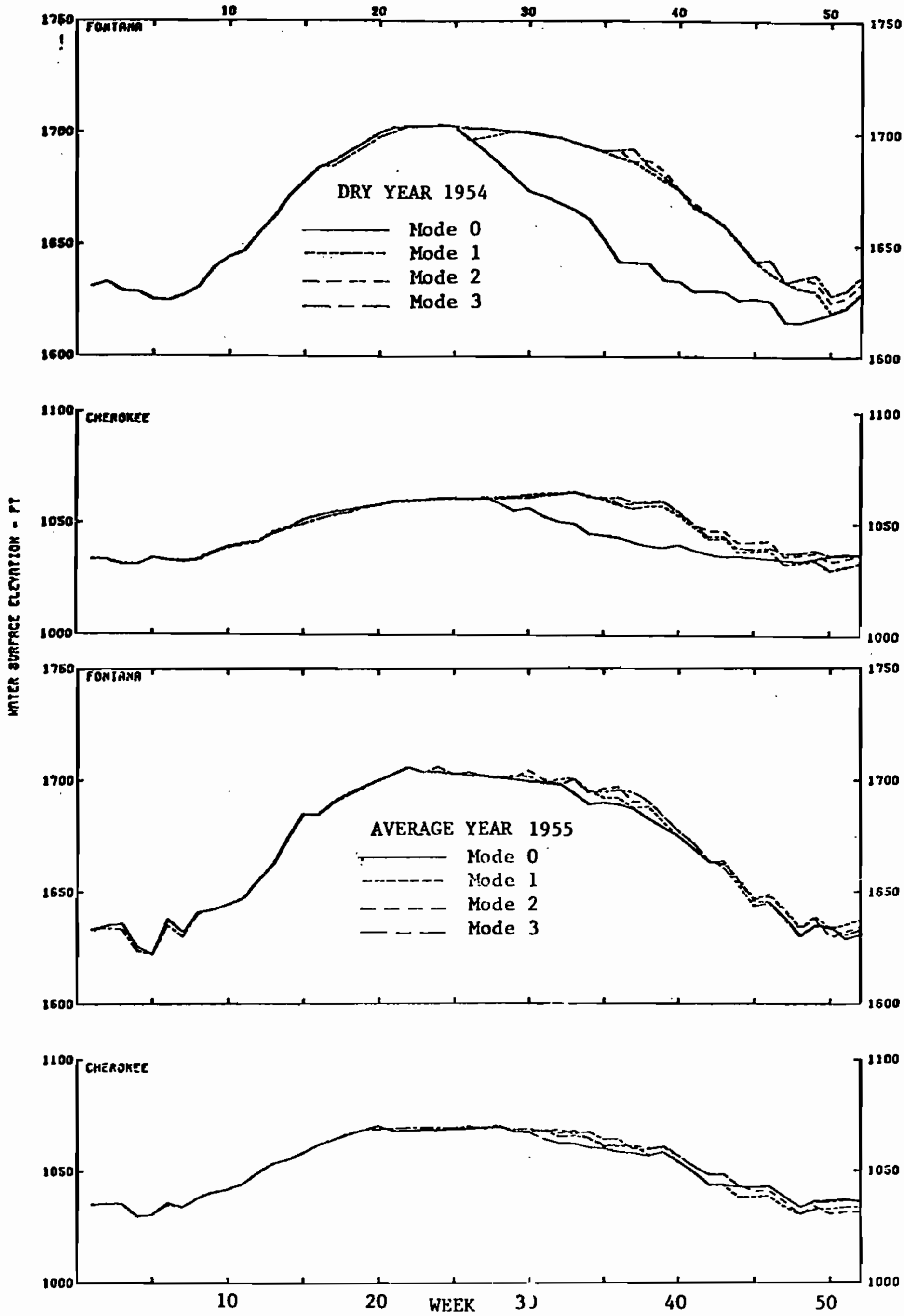


FIGURE 3.5 TRIBUTARY RESERVOIR LEVELS - 1954 AND 1955

8. The water quality regime in TVA tributary reservoirs is known to be strongly influenced by inflow, outflow and storage. The outflow and storage results of the weekly scheduling model were used to assess the impact of Browns Ferry operations on these reservoirs (350 miles and more upstream from Browns Ferry). Water quality was assessed only in terms of outflow temperatures. No impact was found in the wet year 1950 and a very minor one in the average year 1955. In these years, there is no difference in outflow temperatures between modes. In the dry year, mode 1 which produced about the same water level as mode 3 (no impact on water level) can be considered representative for the outflow temperature without impact by Browns Ferry. As it is typical for dry years, less water is drawn from the reservoirs due to lesser inflows thus preserving the cold water reserve longer than in a wet year such as 1950, see figure 3.6. The drawdown in mode 0 of the dry year causes accelerated depletion of the cold water reserve and results in an accelerated rise of outflow temperature, thus influencing the downstream water temperature and quality regime.

The study results discussed in the foregoing, though typical to the TVA system, illustrate the general type of problem which may arise in a large water system operated for a wide variety of objectives. The study also vindicates the intuitive assumption that most economic operation entirely within the bounds of operation constraints can be achieved by proper use of <u>all</u> available system capabilities. It should be obvious from the examples cited that this is only possible if comprehensive methods for planning and operation of large systems are available.

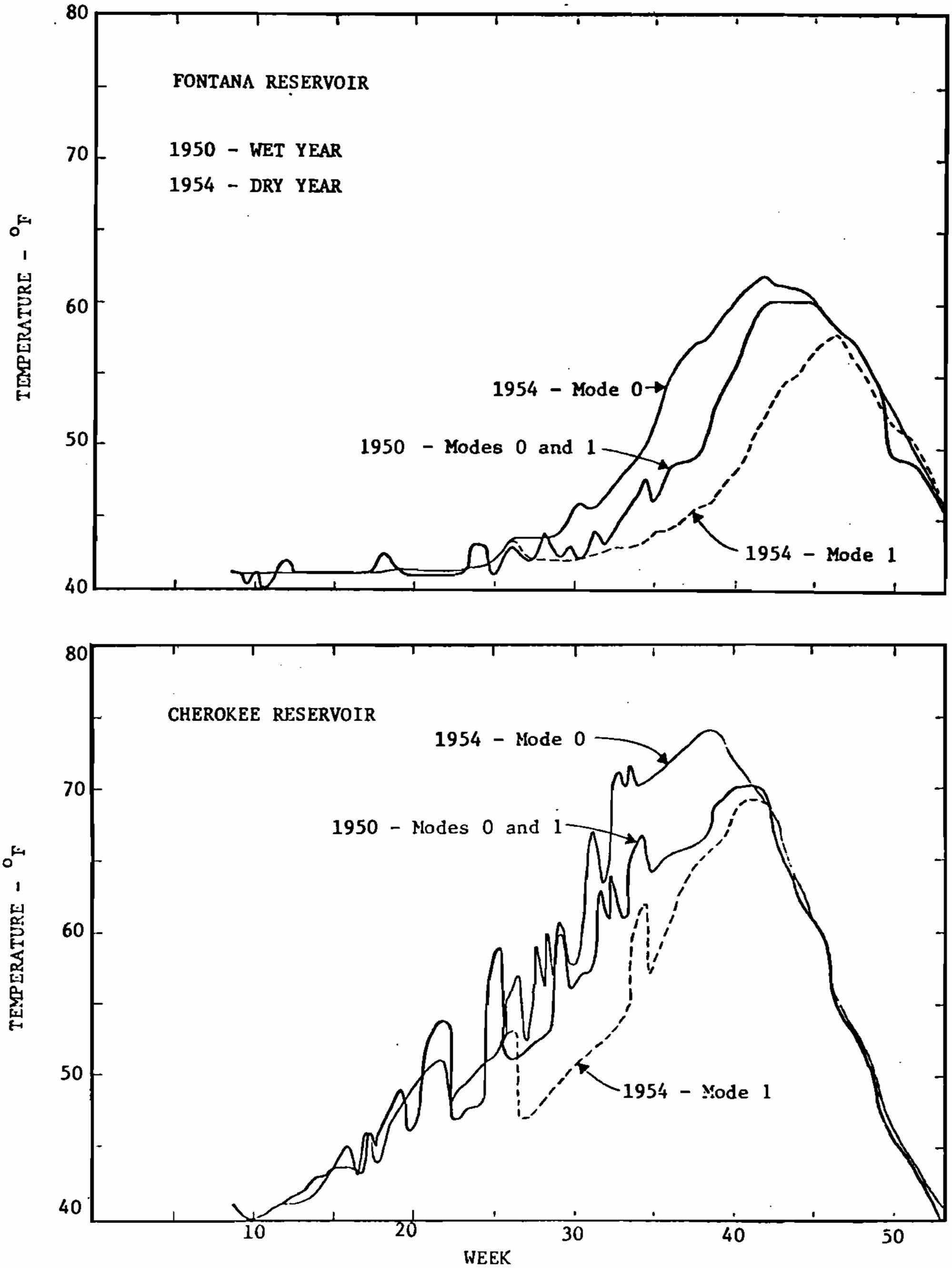


FIGURE 3.6 FONTANA AND CHEROKEE RESERVOIR OUTFLOW TEMPERATURES - 1950 AND 1954

4. COMPARISON OF METHODS FOR OPTIMAL RESERVOIR RELEASE SCHEDULING

4.1 General

In order to gain experience with different optimization methods as to their usefulness in TVA's reservoir release scheduling procedures, tests of the applicability of several algorithms were made:*

- a special linear programing technique called "out-of-kilter algorithm"
- discrete differential dynamic programing
- dynamic programing by successive approximation
- reduced gradient algorithm

In these tests, a subsystem of six major TVA tributary reservoirs was used as shown in figure 4.1. Allowable storage variations for those reservoirs are listed in table A1 of the Appendix. They are shown as maximum and minimum limits in figure 4.6. At first the objective function commonly used with all four methods will be described. Then the methods will be briefly described and the results compared.

4.2 Objective Function

The objective used was the maximization of the annual benefits derived from hydropower generation of these six hydro plants, all other hydro projects being considered as nonexistent. The hydro plant characteristics were defined as

$$P - \min (R \times PC, PCAP) \tag{4.1}$$

---

*A separate report containing detailed information is in preparation by the Water Resource Management Methods Staff, Division of Water Control Planning, Tennessee Valley Authority.

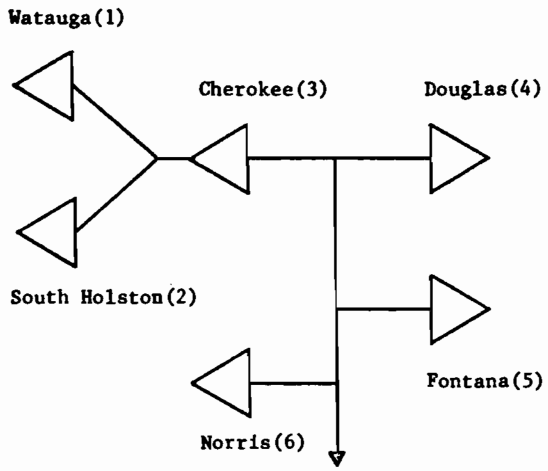


FIGURE 4.1 SUBSYSTEM FOR TESTING OPTIMIZATION ALGORITHMS

where P is the weekly plant generation level, in MW;

R is the weekly plant release, in 100 ft^3/s;

PC is the plant power factor, defined as power output per unit release, in MW/(100 ft^3/s), and

$PCAP$ is the plant capacity in MW.

The power factor is computed as a function of reservoir storage by

$$PC = B1 + S(B2 + S(B3 + S(B4 + S(B5 + S \times B6)))) \qquad (4.2)$$

where S is reservoir storage, in 100 ft^3/s-wk*; B1 to B6 are polynomial coefficients as given in table A2 of the Appendix.

The plant capacity is computed by

$$PCAP = A(2), \text{ if } S \geq A(1);$$

otherwise

$$PCAP = A(7) + S(A(8) + S(A(9) + S \times A(10))), \qquad (4.3)$$

where A are coefficients as given in table A3 of the Appendix.

The total value of hydropower generation was computed as the sum of the weekly peak and offpeak value

$$TRET = \sum_{I=1}^{52} (PRET(I) + OPRET(I)) \qquad (4.4)$$

where TRET is the total return from the subsystem's power generation, in dollars; PRET is the weekly return from peaking power, in dollars; OPRET is the weekly return from offpeak power, in dollars. Of each 168 hour weekly period 64 hours were considered to be peaking period. Thus the peaking power from each plant was determined by

$$PE = \min\ (168\ P/64,\ PCAP) \qquad (4.5)$$

where PE is the plant weekly peaking level, in MW.

---

*100 ft^3/s-wk is a volume supplying an average flow of 100 ft^3/s one week long.

The offpeak power from each plant was determined by

$$OPE = \max((168\ P - 64\ PCAP)/104, 0) \tag{4.6}$$

where OPE is the plant weekly offpeak generation level, in MW.

After summing up PE and OPE for all plants, PRET and OPRET values were determined using preconstructed return functions. These functions were derived from power system load estimates, reserve requirements and thermal unit cost-capacity relationships similar to those described in section 5.3. The peaking power return was computed as follows

For $SPE(I) \leq AHYRO(I,1)$, $PRET(I) = 64\ SPE(I) \times AHYRO(I,2)$ (4.7)

where I is the week number; SPE is the sum of PE of all six hydro projects and AHYRO are coefficients as given in table A4 of the Appendix.

For $SPE(I) > AHYRO(I,1)$, (4.8)

and
$$PRET(I) = 64(AHYRO(I,1) \times AHYRO(I,2) + DPSE(AHYRO(I,3) + DPSE(AHYRO(I,4) + DPSE \times AHYRO(I,5)))) \tag{4.9}$$

where $DPSE = \max(SPE(I) - AHYRO(I,0), 0)$

The offpeak power return was computed from

$$OPRET(I) = 104\ SOPE(I)\ (AHYRO(I,6) + DPSE \times AHYRO(I,7) + SOPE \times AHYRO(I,8)) \tag{4.10}$$

where SOPE is the sum of OPE of the six hydro projects.

The limits on releases were

$$R(J,I) \geq 0 \tag{4.11}$$

and

$$\sum_{J=3}^{6} R(J,I) \geq RS(I) \tag{4.12}$$

where J is the reservoir number; I is the week number; R is the reservoir release, in 100 ft^3/s, as given in table A5 of the Appendix. The equality constraints were

$$R(J,I) = Q(J,I) + S(J,I+1) - S(J,I) \text{ for } J \neq 3$$

and $$R(3,I) = Q(3,I) + S(3,I+1) - S(3,I) + R(1,I) + R(2,I) \qquad (4.13)$$

where Q is the weekly local inflow, in 100 ft^3/s, as given in table A5 of the Appendix.

The test problem was a deterministic optimization problem maximizing the return from hydropower while rigidly observing flood control and release requirements. The starting and ending storage levels, fixed for all reservoirs, are given in table A6 of the Appendix.

4.3 Out-of-Kilter Algorithm (OKA)

The reservoir scheduling problem can be conceptualized as a network flow problem as shown in figure 4.2. The reservoirs can be considered as nodes and the inflows, releases, starting and ending storages as flows along arcs. Figure 4.2 shows the configuration for a three reservoir, two time period example. A special purpose linear programing technique called "Out-of-Kilter Algorithm" was available and deemed more efficient than a standard linear programing technique dealing with a linear network

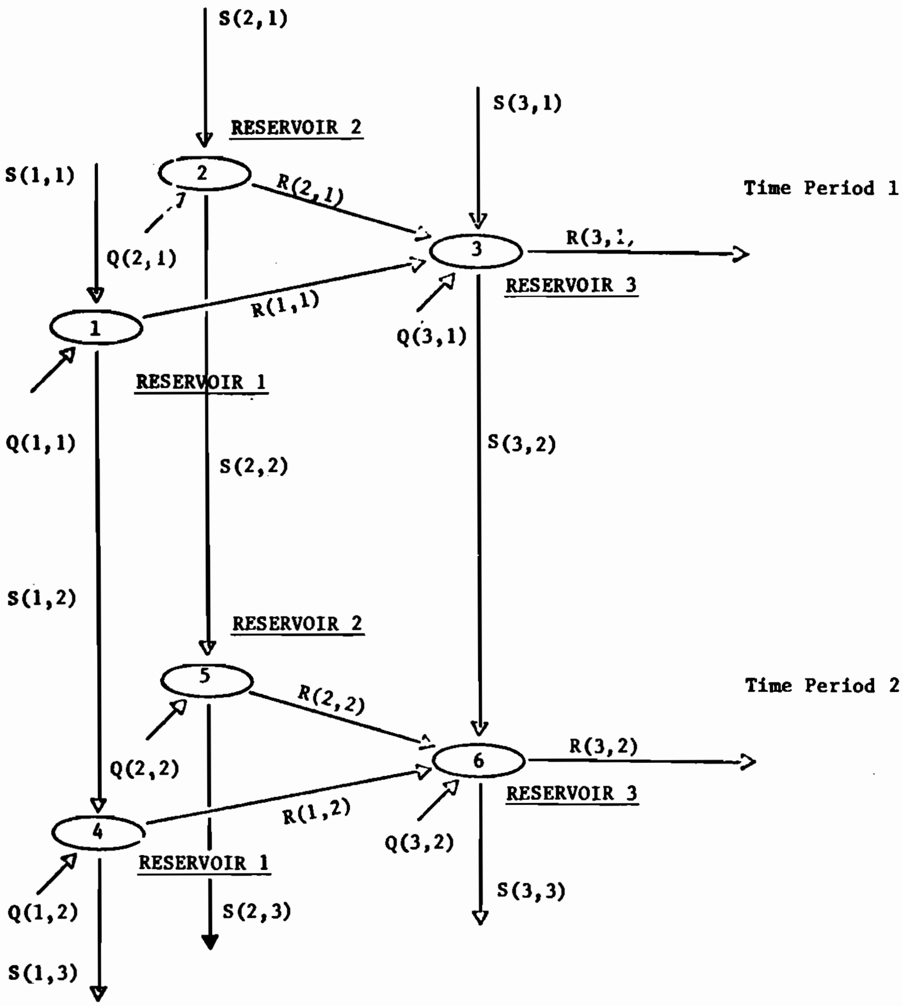


FIGURE 4.2 REPRESENTATION OF RESERVOIR SCHEDULING AS A NETWORK FLOW PROBLEM

flow problem. The algorithm has been described in detail by Fulkerson (1961), Ford and Fulkerson (1962) and Durbin and Kroenke (1967). An application of this algorithm to water resources planning problems was made by the Texas Water Development Board (1969) and by Kibler and King (1971). A computer code of this algorithm in Fortran was available when this test was made.

The general problem the Out-of-Kilter Algorithm (OKA) can handle is as follows:

$$\sum_j X_{ij} - \sum_j X_{ji} = 0 \quad \text{for all } i \tag{4.14}$$

where X_{ij} is the flow into i^{th} node from j^{th} node,

$$\ell_{ij} \leq X_{ij} \leq U_{ij} \quad \text{for all } i, j \tag{4.15}$$

where ℓ is the lower bound of X and U is the upper bound of X

with the objective function

$$\max \sum_{ij} V_{ij} X_{ij} \quad \text{or} \quad \min \sum_{ij} (- V_{ij} X_{ij}) \tag{4.16}$$

where V_{ij} is the value per unit flow along the arc ij.

The application of OKA to the test problem met the requirement of flow continuity and of the flow constraints. However its applicability was impeded by the nonlinearities involved in the objective function described in the previous section. Since the computer code was readily available, it was decided to examine the effectiveness of this algorithm and to test ways in dealing with the nonlinearities.

The formulation of the program included two additional downstream reservoirs, namely Guntersville and Wheeler, for studying a flow requirement in Wheeler Reservoir. The basic network considered is shown in figure 4.3. Specifications of the arcs are listed in table 4.1. The release from each reservoir was split into two arcs, one for turbine release and the other for spill which has no value per unit flow. The flow demand imposed on the average of Guntersville and Wheeler releases was handled by a special iterative scheme which successively adjusted the lower bound of the Guntersville release arc. Decomposition was used to reduce the size of the problem by solving subprograms covering shorter but overlapping time horizons as shown in figure 4.4.

Two different methods were used to deal with the nonlinearities of the objective function. The first was to compute the value of power factors based on the initially assumed storages or storages obtained in the previous iteration. Then corresponding hydro values were assigned to all the turbine release arcs whereupon another iteration was performed based upon this set of values. The second method was more elaborate by computing values based upon derivatives of the objective function with respect to flow. Values were estimated for turbine release arcs as well as for storage arcs. Recognizing the fact that the optimal solution of the nonlinear problem may not occur at any vertex of the feasible region, searches were made by linearly combining solutions by OKA with the best solution being kept. Both methods were very time-consuming and convergence was not monotonic. Thus testing of OKA was terminated in favor of dynamic programing techniques.

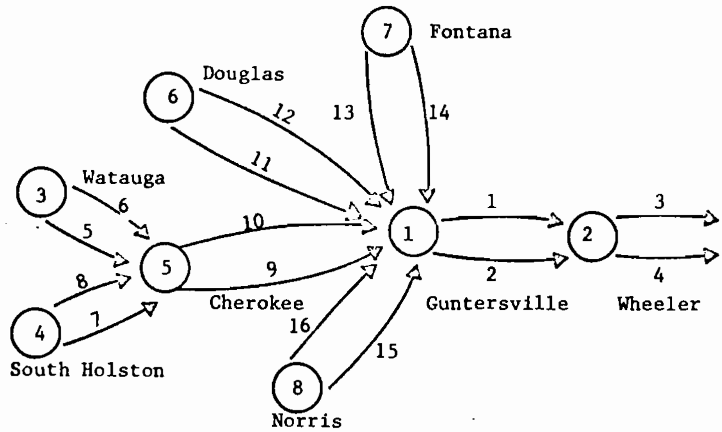
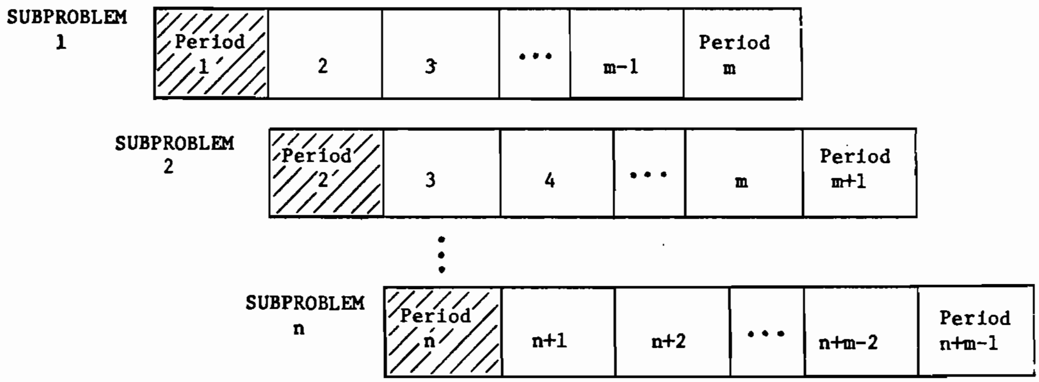


FIGURE 4.3 BASIC NETWORK FOR OKA

TABLE 4.1 DESCRIPTION OF FLOW ARCS OF THE BASIC NETWORK OF OUT-OF-KILTER ALGORITHM

Arc No.	Description	Lower Limit 100 ft^3/s	Upper Limit 100 ft^3/s
1	Guntersville turbine release	FX*	480
2	Guntersville spill	0	5160
3	Wheeler spill	0	5650
4	Wheeler turbine release	0	1100
5	Watauga spill	0	735
6	Watauga turbine release	0	35
7	South Holston spill	0	540
8	South Holston turbine release	0	31
9	Cherokee spill	0	3420
10	Cherokee turbine release	0	191
11	Douglas spill	0	2860
12	Douglas turbine release	0	192
13	Fontana spill	0	1900
14	Fontana turbine release	0	94
15	Norris spill	0	2500
16	Norris turbine release	0	89

*FX is initially set at 326. If the flow in arc 4 is greater than the flow in arc 1, then FX is reduced. FX is increased when the opposite occurs and remains unchanged if both flows are equal.



NOTE: cross-hatching indicates final solution

FIGURE 4.4 SOLUTION BY OUT-OF-KILTER ALGORITHM
USING DECOMPOSITION INTO SUBPROBLEMS

4.4 Discrete Differential Dynamic Programing (DDDP)

The number of state variables of the test problem is too large for the standard dynamic programing (DP) technique to be applicable. Two special DP algorithms were tested for their applicability. One of them is the so-called "Discrete Differential Dynamic Programing" (DDDP). The technique was developed by Heidari, Chow and Meredith (1971) for application to water resources systems based upon the differential dynamic programing approach by Mayne (1966), Jacobson (1968), and Jacobson and Mayne (1970).

The basic scheme of this algorithm is to restrict the optimization to only the neighboring states of an initial trajectory of states or a trajectory obtained in a previous iteration. The solution is improved iteratively. By restricting the number of states to be examined at each iteration, significant savings in both computer memory and processing time can be achieved. For a six state variable problem, such as the test problem, if each state variable is discretized into 10 values, the standard DP technique will require examination of 10^{12} state combinations at each stage! The corresponding memory requirement will be the order of 10^6. This is definitely beyond present computer capability without mentioning the full-sized scheduling problem in the TVA system when 19 or more state variables have to be dealt with.

In the DDDP algorithm, during each iteration only two states near the previously obtained trajectory forming a corridor with or around the trajectory and the trajectory states generally at the center of this corridor are examined as shown in figure 4.5. For each stage and each reservoir 3^2 state combinations need to be examined. For

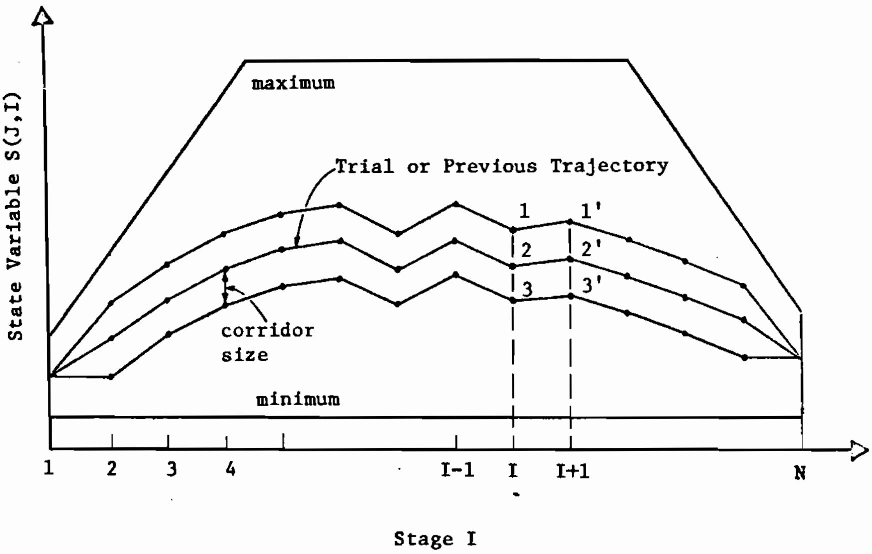


FIGURE 4.5 CORRIDOR CONFIGURATION FOR DISCRETE DIFFERENTIAL DYNAMIC PROGRAMING (DDDP)

six reservoirs this amounts to a total of 3^{12} combinations. Even though it was feasible to handle this problem on the computer, the computation time requirement was found to be excessive. It was concluded that further decomposition was necessary.

4.5 Dynamic Programing by Successive Approximation (DPSA)

This is a simple decomposition technique that can be used to handle systems with many state variables. It successively deals with only one state variable at an iteration while all other state variables remain unchanged. Bellman (1957) and Larson (1964) used this technique to solve a variety of problems. A convergence proof was given by Larson and Korsak (1970) for some special cases. The technique was applied to water resource system scheduling by Trott and Yeh (1971) coupling it with "Incremental Dynamic Programing" which is similar to DDDP except that only one reservoir is considered at each iteration.

Trott and Yeh's technique was applied to the test problem. An attractive feature of this algorithm is the reduction in problem size from 3^{12} state combinations for each stage in DDDP to only 3^2 combinations in DPSA. During the I^{th} stage, as shown in figure 4.5, only 1-1', 2-1', 3-1', 2-1', 2-2', 2-3', 3-1', 3-2' and 3-3' need to be evaluated. Since 2-2' is the original trajectory, only eight state combinations remain. The question to be answered by testing the method was the convergence behavior of the iterative scheme.

Nine cases were run covering different trial policies*, starting reservoirs, corridor sizes, tolerance limits (stopping criteria) and

*Trial policy denotes here the initial sequence of decision variables while trial trajectory denotes the corresponding state variables.

specified numbers of loops to be made over all the reservoirs as shown in table 4.2. Cases 2 to 8 used a method of computing hydro generation slightly different from case 1, but the resulting trajectories of cases 1 and 2 were almost identical. Except case 4a, all cases were run with three loops over all reservoirs. Case 4a was run by specifying 900 seconds of running time. It was determined from this run that three loops would be sufficient to achieve the desired convergence.

Three different trial policies were used. Trial policy A corresponded to reservoir storage trajectories in the normal range of past operations. Trial policies B and C corresponded to low and very low storage trajectories. Trial policy A is listed in table A7 of the Appendix.

The hydro return based on the trial policies varied between 14.2 and 17.4 million dollars. The solutions obtained for the different trial policies were found to be almost identical. Total hydro returns varied from 21.48 to 21.51 million dollars for cases 2,7 and 8. Hence, significant improvements of total hydro return were achieved by the optimization algorithm over the return from the initial trial trajectory, varying from 4 to 7 million dollars annually. Changing the reservoir sequence in the iteration showed little effect (case 2 vs case 3). Increasing the tolerance limit and/or the finest corridor size produced slightly poorer solutions (cases 3 vs 5 or 6 and case 3 vs case 4). The computation time depended on the adequacy of the trial trajectory and on the specified tolerance limit.

Numerical results of the solution for case 1 are listed in tables A8, A9 and A10 of the Appendix. Comparisons of trial and solution

TABLE 4.2 SUMMARY OF DPSA RUNS

Case No.	Final Policy Return 10^6\$	Trial Policy Return 10^6\$	Trial Policy	Starting Reservoir No.	Finest Corr. Size ft^3/s-wk	Tolerance Limit \$	CPU Time IBM 360/50 s	No. of Iterations
1	21.40	17.44	A	4	50	50	746	245
2	21.48	17.37	A	4	50	50	-	266
3	21.47	17.37	A	1	50	50	729	285
4	21.43	17.37	A	1	100	100	556	234
4a	21.48	17.37	A	1	100	100	900	-
5	21.47	17.37	A	1	50	200	593	242
6	21.44	17.37	A	1	50	1000	488	177
7	21.51	16.30	B	4	50	50	701	305
8	21.48	14.16	C	4	50	50	1220	380

trajectories for Cherokee, Douglas, Fontana and Norris Reservoirs are shown in figure 4.6. The difference between solution trajectories is small and the convergence is considered to be satisfactory.

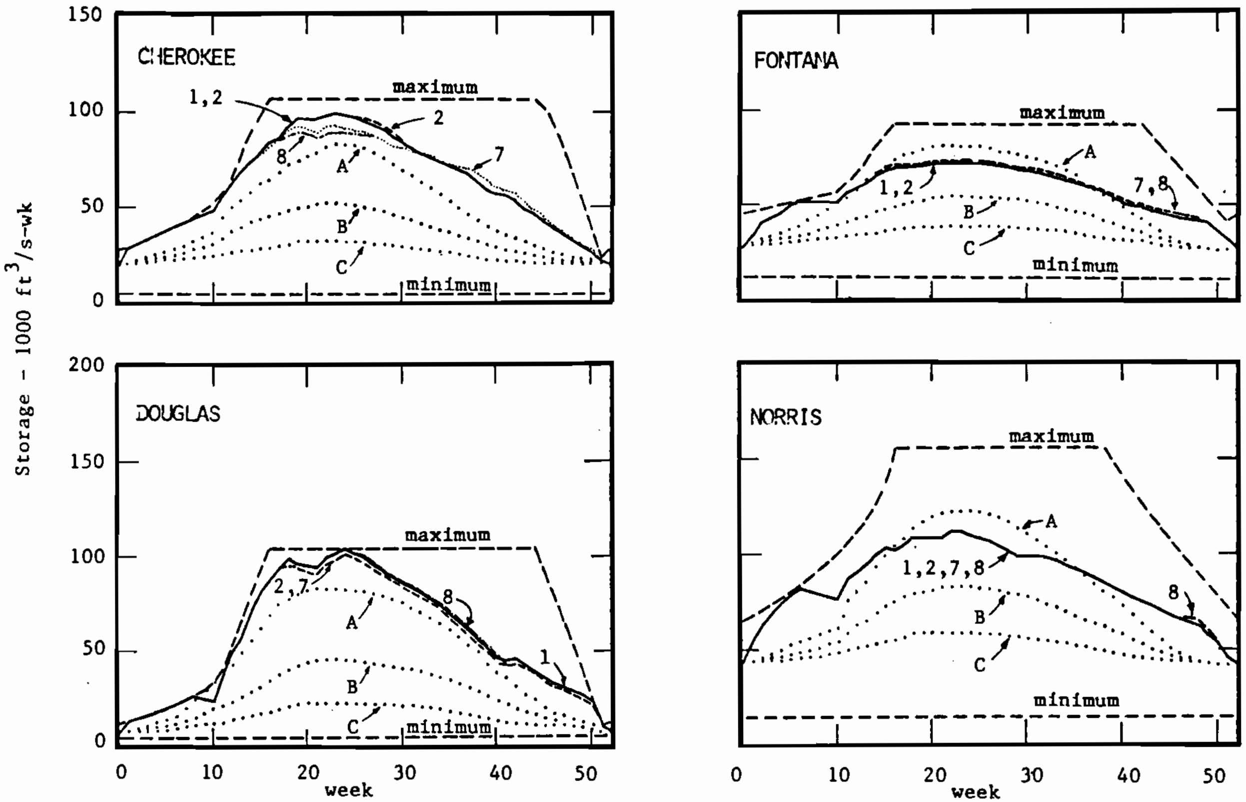


FIGURE 4.6 COMPARISON OF TRIAL AND SOLUTION TRAJECTORIES FOR DPSA

4.6 Reduced Gradient Method (REDGRAD)

The reservoir release scheduling problem can be formulated as a network flow problem with releases from and storages in reservoirs represented by flows along arcs in the network as explained in section 4.3. The gradient method developed to solve this problem, therefore, relied heavily on network theory as described by Ford and Fulkerson (1962) and Dantzig (1963). A brief description of the method follows.

The system variables in the network problem refer to the release and storage variables. These variables may be mathematically separated into sets of independent and dependent variables where dependency arises from the constraints imposed by the conservation of flow equations. A connected network having n nodes and (n-1) arcs is called a tree. If certain arcs in a network are deleted so that the remaining network, called a subnetwork of the original network, forms a tree, then this subnetwork is called a spanning subtree. The node-arc incidence matrix corresponding to a network is that matrix whose (i,j) element is 0 if arc j is not incident with node i, -1 if node i is the terminal node for arc j, and +1 if node i is the origin node for arc j. A feasible operational policy is a policy which satisfies the conservation of flow equations and lies within the operational bounds imposed on the releases and storages.

The following two network properties are used in the program: 1.) arcs corresponding to a set of dependent variables of the reservoir network model form a spanning subtree, and, conversely, if a set of arcs forms a spanning subtree, the corresponding set of variables forms a dependent collection; and 2.) the node-arc incidence matrix corresponding to the dependent variables, also called tree variables, can be triangularized via row and column permutations. Property 2 is used to solve two sparse systems of equations, one arising from the calculation of the gradient of the hydropower return function with respect to the independent variables and the other from the search direction for the dependent arcs.

Let $\overline{X}$ denote a proper vector of independent variables, which may consist of both release and storage variables, and $\overline{Y}$ the related dependent vector. Let the conservation of flow equations be expressed by

$$C\overline{X} + D\overline{Y} + \overline{R} = \overline{0} \tag{4.17}$$

where C and D are square node-arc incidence matrices with D nonsingular, $\overline{R}$ a vector of lateral inflows and initial storages, and $\overline{0}$ the zero vector. The modular program REDGRAD then proceeds as follows: <u>Step 1</u> - Input an initial feasible operational trajectory $(\overline{X},\overline{Y})$ such that the dependent vector $\overline{Y}$ is interior to its domain of definition which is some interval on the nonnegative real axis; <u>Step 2</u> - Evaluate the hydropower return function for the trajectory under consideration; <u>Step 3</u> - Determine a search direction vector $\Delta S = (\overline{\Delta S}_{\overline{X}}, \overline{\Delta S}_{\overline{Y}})$ from which to proceed from the trajectory $(\overline{X},\overline{Y})$ in the space of feasible trajectories; <u>Step 4</u> - Use a one-dimensional search technique to determine a new trajectory $(\overline{X},\overline{Y})$ along the given search direction with a higher hydropower return value; <u>Step 5</u> - If no new policy can be found with a higher return, either determine another search direction and return to Step 4 or terminate. <u>Step 6</u> - Determine for the new policy whether or not the dependent variables are still interior to their domain of definition. If not, exchange those which are not for independent ones which are interior;

otherwise, retain the same sets of independent and dependent variables.
Step 7 - Return to Step 2 provided certain flags have not been set; otherwise, terminate.

Steps 3 and 6 constitute the basis of the method programed. In Step 3 the gradient of the hydropower return function as a function of $\overline{X}$ is determined. Then either this gradient vector or a conjugate gradient vector which is essentially an acceleration of convergence aid and takes into account the previous search direction is used as a basis for the one-dimensional search direction. This vector $\overline{\Delta X}$ is then projected onto the simple bound constraints to obtain a normalized search direction $\overline{\Delta S}_{\overline{X}}$ from which by solving

$$D\,\overline{\Delta S}_{\overline{Y}} = -C\,\overline{\Delta S}_{\overline{X}} \qquad (4.18)$$

for $\overline{\Delta S}_{\overline{Y}}$ the desired direction $\Delta S = (\overline{\Delta S}_{\overline{X}}, \overline{\Delta S}_{\overline{Y}})$ is found. If neither of these directions yields a new policy, additional feasible directions are used to continue the procedure. Step 6 is based upon certain properties of network trees thereby avoiding simplex-like variable exchanges. The exchanges are made by cutting the spanning subtree of dependent variables at a proper place and adjoining another arc corresponding to an independent variable to form another tree. A numerical approximation to the Fibonacci search technique constitutes Step 4.

The REDGRAD program was tested on three different trial trajectories. Figure 4.7 shows REDGRAD convergence for trial policies A and C. The slow convergence when compared to the DPSA method can be traced to three segments of the program: the manner in which partial derivatives are

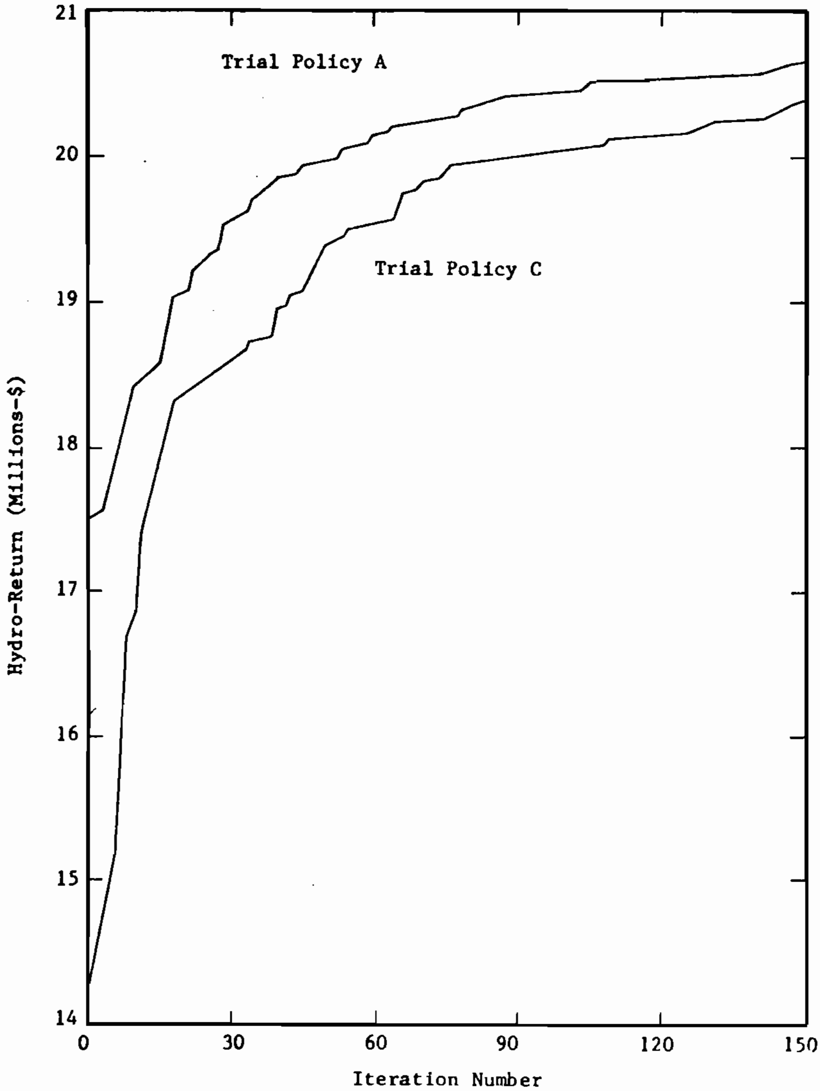


FIGURE 4.7 CONVERGENCE OF REDGRAD

calculated at branch points of the objective function, i.e., points at which the derivatives are not continuous; the method of exchange between the independent and dependent variables; and the one-dimensional search technique employed. Improvements of these REDGRAD segments could result in increased efficiency of the algorithm.

A comparison of results obtained by REDGRAD and by DPSA is given in figure 4.8. The trajectories obtained by REDGRAD have similar profiles to those obtained by DPSA. However, REDGRAD apparently has difficulty with handling the storages in the latter weeks; the storages are depleted too rapidly thus causing large releases during these periods.

4.7 Summary and Conclusions

Among the methods tested the DPSA algorithm was deemed most promising. The algorithm is simple and requires very little computer memory. The computer time is also modest in comparison with the others. Additionally, the algorithm is flexible to allow inclusion of stochastic considerations. The convergence behavior was adequate for the test problem conditions. Therefore, the method was selected for application to the full TVA system for the development of a weekly planning model as described in chapter 5.

The linear programing technique OKA was found inadequate for release scheduling purposes since the system and the objective function involved are strongly nonlinear. Efforts to overcome this inadequacy were unseccessful.

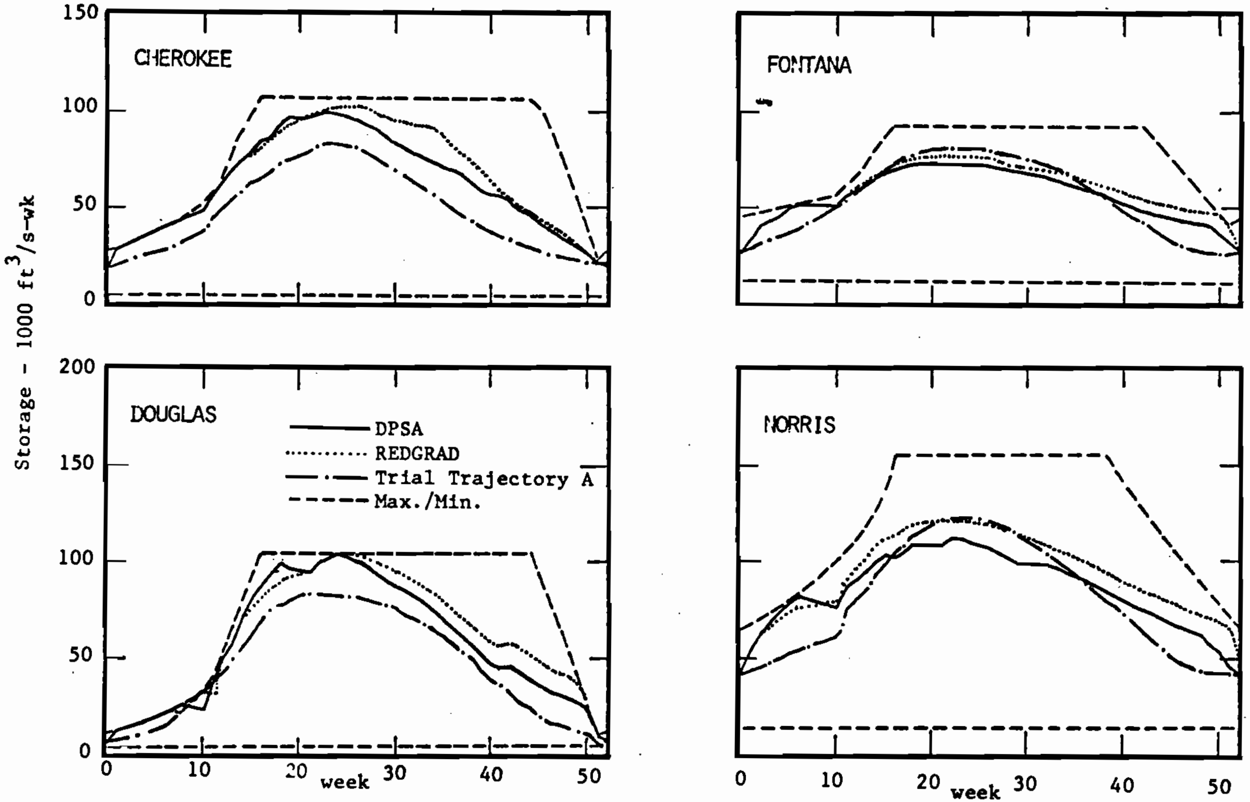


FIGURE 4.8 COMPARISON OF DPSA AND REDGRAD RESULTS FOR TRIAL TRAJECTORY A

The reduced gradient technique was found to give solutions slightly inferior to those by DPSA. It is likely that this technique when modified properly may become as effective as DPSA.

The DDDP technique is implicitly used in the DPSA algorithm. It seems to effectively deal with groups of up to four reservoirs. Large systems must be decomposed before this algorithm can be applied. The question remains as to what would be an optimal decomposition. The DPSA scheme used decomposed the system into single reservoirs.

Even though the test problem does not correspond to the real system conditions, it nevertheless demonstrates the strong dependence of the operating policy on the objective function. It is concluded that fixed operation of reservoirs may cause significant economic losses.

5. LONG-RANGE MULTIPURPOSE RESERVOIR RELEASE SCHEDULING MODEL

5.1 General

The proposed water resource management scheme will include a system-wide long-range release scheduling model by weekly time steps. This model will be used for long-range planning of reservoir operations (see also section 6.1). It consists of two major parts, an optimization algorithm and a multiple purpose objective function. At present only the hydropower objective function has been implemented, while the flood control objective function is under development. The optimization algorithm and the two objective function segments will be described in the following sections.

5.2 Optimization Algorithm

The analysis of the methods described in the previous chapter revealed that the DPSA technique was best suited for use as the optimization procedure in the long-range scheduling model. This justified its implementation on the entire TVA system encompassing 42 major reservoirs of which 19 are classified as storage projects while the others are either prescribed-storage or nonstorage (run-of-river) projects with each having a hydro generation capability.

This expanded system in control theoretic terminology consists of 19 state (storage) and control (releases from storage projects) variables over 52 weekly stages. The DPSA technique, differing from conventional DP, reduces computational and storage requirements by fixing all but one of the state variables while allowing the remaining one to be incremented and decremented once at each stage and, thereby, due to the constraints imposed by the transition equations (conservation of flow equations) reducing the number of control variables to one. The theoretical background of the method has been described in more detail in section 4.5. To further reduce storage requirements and to simplify the program structure the reservoir system was decomposed into several subsystems corresponding to different river reaches: Holston-French Broad Rivers; Little Tennessee-Clinch Rivers; Hiwassee-Elk Rivers; Cumberland River except the Barkley project; and Tennessee River including the Barkley project.

The successful practical use of the method on a large reservoir system depends to a large degree on the efficient use of the available computer capabilities. The programing technique used will be outlined below.

The division of the system permits use of a storage reduction facility of the TVA IBM 370/165 system, namely the overlay technique provided by the IBM operation system linkage editor. This system allows designated control sections (subroutines and named common blocks) to use the same main core locations, one at a time, as needed. Through use of this technique, the total main core requirement of the program is equal to the core requirement of the root segment plus the core requirement of the largest transient routine rather than the sum of the requirements of the transient routines. However, certain data problems arise from the overlay technique. When an overlayed routine is reinstated, the original copy is placed in core. As a result all variables that are not in a named common block resident in the root segment are lost. To overcome this loss of information sequential files were used to store variables on disc storage devices as described in the following paragraphs.

The program has three named common areas. The first represents a block which contains data on the entire system and is used by most of the routines. The second area is used by all four optimization routines with each having its unique definition of the shared area. When an optimization routine is loaded by the overlay supervisor and receives control, its data is read from the disk into this space. Just before giving up control, the routine writes to the disk the revised data. Each of the four optimization routines has its own work file for this purpose; hence, each routine's data is saved for subsequent reuse. The third area keeps the data handling consistent to facilitate the checkpoint system, which provides the ability to write at timed intervals during the program, the values of the common blocks to their respective work data sets. In the event of a machine or program error, the program may be restarted from the most recent checkpoint rather than starting from the beginning.

The above scheme involves the use of six temporary work files corresponding to the common blocks. These files are created at the beginning of execution by disaggregating a single input dataset (trial policy) and are combined at the end of the run into a single output dataset. The other input to the program consists of one data set that supplies the objective function values and, optionally, data to change the weekly Paducah elevations. A small deck of card input is needed to specify program control parameters.

The DPSA program begins execution with a control routine which reads the input options, determines the proper sequence of operations, and calls the appropriate routines. The hydro-return function routine is called upon throughout the program to determine the hydro benefit for a given policy. Two routines are written in IBM 1360 assembler language. One provides fast and efficient input/output of large amounts of data. The other is a timing routine that protects against program looping and provides the interval for taking checkpoints.

Several initialization routines determine the power generation parameters and the resulting hydro benefits for their respective subsystems. The optimization routines use the DPSA algorithm to determine the optimum hydro benefit for the respective subsystems. In conjunction with the subsystem optimization routines, the power generation parameters for the Tennessee River plants and for Barkley are determined. Finally, the work datasets are combined into the output policy dataset and a final summary is printed.

5.3 Hydropower Objective Function

An important component of the overall multiple-purpose objective function to be used in scheduling the reservoir system is the benefit function for hydropower generation. A procedure was developed for establishing the hydropower benefit function for a weekly planning model (TVA, 1974b). Instead of determining absolute values of hydro generation, it was sufficient to compute the cost of the complementary thermal generation required to meet specified system loads.

The first step was to compute thermal system generation costs for various load levels. The thermal system excluding gas turbines consists of more than sixty units with different generating costs, generating characteristics and reliability. A special method was developed to treat the probabilistic nature of unit availability. This method was found to be superior to using Monte Carlo simulation and is described in the following.

Since the unit availability is generally less than one, the contributions of individual units to meeting a given designated load must be determined on a probabilistic basis. In order to determine the expected use e_i of a unit for a given load L it is assumed that there are N units available, excluding those on scheduled maintenance, which are arranged in the ascending order of average costs at full capacity

$$\overline{C}_i < \overline{C}_{i+1} \; , \; i = 1 \text{ to } N-1$$

whose unit availability is $a_i \leq 1$, $i = 1$ to N and whose unit maximum capacity is $qmax_i$, $i = 1$ to N.

There are two types of units. The first type consists of those which will be used whenever they are available independent of other units. The second typ: consists of units whose usage is dependent on the outages of preceding units. The distinction is determined by a reference unit number k satisfying the following condition

$$\sum_{i=1}^{k} qmax_i \leq L \text{ and } \sum_{i=1}^{k+1} qmax_i > L \tag{5.1}$$

All units with $i \leq k$, are of the first type, all others are of the second type. The expected use for $i \leq k$ is simply

$$e_i = a_i \tag{5.2}$$

For $i > k$, the unit will be used only if sufficient outages occurred in the preceding units. Thus their expected use is less than their respective availability. For the n^{th} unit with $n > k$, the probability of being used is

$$P_n = P_r \left\{ \sum_{i=1}^{n'} qmax_i \, X_i < L \right\} \tag{5.3}$$

where $X_i = 1$, when i^{th} unit is available, and $X_i = 0$ otherwise; X_i is a random variable and $n' = n-1$. The expected use of the n^{th} unit is then

$$e_n = p_n \, a_n \tag{5.4}$$

According to the Central Limit Theorem, the distribution of the sum of random variables, $\sum_{i=1}^{n'} qmax_i \, X_i$, approaches the normal (Gaussian) distribution when n' becomes large. The normal distribution is defined by its mean and its standard deviation. The mean is

$$m = E\left(\sum_{i=1}^{n'} qmax_i \, X_i\right) = \sum_{i=1}^{n'} qmax_i \, a_i \tag{5.5}$$

The standard deviation, S_d is computed as

$$S_d^2 = \sum_{i=1}^{n'} qmax_i^2 \, a_i \, (1-a_i) \tag{5.6}$$

The probability p_n defined by a normal distribution with mean m and standard deviation S_d is

$$p_n = \frac{1}{\sqrt{2\pi}\, S_d} \int_{-\infty}^{L} \exp\left[-(t-m)^2/(2S_d^2)\right] dt \tag{5.7}$$

To verify the approximation formula, Monte Carlo method results were obtained for a test case. A system of 53 units with a total capacity of 13,177 MW was analyzed to meet a designated load of 10,000 MW. A total of 10,000 trials (grouped in ten runs) was simulated by the Monte Carlo method. The results agreed well with those obtained by the approximation formula as shown in figure 5.1. The largest error occurred near the region where $\sum_{i=1}^{n'} qmax_i$ is close to the designated load.

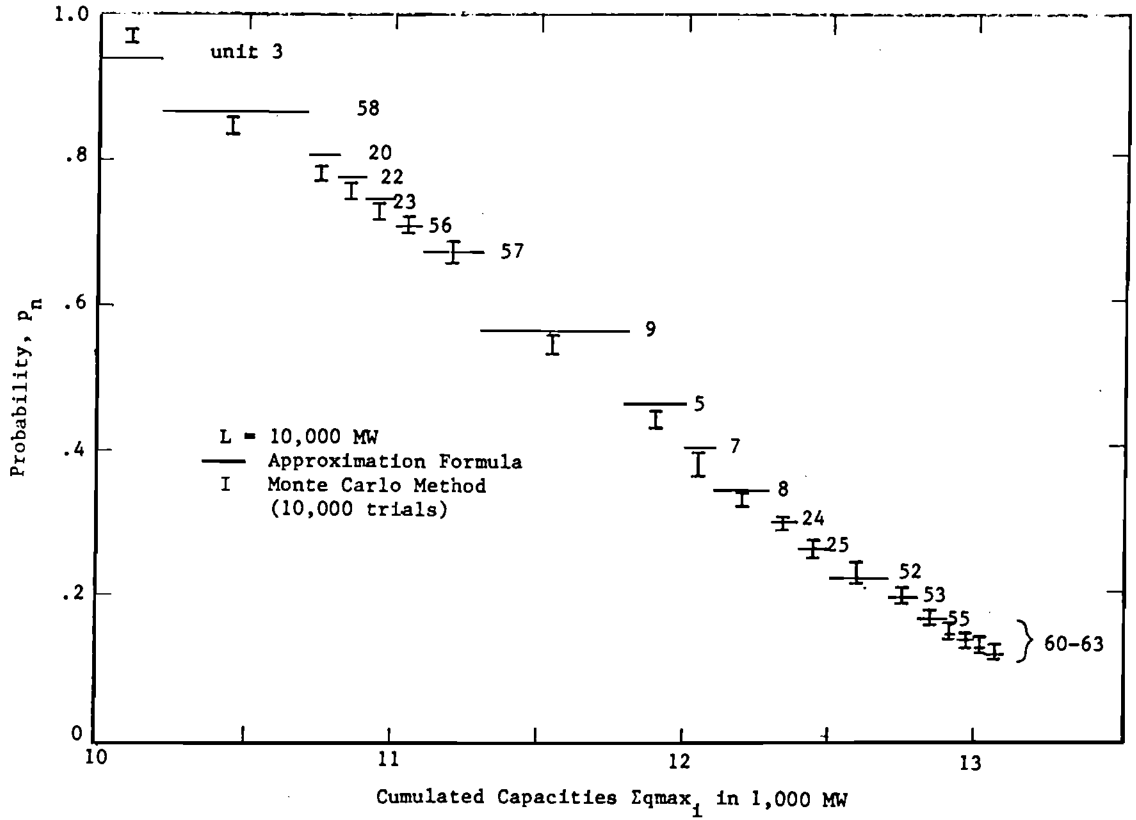


FIGURE 5.1 COMPARISON OF EXPECTED USES OF THERMAL UNITS AS COMPUTED BY APPROXIMATION FORMULA AND MONTE CARLO METHOD

With the expected use rates of all units, it was possible to construct a realistic cost function. The procedure was divided into two steps. First, the data and information on unit heat rate versus capacity curves; fuel, labor and maintenance costs, availability rates, operation requirements, system peak shaving arrangements, reserve requirements were used to obtain lumped thermal system cost representations. In the second step, these results were combined with system load estimates, load duration curves, temperature adjustment coefficients and temperature deviation values to construct the overall hydropower objective function.

This function consists of three major parts:

1.) System load data for the week, including peak load, and weekly load duration curve represented by 21 eight-hour average values;

2.) Weekly system peaking costs, PKCST, in terms of HCAP, i.e. peak carried by the hydro plus the required system reserve

$$\text{PKCST} = A + \text{HCAP}(A_1 + \text{HCAP}(A_2 + \text{HCAP} \times A_3) \qquad (5.8)$$

where $A_0 \ldots A_3$ are polynomial coefficients computed in the procedure;

3.) Weekly system offpeak generation costs, OPKCST, in terms of required offpeak thermal generation

$$\text{OPKCST} = f(\text{THGN(I)}) \quad I = 1,21 \qquad (5.9)$$

where THGN(I) is the required thermal generation during the I^{th} eight-hour period determined from available hydro generation.

A suboptimization scheme was used to determine THGN and HCAP from available hydro capacity and hydro generation. By summing up both peaking and offpeak generation costs for all weeks, total generation cost associated with the given hydro schedule can be computed.

5.4 Flood Control Objective Function

The flood control objective function to be incorporated into the weekly planning model was formulated to consider two types of damages: the first type is the actual damage suffered all flooded areas during a flood. The second is an expected damage in these areas associated with any tributary reservoir storage configuration. The latter type is essential in assessing the needs to provide reserved storage for flood control. The overall flood control objective function is a combination of these two types of damages.

The actual damages suffered at flooded areas due to flood flows are based upon flood damage surveys and can be expressed as functions of stage or flow.

The expected damages for a given tributary storage configuration are assessed based upon flood hydrology, reservoir operating procèdure during a flood and damage-stage functions. The procedure to establish such expected damage functions consists of three steps:

1.) Development of a relationship between storage space combinations in reservoirs upstream from the site to be protected to the resulting flood hydrograph at the site for observed floods;
2.) Determination of the probability of occurrence of flood events on record for weekly time periods;
3.) Computation of expected damages as function of storage space combinations in the controlling reservoirs for weekly periods.

In the TVA system, Chattanooga is the most important site for flood protection. Of the 22 reservoirs located upstream from Chattanooga, 13 are operated for flood control purposes. A flood routing program was developed for 12 of these reservoirs using fixed rules of operation which guide release decisions as a function of reservoir initial elevation, amount of inflow and resulting water level rise (TVA, 1974c). Omitting Boone because of limited storage space reduces the number of reservoirs controlling the drainage basin upstream of Chattanooga (21,400 sq. miles) to 12. The routing program uses time steps of six hours for the tributary reservoirs and one day for the main river reservoirs. The outflow from upstream reservoirs are simply translated by constant time lag (see figure 5.2) into the next reservoir downstream.

To limit the number of initial storage elevations and thus the number of routings per flood event each of the five major tributary storage reservoirs was assigned five initial levels at equal storage intervals between the minimum level and the top-of-the-gates level. For the small tributary reservoirs (South Holston, Watauga, Chatuge and Nottely) and for the three main river reservoirs initial levels were kept constant at intermediate levels. The routing scheme was first tested using three major historical floods. As an example, the test results for the March 1963 flood are shown in figure 5.3. The Chattanooga stage above which damage results is 30 ft. The observed hydrograph is slightly higher but close to the computed hydrograph using fixed rules and the actual storage levels at the start of the flood. Complete agreement cannot be expected since actual reservoir operation did not follow closely the fixed rules.

An analysis was made of all damage producing floods on record since 1875. Prior to 1936, before the first flood control project was completed upstream of Chattanooga, systematic records were kept only of floods with a peak discharge larger than approximately 210,000 ft^3/s.

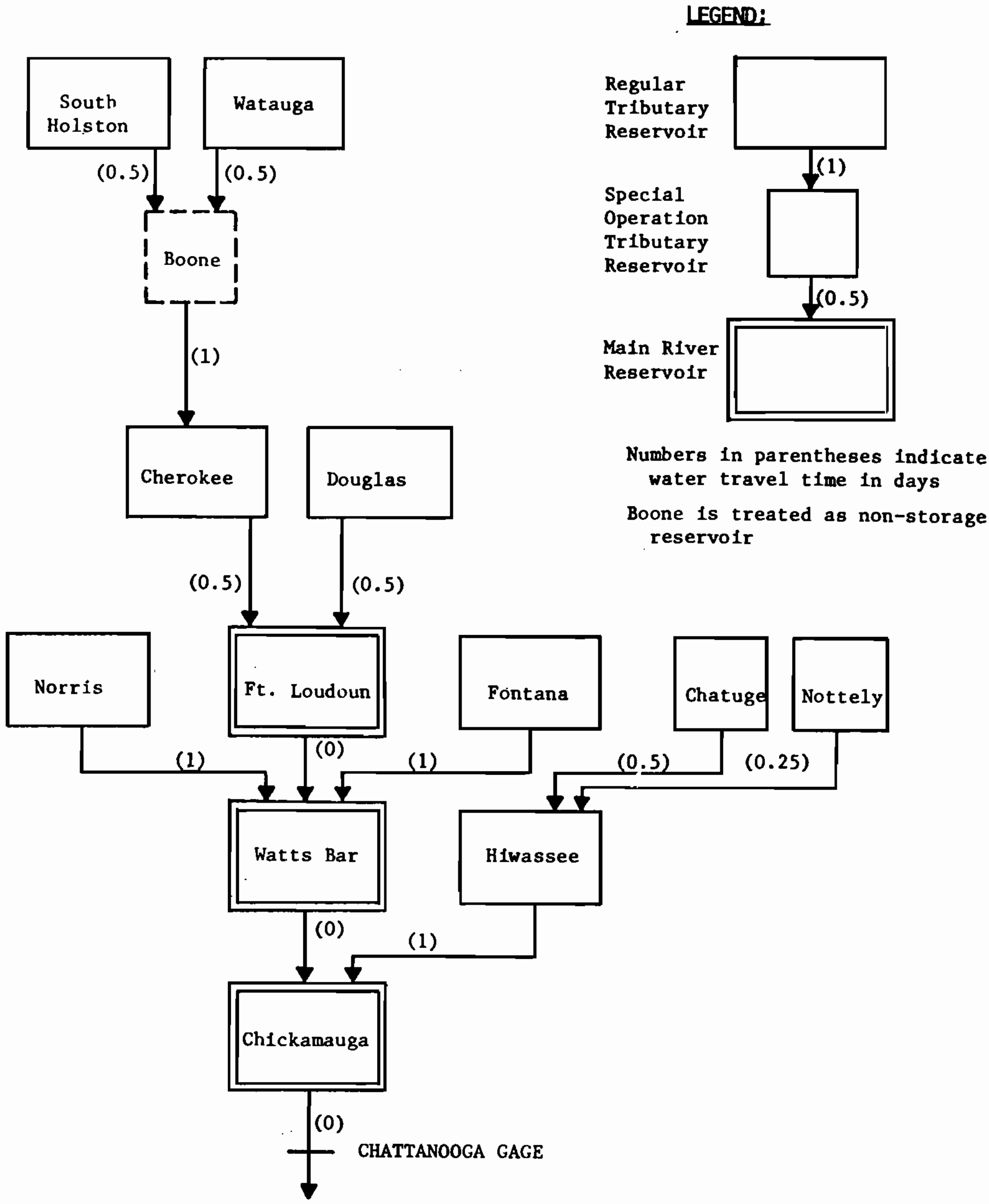


FIGURE 5.2 FLOOD ROUTING SEQUENCE

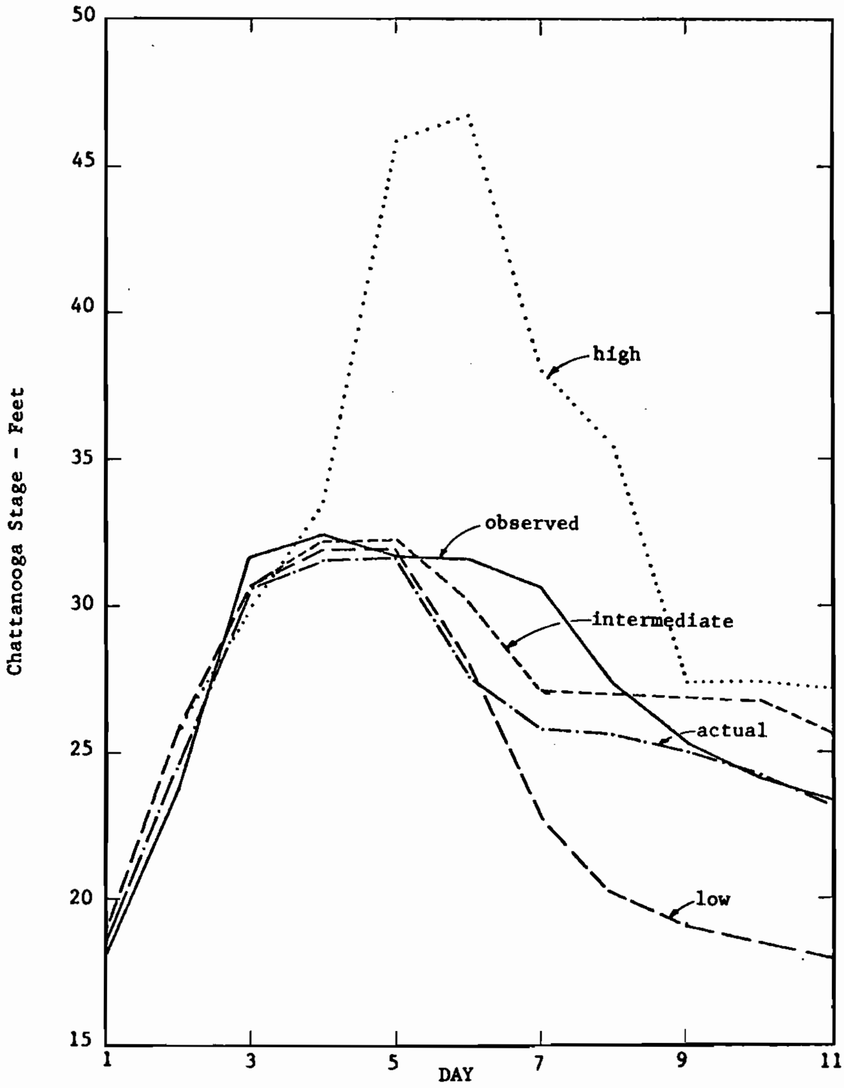


FIGURE 5.3 MARCH 1963 FLOOD-OBSERVED AND COMPUTED CHATTANOOGA HYDROGRAPHS FOR VARIOUS INITIAL TRIBUTARY RESERVOIR LEVELS

After this date the natural crest was determined for all floods requiring regulation and called natural flood. Based on these records, probabilities of occurrence were determined for natural floods at Chattanooga during a given week. The records were grouped into three-week subsets to produce an equivalent average for the center week to overcome the data scarcity of one-week subsets. The three-week subsets were graphically adjusted using the method of extreme values by Gumbel (1954) and produced remarkably straight adjustment lines. The one-week probability was simply taken as a one-third of the three-week probability since the method used practically multiplied by three the number of extreme values in each week.

For simplicity it was assumed that the regulated crests retain the same probability as the natural floods producing them. The total expected flood damage during a given week for a selected storage combination is then

$$TD = \sum_{i=1}^{k} D(i) \times P(i) \tag{5.10}$$

with k the number of flood events i used to represent the range of damage producing floods; D(k) the damage produced by the flood event i; P(i) the probability of occurrence of the flood event i during the week studied. D(i) depends on the flood magnitude and on the state of initial levels in the storage reservoirs. P(i) depends on the flood magnitude and on the week studied.

A certain number of floods ranging from just above 215,000 ft^3/s, the damage limit, to the highest flood observed will be routed starting from any practical combination of reservoir levels. The resulting damages will be associated with the corresponding probabilities of occurrence for every week.

In routing a given flood starting from all selected combinations a certain strategy must be followed to reduce computer time and memory requirements. As indicated before, only five major tributary reservoirs with five initial levels are included which reduces the number of storage combination to 5^5. Furthermore if one regards as improbable that any two of the five reservoirs are at levels differing by more than two levels, the number of cases to be studied is reduced to 665 for each flood event.

The expected damage can then be expressed as a function of storage combinations by a multi-variate regression or a look-up table. Since it is based upon a rigid fixed rule operating procedure without the benefit of flood forecast and other flexibilities available during actual operation, the values should be considered as upper limits.

5.5 Other Objective Functions

Other objectives being considered for inclusion in a multipurpose objective function account for navigation, water quality maintenance, water supply and recreation. The basic principle for inclusion of these objectives is to relate their associated benefits or costs to parameters which are influenced by operation of the reservoir system, such as discharge from dams, flow velocities and water levels in rivers and reservoirs and the rates of change of these characteristics. At present, no such formulation is yet complete.

6. PLANNED METHODOLOGY DEVELOPMENT

An outline is given of the planned model development for future day-to-day multipurpose water management of the TVA system, the use of the various models in the overall scheme and the hardware requirements to implement the scheme. The plan is still tentative pending further evaluation.

6.1 Planning and Operation Models

The proposed program is basically aimed at the development of operational decision aids in form of mathematical models. Some of these models will be used in a planning mode for long-range planning of system operations, others will be used weekly, daily or more often as required by operational decisions of day-to-day water management. The former models are termed "planning" models, the latter ones "operation" models.

The activities proposed for the principal program phase are centered around the development of four mathematical models considered essential for preparation and execution of day-to-day water resource management:

1. Weekly planning model: to be used in long-range operational planning studies for given system configuration and characteristics; operating on generated or historic input data to meet projected system operation goals, over yearly or longer time horizons by weekly time steps.
2. Weekly operation model: of similar design as the planning model but with input data and system operation goals continually updated based on forecasts projecting from the current data

base into an uncertain future, over periods of several weeks or months by weekly time steps.

3. <u>Daily planning model</u>: to be used for disaggregating output from the weekly planning model into daily schedules; hourly schedules will be computed as needed, at critical sites where transient phenomena, such as diurnal cycles, unsteady flow, etc. become important or have impact on the daily or weekly schedules; operates on daily or hourly input data.
4. <u>Daily operation model</u>: an expanded version of the daily planning model with extensive data updating capabilities using latest forecasts of power, meteorologic and hydrologic data to update release schedules; to be used in sequence with the weekly operation model; disaggregates weekly schedules into daily or if needed hourly schedules; produces forecasts of release schedules for the same day and several days ahead.

Presently under development is the weekly planning model as described in chapter 5. As a general rule, release scheduling becomes more complex with decreasing time step size. For example, water travel time and transient phenomena, unimportant in the weekly models, must be considered in daily or hourly scheduling. Also storage and head of the main stream reservoirs which are prescribed in weekly scheduling become variables for daily or hourly time steps.

The proposed models are planned to be used as segments of a reservoir scheduling cycle. At the start, the long-range planning model will be used to determine a reservoir operation policy for an extended period, such as a year in advance, using expected input data, system characteristics and system operation objectives. This system operation study will make use as needed also of the daily planning model. The weekly operation model will then produce an updated operation policy for the next few weeks ahead, based on the most recent data forecasts which extend the input into the future based on the present state of the system. Only the first two weeks of this schedule will then be used as input to the daily operation model, which disaggregates the weekly schedule into daily or hourly schedules as needed. The daily operation model continually updates the input data forecasts and recomputes the daily operation schedule one day or less ahead of actual operations until the end of the first week of the biweekly period. After the first week has elapsed, or earlier if considerable departures between predicted and actual input data occur, the computation returns to the weekly operation model. The weekly policy is updated for the next few weeks ahead using most recent input data. In case of important events, such as floods or droughts, undesirable reservoir water quality developments or changes in system characteristics, a revised long-range operation policy is computed using the weekly planning model, thus completing the scheduling cycle.

6.2 Implementation

As presently envisioned, the hardware required for implementation of the water management methodology is rather modest. It will consist of a small dedicated real-time processor and peripheral equipment, see figure 6.1. All models used in the operational mode, especially the weekly and daily operation models, the various input data forecasting models and input/output analysis programs will be coordinated by this on-line computing facility

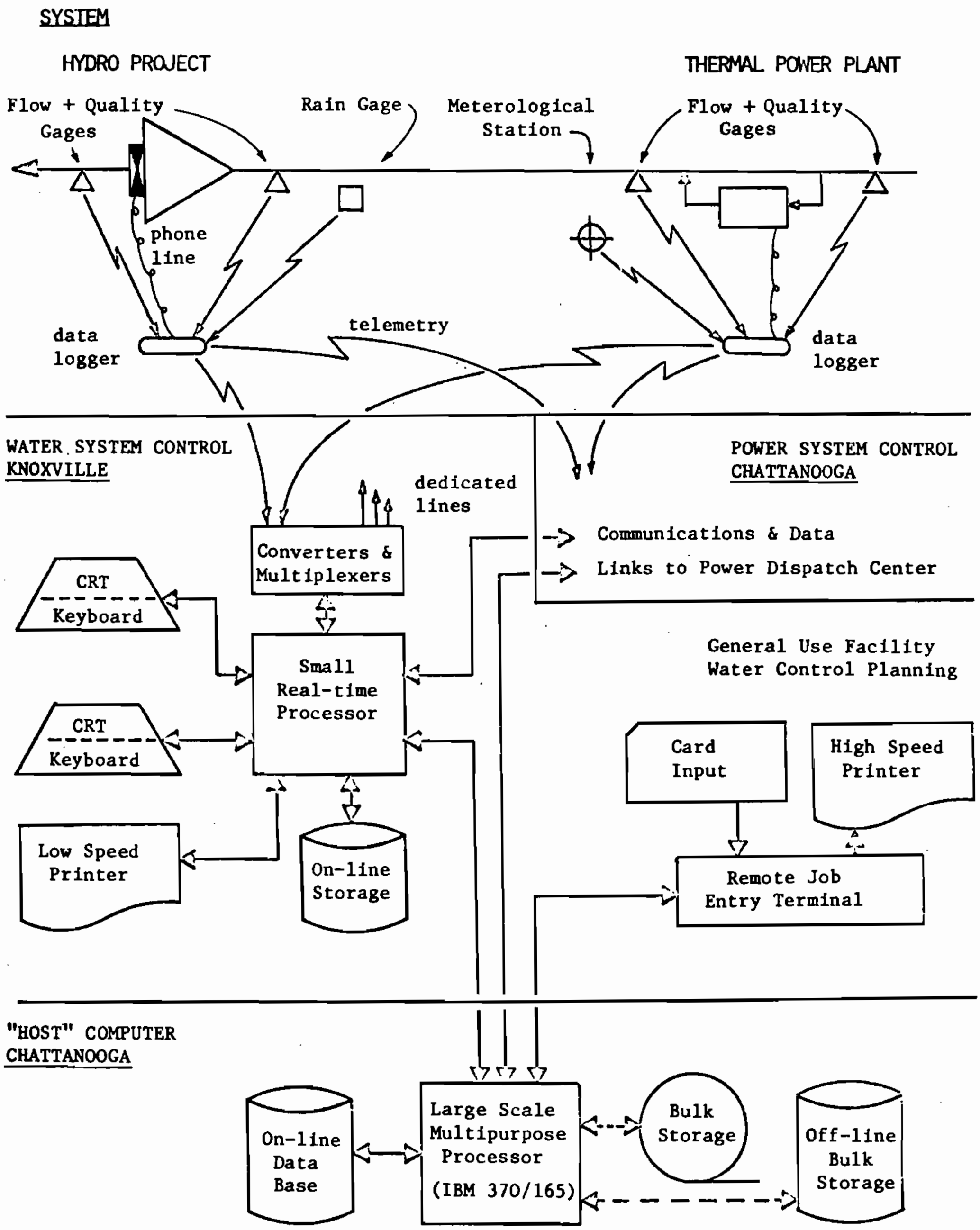


FIGURE 6.1 ENVISIONED COMPUTER CONFIGURATION FOR WATER RESOURCE MANAGEMENT

in the water control center at Knoxville. This equipment will have the capability to handle analog and digital input and output. It will monitor automatically at predetermined intervals important data such as flows, reservoir levels, water quality and meteorological parameters. These will be logged and checked against desired targets. Alarms will be prompted if corrective action is required.

The small real-time computer will be connected to TVA's large general-purpose host computer (currently an IBM 370/165 in Chattanooga). There the data will be collected in an on-line data base. The real-time processor in Knoxville will have the ability to initiate, either in a normal batch mode or in an immediate mode, programs on the host machine, automatically, on a scheduled basis, or at the request of the operator. All large "number crunching" programs will be executed on the host machine. The results of these runs will be available to the operator via the real-time processor or directly from a line printer.

At the water control center in Knoxville, the operator will interact with the computer system by means of cathode ray tube (CRT) displays and typewriter keyboards. The operator can request a variety of tables, graphs, or charts depicting the status of the system or program output. Commands may be issued by the operator through the keyboard or by touching "poke points" on the CRT with a light pen. The real-time processor either responds directly to the command or passes it along to the host computer. A low speed printer will keep a hardcopy log of operator actions, short responses, and alarm conditions. A disk storage device connected to the real-time processor will provide storage for the processor's program library, and temporary data storage. It also acts as a communications buffer for messages between the real-time processor and the host machine. High speed printing for the Knoxville water control center can be produced by a general purpose remote job entry terminal. This terminal is independent of the real-time processor and would have limited capabilities as a backup in the event of failure of the real-time processor. The water control center will have communications and data links with the power system dispatch center in Chattanooga for data sharing and for proper coordination of reservoir operations. After the operation schedule is decided upon the power dispatch center will relay the commands back to the water control points in the system which are mostly hydro plants. No complete system automation is foreseen at the present time.

6.3 Economic Justification

The results of the initial phase indicate that by proper use of all system capabilities at least marginal improvements in system operation and associated costs can be achieved. Also, preliminary results of the optimization studies indicate that by use of optimization methods in reservoir scheduling several million dollars annually can be saved in system generation costs. In comparison, the expense for the proposed methodology development including the initial phase, according to present estimates will cost about $4 million over a period of about ten years. It is therefore concluded that the expense can be recovered over a rather short period, such as ten years, including possible costs for continued methodology updating and improvement. In addition to the monetary benefits, considerable intangible benefits of a socio-political nature will a accrue which are of great importance to TVA.

7. CONCLUSIONS AND OUTLOOK

This report gives account of the status of a program initiated by TVA in 1971. The basic idea underlying this program is to put to work on real world problems the operations research methodology developed in recent years. Such an undertaking is very timely as the experiences of the recent past reemphasize the great challenge to be met by TVA system management to optimally operate the reservoir system for the specified multipurpose uses under observation of all constraints of balanced resource development and conservation.

The TVA reservoir system is practically completed. However, the addition of thermal power generation capacity or other demands on quantity and quality provided by the reservoir system may require future impact assessments in a total system context. A case study of this type of assessment was presented for Browns Ferry Nuclear Plant using system simulation models. The results showed that cooling mode 1 which uses all available system capabilities as needed and as compatible with system constraints allowed most economic system operation.

The search for system analysis techniques to be used for reservoir release scheduling led to the adoption of "dynamic programing by successive approximation" as a promising method to produce flexible multipurpose reservoir operation guidelines.

The overview of future model development shows that considerable work remains to be done in the areas of multipurpose objective function development, especially for navigation, water quality, water supply and recreation, short time step scheduling, water quantity and quality transport modeling in rivers and reservoirs, forecasting for hydrological, meteorological and quality data and for input to the objective functions. Also data management as well as program management techniques must be developed to meld into an operational scheme the various component models for use as a day-to-day decision aid by system management.

REFERENCES

Bellman, R, 1957, "Dynamic Programing," Princeton University Press, Princeton, New Jersey, 342 pages.

Brudenell, R. N. and J. H. Gilbreath, 1959, "Economic Complementary Operation of Hydro Storage and Steam Power in the Integrated TVA System," AIEE Transmission Power Apparatus and Systems, Vol. 78, pp. 138-156.

Dantzig, G. B., 1963, "Linear Programing and Extensions," Princeton University Press, Princeton, New Jersey, 632 pages.

Durbin, E. P. and D. M. Kroenke, 1967, "The Out-of-Kilter Algorithm: A Primer," Prepared for the United States Air Force Project Rand, The Rand Corporation, Santa Monica, California, Memorandum RM-5472-PR, 22 pages.

Ford, L. R., Jr. and D. R. Fulkerson, 1962, "Flow in Networks," Princeton University Press, Princeton, New Jersey, 194 pages.

Fulkerson, D. R., 1961, "An Out-of-Kilter Method for Minimal-Cost Flow Problems," Journal of the Society of Industrial and Applied Mathematics, Vol. 9, No. 1, pp. 18-27.

Gumbel, E. J., 1954, "Statistical Theory of Extreme Values and Some Practical Applications," National Bureau of Standards Applied Mathematics Series 33, U.S. Government Printing Office, Washington, DC, 51 pages.

Heidari, M., V. T. Chow and D. D. Meredith, 1971, "Water Resources Systems Analysis by Discrete Differential Dynamic Programing," Civil Engineering Studies, Hydraulic Engineering Series No. 24, University of Illinois, Urbana, Illinois, 118 pages.

Jacobsen, D. H., 1968, "Second-Order and Second-Variation Methods for Determining Optimal Control: A Comparative Study Using Differential Dynamic Programing," International Journal of Control, Vol. 7, No. 2, pp. 175-196.

Jacobsen, D. H., 1968, "New Second-Order and First-Order Algorithms for Determining Optimal Control: A Differential Dynamic Programing Approach," Optimization Theory and Applications Journal, Vol. 2, No. 6.

Jacobson, D. H. and D. Q. Mayne, 1970, "Differential Dynamic Programing," American Elsevier Publishing Company, Inc., New York, 206 pages.

Kibler, D. F. and I. P. King, 1971, "Mathematical Models for Planning the Development of the Vistula River Basin, Poland," Water Resources Engineers, Inc., Walnut Creek, California.

REFERENCES - Continued

Kothandaraman, V. and R. L. Evans, 1972, "Use of Air-Water Relationships for Predicting Water Temperature," Report of Investigation No. 69, Illinois Department of Registration and Education, Illinois State Water Survey, Urbana, Illinois, pp. 1-11.

Larson, R. E., 1964, "State Increment Dynamic Programing," Presented at the Allerton Conference on Circuit and System Theory, University of Illinois, 19 pages.

Larson, R. E. and A. J. Korsak, 1970, "A Dynamic Programing Successive Approximations Technique with Convergence Proofs," Automatica, Vol. 6, pp. 245-260.

Mayne, D. Q., 1966, "A Second-Order Gradient Method for Determining Optimal Trajectories of Nonlinear Discrete-time Systems," International Journal of Control, Vol. 3, No. 1, pp. 85-96.

Texas Water Development Board, 1970, "Systems Simulation for Management of a Total Water Resource," Report 118, pp. 1-83.

Trott, W. J. and W. W-G. Yeh, 1971, "Multi-Level Optimization of a Reservoir System," ASCE Annual and National Environmental Engineering Meeting, St. Louis, Missouri, 17 pages.

TVA, 1973a, Water Resource Management Methods Staff, "Weekly Scheduling for a Flow Requirement at a Chosen Site," Report A-1, Knoxville.

TVA, 1973b, WRMM Staff, "Water Temperature Prediction Model for Deep Reservoirs," Report A-2, Knoxville.

TVA, 1973c, WRMM Staff, "Air-Water Temperature Correlation for Browns Ferry," Report A-3, Knoxville.

TVA, 1974a, WRMM Staff, "Hourly Scheduling of the Browns Ferry-Guntersville-Wheeler-Wilson Subsystem," Report A-4, Knoxville.

TVA, 1974b, WRMM Staff, "Evaluation of Weekly Hydropower Benefits," Report A-6, Knoxville, (in preparation).

TVA, 1974c, WRMM Staff, "Flood Routing for the Reservoir System Upstream Chattanooga Using Fixed Rules," Report B-10, Knoxville, (in preparation).

APPENDIX

TABLE A1 STORAGE CONSTRAINTS - 100 $ft^3/s\text{-}wk$

Week	Watauga(1) Max.	Watauga(1) Min.	S.Holston(2) Max.	S.Holston(2) Min.	Cherokee(3) Max.	Cherokee(3) Min.	Douglas(4) Max.	Douglas(4) Min.	Fontana(5) Max.	Fontana(5) Min.	Norris(6) Max.	Norris(6) Min.
1	274.	9.	249.	7.	254.	22.	125.	53.	442.	109.	629.	128.
2	280.	9.	253.	7.	274.	22.	141.	53.	453.	109.	652.	128.
3	287.	9.	258.	7.	295.	22.	157.	53.	464.	109.	693.	128.
4	294.	9.	262.	7.	316.	22.	175.	53.	475.	109.	714.	128.
5	301.	9.	267.	7.	338.	22.	194.	53.	486.	109.	730.	128.
6	308.	9.	271.	7.	361.	22.	214.	53.	498.	109.	789.	128.
7	315.	9.	276.	7.	385.	22.	235.	53.	509.	109.	820.	128.
8	323.	9.	281.	7.	410.	22.	258.	53.	521.	109.	857.	128.
9	330.	9.	286.	7.	436.	22.	281.	53.	533.	109.	889.	128.
10	337.	9.	293.	7.	464.	22.	305.	53.	546.	109.	911.	128.
11	345.	9.	301.	7.	505.	22.	346.	53.	568.	109.	997.	128.
12	352.	9.	319.	7.	568.	22.	413.	53.	602.	109.	1039.	128.
13	359.	9.	336.	7.	656.	22.	506.	53.	654.	109.	1101.	128.
14	366.	9.	355.	7.	806.	22.	569.	53.	721.	109.	1146.	128.
15	373.	9.	374.	7.	892.	22.	804.	53.	901.	109.	1264.	128.
16	373.	9.	374.	7.	974.	22.	924.	53.	864.	109.	1391.	128.
17	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
18	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
19	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
20	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
21	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
22	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
23	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
24	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
25	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
26	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
27	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
28	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
29	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
30	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
31	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
32	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
33	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
34	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
35	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
36	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
37	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
38	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
39	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1550.	128.
40	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1467.	128.
41	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1410.	128.
42	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1337.	128.
43	373.	9.	374.	7.	1061.	22.	1054.	53.	931.	109.	1267.	128.
44	373.	9.	374.	7.	1061.	22.	1054.	53.	875.	109.	1198.	128.
45	373.	9.	374.	7.	1061.	22.	1054.	53.	818.	109.	1122.	128.
46	373.	9.	374.	7.	1028.	22.	955.	53.	761.	109.	1049.	128.
47	373.	9.	355.	7.	922.	22.	823.	53.	724.	109.	979.	128.
48	366.	9.	335.	7.	797.	22.	695.	53.	647.	109.	926.	128.
49	340.	9.	312.	7.	668.	22.	548.	53.	590.	109.	872.	128.
50	318.	9.	291.	7.	535.	22.	413.	53.	533.	109.	818.	128.
51	291.	9.	268.	7.	397.	22.	269.	53.	482.	109.	765.	128.
52	267.	9.	244.	7.	236.	22.	110.	53.	432.	109.	711.	128.
53	274.	9.	249.	7.	254.	22.	125.	53.	442.	109.	629.	128.

TABLE A2 POLYNOMIAL COEFFICIENTS FOR COMPUTING PLANT POWER FACTORS

Reservoir Name	No.	10 B1	10 B2	10 B3	10 B4	10 B5	10 B6
Watauga	1	0.10110D 02	0.11090D 00	-0.66887D-03	0.24659D-05	-0.45355D-08	0.32300D-11
S.Holston	2	0.84879D 01	0.51658D-01	-0.95655D-04	-0.24340D-06	0.11802D-08	-0.12068D-11
Cherokee	3	0.21717D 01	0.32156D-01	-0.74499D-04	0.10629D-06	-0.79712D-10	0.23787D-13
Douglas	4	0.80706D 00	0.31454D-01	-0.73449D-04	0.10708D-06	-0.81325D-10	0.24187D-13
Fontana	5	0.12619D 02	0.63654D-01	-0.11785D-03	0.15219D-06	-0.11056D-09	0.32855D-13
Norris	6	0.40294D 01	0.22805D-01	-0.30215D-04	0.25645D-07	-0.11311D-10	0.19795D-14

Note: D 02 is equivalent to 10^2

TABLE A3 COEFFICIENTS FOR COMPUTING PLANT CAPACITIES - A(K)

K	Watauga 1	S.Holston 2	Cherokee 3	Douglas 4	Fontana 5	Norris 6
1	0.13700D 03	0.11733D 03	0.75220D 03	0.10317D 04	0.65394D 03	0.12927D 04
2	0.60000D 02	0.40000D 02	0.14600D 03	0.15200D 03	0.24400D 03	0.12000D 03
3	0.40467D 04	0.39234D 04	0.17759D 05	0.16650D 05	0.91751D 04	0.24714D 05
4	-0.69410D 01	-0.97331D 01	0.10556D 02	0.0	0.23449D 01	-0.28608D 02
5	0.99208D-02	0.15918D-01	-0.24778D-01	0.0	-0.78496D-02	0.17380D-01
6	-0.39941D-05	-0.11129D-04	0.13206D-04	0.0	0.39999D-05	-0.37157D-05
7	0.27521D 02	0.22491D 02	0.25376D 02	0.63987D 01	0.66551D 02	0.30478D 02
8	0.40604D 00	0.21415D 00	0.49093D 00	0.41191D 00	0.61365D 00	0.12840D 00
9	-0.22451D-02	-0.89003D-03	-0.69822D-03	-0.45162D-03	-0.70715D-03	-0.81817D-04
10	0.73961D-05	0.28626D-05	0.34567D-06	0.18491D-06	0.28282D-06	0.27950D-07
11	0.25045D 04	0.26239D 04	0.98530D 04	0.98570D 04	0.67525D 04	0.57024D 04
12	0.87636D 01	0.69538D 01	0.50836D 02	0.36927D 02	0.92823D 01	0.49613D 01
13	-0.40802D-01	-0.30587D-01	-0.96935D-01	-0.56180D-01	-0.13471D-01	-0.17643D-02
14	0.12817D-03	0.51112D-04	0.56936D-04	0.26142D-04	0.50348D-05	-0.16313D-06

TABLE A4 COEFFICIENTS OF WEEKLY HYDROPOWER RETURN FUNCTION

Week	AHYRO (I,K)							
I	K=1	2	3	4	5	6	7	8
1	0.0	0.12000D 02	0.64073D 01	-0.19643D-02	0.33752D-06	0.22226D 01	0.41591D-04	-0.53930D-04
2	0.52200D 03	0.12000D 02	0.11202D 02	-0.56527D-02	0.11841D-05	0.22152D 01	0.11233D-04	-0.51516D-04
3	0.0	0.12000D 02	0.61947D 01	-0.19730D-02	0.36735D-06	0.21114D 01	0.33756D-04	-0.46395D-04
4	0.0	0.12000D 02	0.61670D 01	-0.19214D-02	0.35655D-06	0.20809D 01	0.37972D-04	-0.73961D-04
5	0.0	0.12000D 02	0.29635D 01	-0.31280D-03	0.65811D-07	0.24801D 01	0.39199D-05	-0.58997D-05
6	0.0	0.12000D 02	0.27478D 01	-0.13758D-03	0.36595D-07	0.24556D 01	-0.11662D-09	0.52816D-09
7	0.14370D 04	0.12000D 02	0.11355D 02	-0.64967D-02	0.16443D-05	0.23273D 01	0.36649D-04	-0.58933D-04
8	0.23770D 04	0.12000D 02	0.10710D 02	-0.35051D-02	-0.75604D-06	0.24895D 01	0.72655D-05	-0.73583D-04
9	0.87800D 03	0.12000D 02	0.11220D 02	-0.69579D-02	0.17941D-05	0.21557D 01	0.26723D-04	-0.68196D-04
10	0.30000D 03	0.12000D 02	0.11134D 02	-0.60255D-02	0.13138D-05	0.19800D 01	0.38219D-04	-0.20508D-03
11	0.30000D 03	0.12000D 02	0.11147D 02	-0.60610D-02	0.13175D-05	0.20315D 01	0.47096D-04	-0.10482D-03
12	0.12330D 04	0.12000D 02	0.11270D 02	-0.57117D-02	0.11974D-05	0.21240D 01	0.43267D-05	-0.71728D-04
13	0.0	0.12000D 02	0.59202D 01	-0.15494D-02	0.28055D-06	0.12172D 01	0.24339D-03	-0.32777D-03
14	0.25800D 03	0.12000D 02	0.11156D 02	-0.55185D-02	0.11132D-05	0.22797D 01	0.17618D-04	-0.56439D-04
15	0.12800D 03	0.12000D 02	0.11151D 02	-0.54207D-02	0.10624D-05	0.22211D 01	0.32031D-04	-0.63472D-04
16	0.12800D 03	0.12000D 02	0.11291D 02	-0.55411D-02	0.10971D-05	0.20653D 01	0.35435D-04	-0.71058D-04
17	0.77800D 03	0.12000D 02	0.11299D 02	-0.59124D-02	0.13238D-05	0.21199D 01	0.23697D-04	-0.80750D-04
18	0.18870D 04	0.12000D 02	0.10711D 02	-0.16344D-02	-0.19574D-05	0.21351D 01	0.19605D-04	-0.74017D-04
19	0.81700D 03	0.12000D 02	0.11255D 02	-0.59971D-02	0.13614D-05	0.21975D 01	0.18387D-04	-0.68178D-04
20	0.82400D 03	0.12000D 02	0.11249D 02	-0.59815D-02	0.13505D-05	0.21375D 01	0.40636D-04	-0.74495D-04
21	0.99700D 03	0.12000D 02	0.11128D 02	-0.66077D-02	0.16442D-05	0.21211D 01	0.31066D-04	-0.82322D-04
22	0.0	0.12000D 02	0.11354D 02	-0.67277D-02	0.14597D-05	0.21227D 01	0.40879D-04	-0.60939D-04
23	0.22240D 04	0.12000D 02	0.10418D 02	0.12327D-02	-0.44005D-05	0.20584D 01	0.84649D-06	-0.62292D-04
24	0.24300D 04	0.12000D 02	0.10381D 02	0.12239D-02	-0.44493D-05	0.21491D 01	0.85357D-06	-0.94059D-04
25	0.21620D 04	0.12000D 02	0.10326D 02	0.12130D-02	-0.44056D-05	0.21916D 01	0.13695D-04	-0.80797D-04
26	0.26985D 04	0.12000D 02	0.10482D 02	-0.62177D-03	0.13635D-05	0.21367D 01	0.46257D-04	-0.96554D-04
27	0.15810D 04	0.12000D 02	0.11033D 02	-0.41192D-02	-0.32106D-09	0.22011D 01	-0.82466D-07	-0.96699D-04
28	0.18400D 04	0.12000D 02	0.10779D 02	-0.17696D-02	-0.18822D-05	0.20543D 01	-0.49415D-05	-0.53170D-04
29	0.15810D 04	0.12000D 02	0.10975D 02	-0.38859D-02	-0.16222D-06	0.21420D 01	0.31262D-04	-0.72996D-04
30	0.17150D 04	0.12000D 02	0.10733D 02	-0.16998D-02	-0.19171D-05	0.21394D 01	0.31132D-05	-0.77765D-04
31	0.21220D 04	0.12000D 02	0.10381D 02	0.12241D-02	-0.44495D-05	0.21428D 01	0.27586D-05	-0.77618D-04
32	0.21220D 04	0.12000D 02	0.10318D 02	0.15994D-02	-0.47317D-05	0.21454D 01	0.30322D-05	-0.64515D-04
33	0.25240D 04	0.12000D 02	0.10467D 02	-0.13415D-03	0.59303D-04	0.21443D 01	-0.13635D-05	-0.80243D-04
34	0.29260D 04	0.12000D 02	0.10451D 02	0.0	0.0	0.21506D 01	-0.45697D-06	-0.89913D-04
35	0.14400D 04	0.12000D 02	0.11193D 02	-0.53675D-02	0.91023D-06	0.20844D 01	0.26976D-04	-0.83185D-04
36	0.11390D 04	0.12000D 02	0.11243D 02	-0.57765D-02	0.12268D-05	0.20370D 01	0.14368D-04	-0.97930D-04
37	0.50200D 03	0.12000D 02	0.11312D 02	-0.59644D-02	0.12558D-05	0.20620D 01	0.19371D-04	-0.84496D-04
38	0.12060D 04	0.12000D 02	0.11327D 02	-0.58710D-02	0.12635D-05	0.19964D 01	0.93965D-05	-0.10453D-03
39	0.11060D 04	0.12000D 02	0.11384D 02	-0.63896D-02	0.13902D-05	0.19674D 01	0.20389D-04	-0.98371D-04
40	0.11700D 04	0.12000D 02	0.11177D 02	-0.56919D-02	0.11530D-05	0.22019D 01	0.21211D-04	-0.86796D-04
41	0.26000D 03	0.12000D 02	0.11242D 02	-0.57056D-02	0.12061D-05	0.21273D 01	0.38592D-04	-0.73913D-04
42	0.15600D 04	0.12000D 02	0.11002D 02	-0.49214D-02	-0.66061D-07	0.20964D 01	0.15724D-04	-0.75408D-04
43	0.15550D 04	0.12000D 02	0.10969D 02	-0.39881D-02	-0.89303D-07	0.22109D 01	-0.55589D-05	-0.36650D-04
44	0.25250D 04	0.12000D 02	0.10474D 02	-0.12318D-03	0.26545D-06	0.21413D 01	0.29534D-04	-0.88018D-04
45	0.16450D 04	0.12000D 02	0.10571D 02	-0.15618D-02	-0.19549D-05	0.22706D 01	0.26122D-05	-0.57225D-04
46	0.35430D 04	0.12000D 02	0.12000D 02	0.0	0.0	0.21017D 01	0.0	-0.94482D-04
47	0.15530D 04	0.12000D 02	0.11013D 02	-0.40952D-02	0.36441D-07	0.21054D 01	0.15582D-04	-0.65894D-04
48	0.36800D 03	0.12000D 02	0.11230D 02	-0.56249D-02	0.11553D-05	0.21401D 01	0.32836D-04	-0.66273D-04
49	0.15940D 04	0.12000D 02	0.11015D 02	-0.58464D-02	0.11315D-05	0.23193D 01	-0.26755D-05	-0.69292D-04
50	0.12040D 04	0.12000D 02	0.11088D 02	-0.65939D-02	0.17038D-05	0.23023D 01	0.17196D-04	-0.44454D-04
51	0.10740D 04	0.12000D 02	0.11131D 02	-0.66497D-02	0.17280D-05	0.22135D 01	0.27412D-04	-0.64048D-04
52	0.94400D 03	0.12000D 02	0.11079D 02	-0.63917D-02	0.15573D-05	0.23106D 01	-0.16762D-05	-0.52457D-04

TABLE A5 WEEKLY LOCAL INFLOWS AND SUBSYSTEM RELEASE REQUIREMENTS

100 ft^3/s

Week	Local Inflows - Q(J,I)						Required Release
I	J=1*	2	3	4	5	6	RS(I)
1	13.000	24.000	82.000	128.000	79.000	120.000	0.0
2	14.000	21.000	85.000	172.000	104.000	122.000	0.0
3	9.000	12.000	49.000	91.000	62.000	56.000	0.0
4	15.000	23.000	44.000	92.000	51.000	60.000	0.0
5	12.000	20.000	36.000	85.000	46.000	44.000	0.0
6	6.000	10.000	23.000	63.000	38.000	33.000	0.0
7	4.000	7.000	13.000	48.000	32.000	20.000	0.0
8	4.000	5.000	19.000	43.000	28.000	15.000	0.0
9	4.000	5.000	12.000	42.000	27.000	14.000	0.0
10	7.000	8.000	23.000	50.000	32.000	18.000	0.0
11	23.000	34.000	90.000	225.000	89.000	128.000	0.0
12	10.000	15.000	52.000	106.000	53.000	75.000	0.0
13	14.000	16.000	39.000	89.000	47.000	47.000	0.0
14	16.000	22.000	53.000	139.000	76.000	84.000	0.0
15	8.000	10.000	31.000	88.000	52.000	56.000	0.0
16	6.000	7.000	23.000	64.000	39.000	31.000	0.0
17	7.000	18.000	45.000	72.000	36.000	51.000	0.0
18	6.000	14.000	41.000	60.000	33.000	64.000	0.0
19	5.000	8.000	20.000	45.000	33.000	27.000	0.0
20	4.000	7.000	23.000	55.000	42.000	40.000	0.0
21	5.000	8.000	19.000	40.000	32.000	26.000	0.0
22	7.000	20.000	31.000	55.000	30.000	60.000	0.0
23	7.000	9.000	23.000	94.000	39.000	32.000	0.0
24	6.000	7.000	16.000	82.000	33.000	22.000	15.00
25	3.000	6.000	3.000	45.000	26.000	16.000	38.00
26	2.000	4.000	11.000	35.000	21.000	12.000	49.00
27	2.000	3.000	7.000	30.000	21.000	10.000	86.00
28	3.000	4.000	6.000	33.000	22.000	7.000	57.00
29	2.000	3.000	11.000	34.000	20.000	9.000	34.00
30	2.000	4.000	12.000	33.000	17.000	15.000	59.00
31	3.000	5.000	25.000	36.000	27.000	37.000	48.00
32	2.000	4.000	21.000	38.000	10.000	21.000	65.00
33	3.000	5.000	13.000	29.000	18.000	15.000	66.00
34	1.000	3.000	14.000	22.000	16.000	9.000	98.00
35	1.000	2.000	7.000	18.000	17.000	5.000	99.00
36	2.000	2.000	5.000	20.000	14.000	6.000	89.00
37	1.000	2.000	11.000	19.000	13.000	13.000	108.00
38	1.000	2.000	2.000	19.000	15.000	7.000	81.00
39	1.000	1.000	7.000	16.000	13.000	4.000	103.00
40	2.000	2.000	5.000	19.000	16.000	5.000	71.00
41	2.000	2.000	0.0	17.000	14.000	7.000	86.00
42	9.000	5.000	14.000	74.000	21.000	7.000	91.00
43	2.000	2.000	-1.000	40.000	14.000	7.000	120.00
44	2.000	2.000	10.000	23.000	13.000	6.000	70.00
45	2.000	2.000	2.000	27.000	16.000	7.000	97.00
46	5.000	5.000	9.000	31.000	25.000	10.000	56.00
47	5.000	5.000	20.000	53.000	25.000	20.000	39.00
48	3.000	3.000	8.000	32.000	22.000	11.000	55.00
49	3.000	4.000	8.000	34.000	26.000	15.000	66.00
50	2.000	3.000	1.000	26.000	22.000	12.000	57.00
51	4.000	5.000	10.000	32.000	36.000	14.000	0.0
52	7.000	7.000	29.000	63.000	47.000	38.000	0.0

*J=Reservoir number, see table A1.

TABLE A6 STARTING AND ENDING STORAGE LEVELS

100 ft^3/s-wk

S(1,1)*	= S(1,53)	= 250
S(2,1)	= S(2,53)	= 220
S(3,1)	= S(3,53)	= 178
S(4,1)	= S(4,53)	= 85
S(5,1)	= S(5,53)	= 279
S(6,1)	= S(6,53)	= 405

*S(1,1) is reservoir 1 at start of week 1; for reservoir numbers see table A1.

TABLE A7 TRIAL TRAJECTORY A: STORAGE

S(J,I) - 100 ft^3/s-wk

Week I	Watauga J=1	S.Holston 2	Cherokee 3	Douglas 4	Fontana 5	Norris 6
1	250.000	220.000	178.000	85.000	279.000	405.000
2	255.986	224.973	189.765	93.943	292.742	420.590
3	261.000	230.983	201.763	105.930	311.733	438.590
4	265.013	236.992	217.756	115.922	330.724	454.593
5	271.026	245.000	236.749	130.909	345.722	474.594
6	278.039	252.011	257.743	145.899	367.718	502.591
7	284.039	258.181	280.743	167.607	389.395	525.035
8	288.039	265.181	293.743	212.813	420.189	545.035
9	292.039	270.181	312.743	255.813	448.188	560.035
10	296.039	275.181	324.743	297.813	475.198	574.035
11	303.039	283.181	347.743	347.813	507.183	592.035
12	318.168	301.224	437.743	393.381	539.448	720.035
13	324.061	309.137	489.743	444.695	573.327	795.035
14	334.543	321.092	528.743	514.997	613.598	842.035
15	337.831	328.672	581.743	560.046	649.572	926.035
16	344.487	337.500	612.743	637.293	695.940	992.035
17	350.497	344.499	635.743	701.293	734.939	1013.035
18	355.797	359.603	680.743	762.891	764.927	1064.035
19	355.606	361.107	721.743	798.687	777.920	1128.035
20	357.344	362.189	741.743	816.717	797.970	1155.035
21	354.597	353.868	764.743	833.147	807.235	1189.409
22	353.926	349.229	783.743	844.490	813.241	1203.370
23	349.459	341.228	814.743	848.319	811.245	1214.005
24	348.198	333.148	833.678	849.684	807.723	1215.569
25	346.198	323.151	829.678	844.684	809.721	1213.567
26	344.197	316.153	814.681	840.683	807.719	1208.566
27	339.198	306.156	803.682	832.682	802.713	1197.564
28	337.196	299.156	783.685	818.693	792.717	1186.562
29	331.195	290.157	759.687	803.681	783.714	1153.565
30	326.194	283.157	724.694	798.680	773.711	1132.563
31	320.193	276.157	690.700	771.678	759.709	1100.564
32	316.190	269.156	662.703	747.678	740.708	1069.564
33	309.188	262.155	625.710	722.679	723.705	1038.563
34	303.185	254.155	594.713	692.690	704.702	998.564
35	297.181	247.153	564.716	650.682	683.701	958.566
36	289.178	238.152	527.721	623.636	652.700	921.563
37	283.172	231.148	492.726	585.689	623.703	874.565
38	275.168	223.145	465.726	547.694	588.703	834.563
39	271.159	217.140	427.732	502.706	557.704	776.559
40	263.152	209.135	396.734	445.721	527.703	754.555
41	260.141	205.128	363.739	395.739	497.704	718.559
42	254.134	201.121	346.736	370.734	460.714	659.560
43	246.122	199.107	322.731	313.767	430.712	620.562
44	243.107	197.095	304.727	279.781	399.719	572.570
45	239.095	197.082	286.725	256.788	371.727	530.582
46	235.078	197.064	267.722	217.814	342.736	495.595
47	235.061	198.048	253.720	192.831	320.744	463.595
48	233.046	200.031	239.721	169.850	300.754	440.599
49	235.029	202.016	230.719	152.865	282.756	420.605
50	237.012	205.000	223.716	134.885	264.781	407.606
51	239.000	208.000	217.852	122.658	252.473	399.016
52	243.000	213.000	214.384	112.014	263.029	393.572
53	250.000	220.000	178.000	85.000	279.000	405.000

TABLE A8 DPSA SOLUTION FOR CASE 1: STORAGE

S(J,I) - 100 ft^3/s-wk

Week I	Watauga J=1	S.Holston 2	Cherokee 3	Douglas 4	Fontana 5	Norris 6
1	250.00	220.00	178.00	85.00	279.00	405.00
2	262.99	229.97	256.76	141.00	327.74	524.59
3	273.00	240.48	295.00	157.00	400.73	617.59
4	281.51	239.99	316.00	175.00	431.22	670.09
5	296.03	246.00	325.25	194.00	450.72	729.59
6	308.00	266.00	361.00	214.00	496.72	773.59
7	313.54	276.00	384.24	235.00	509.00	806.54
8	314.04	273.00	410.00	258.00	509.69	796.54
9	307.54	268.18	435.00	266.50	506.19	781.54
10	301.04	263.18	448.24	249.50	501.69	765.54
11	308.04	268.18	474.24	249.31	502.19	754.04
12	330.67	298.72	568.00	413.00	559.95	852.04
13	330.06	303.64	640.24	506.00	581.83	896.54
14	344.04	319.58	679.24	595.00	618.10	943.54
15	359.83	332.17	741.74	733.55	663.17	997.04
16	367.49	341.50	773.74	821.29	684.44	1022.04
17	373.00	345.50	799.74	885.29	692.94	1022.04
18	373.00	353.60	861.24	956.89	698.43	1042.04
19	372.00	358.11	918.24	1008.19	700.82	1074.54
20	367.00	356.69	956.24	988.22	703.47	1070.04
21	360.60	353.87	959.24	977.65	715.24	1078.91
22	355.43	352.23	957.74	952.99	716.74	1073.37
23	362.00	372.00	989.24	1007.82	716.74	1102.00
24	358.50	371.65	988.18	1036.18	725.22	1102.57
25	354.20	369.15	984.18	1052.68	723.22	1091.07
26	346.70	365.65	969.18	1031.68	724.22	1075.57
27	338.20	360.16	945.18	1000.68	714.72	1056.06
28	329.70	353.66	918.18	965.18	705.22	1034.56
29	322.20	348.16	888.69	933.18	696.71	1010.56
30	323.19	341.66	854.69	902.68	686.21	987.56
31	324.19	336.16	821.20	871.18	672.71	971.56
32	327.19	332.16	798.70	843.18	668.71	977.56
33	329.19	331.16	767.71	817.18	656.70	967.56
34	329.69	326.16	735.71	782.18	643.70	951.56
35	325.18	319.15	707.22	740.18	628.70	929.57
36	320.68	311.15	671.22	694.19	614.70	904.06
37	312.17	303.15	637.73	649.69	597.20	879.56
38	313.17	295.15	652.73	604.19	578.70	862.06
39	304.16	287.14	615.73	558.70	562.20	838.56
40	295.15	278.14	583.23	510.22	543.70	812.05
41	286.14	270.13	549.24	464.74	528.20	787.05
42	298.13	269.12	551.74	455.23	510.71	764.06
43	286.12	264.11	526.23	464.77	500.21	741.06
44	277.11	256.10	485.23	440.78	492.72	718.07
45	269.09	248.08	453.73	399.79	464.23	694.08
46	260.08	240.06	415.22	363.81	448.74	671.08
47	254.06	235.05	383.22	332.83	442.24	651.09
48	249.05	230.03	361.22	324.35	435.75	640.10
49	252.03	231.02	322.22	295.37	425.27	619.11
50	245.01	225.00	280.72	269.38	415.28	563.11
51	247.00	218.00	230.35	224.16	355.97	500.02
52	243.00	213.00	207.88	110.00	311.53	440.07
53	250.00	220.00	178.00	85.00	279.00	405.00

TABLE A9 DPSA SOLUTION FOR CASE 1: RELEASE

R(J,I) - 100 ft^3/s

Week	Watauga J=1	S.Holston 2	Cherokee 3	Douglas 4	Fontana 5	Norris 6
1	0.01	14.03	17.28	72.00	30.26	0.41
2	3.99	10.49	61.24	156.00	31.01	29.00
3	0.49	12.49	40.98	73.00	31.51	3.50
4	0.49	16.99	52.23	73.00	31.50	0.50
5	0.03	0.00	0.27	65.00	0.00	0.00
6	0.46	0.0	0.22	42.00	25.72	0.06
7	3.50	10.00	0.74	25.00	31.31	30.00
8	10.50	9.82	13.32	34.50	31.50	30.00
9	10.50	10.00	20.26	59.00	31.50	30.00
10	0.0	3.00	0.0	50.19	31.50	29.50
11	0.37	3.46	0.07	61.31	31.24	30.00
12	10.61	10.09	0.45	13.00	31.12	30.50
13	0.02	0.05	0.07	0.00	10.73	0.0
14	0.21	9.41	0.12	0.45	30.93	30.50
15	0.34	0.67	0.02	0.25	30.73	31.00
16	0.49	3.00	0.49	0.00	30.50	31.00
17	7.00	9.90	0.40	0.49	30.51	31.00
18	7.00	9.50	0.50	8.70	30.61	31.50
19	10.00	9.42	1.42	64.97	30.35	31.50
20	10.40	9.82	40.22	65.57	30.23	31.13
21	10.17	9.64	40.31	64.66	30.49	31.54
22	0.43	0.23	0.16	0.17	30.00	31.36
23	10.50	9.35	43.92	65.63	30.52	31.44
24	10.30	9.50	39.80	65.50	30.00	31.50
25	10.50	9.50	38.00	66.00	30.00	31.50
26	10.50	9.50	55.00	66.00	30.50	31.50
27	10.50	9.50	54.00	65.50	30.50	31.50
28	10.50	9.50	55.50	65.00	30.50	31.00
29	1.00	9.50	55.49	64.50	30.50	31.00
30	1.00	9.50	56.00	64.50	30.50	31.00
31	0.00	9.00	56.50	64.00	31.00	31.00
32	0.00	5.00	57.00	64.00	31.00	31.00
33	2.50	10.00	57.50	64.00	31.00	31.00
34	5.50	10.00	58.00	64.00	31.00	31.00
35	5.50	10.00	58.50	64.00	31.00	30.50
36	10.51	10.00	59.00	64.50	31.50	30.50
37	0.00	10.00	6.01	64.49	31.50	30.50
38	10.01	10.00	59.01	64.49	31.50	30.50
39	10.01	10.01	59.51	64.48	31.50	30.50
40	11.01	10.01	60.01	64.48	31.50	30.01
41	0.01	3.01	0.52	26.50	31.49	29.99
42	11.01	10.01	60.53	64.47	31.50	30.00
43	11.01	10.01	61.03	63.99	31.49	29.99
44	10.01	10.01	61.53	63.99	31.49	29.99
45	11.02	10.02	61.54	62.97	31.49	30.00
46	11.02	10.02	62.04	61.98	31.49	29.99
47	10.01	10.02	62.03	61.48	31.49	31.00
48	0.02	2.02	49.03	60.98	32.49	31.99
49	10.02	10.02	61.53	59.98	35.99	71.00
50	0.01	10.00	60.38	71.23	91.31	75.09
51	8.00	10.00	59.47	146.16	80.44	73.94
52	0.0	0.0	58.89	88.00	79.53	73.07

TABLE A10 DPSA SOLUTION FOR CASE 1: SYSTEM SUMMARY

I	System Release 100 ft^3/s	Required Release R(J,I) 100 ft^3/s	Peak Gen. SPE(I) MW	Offpeak Gen. SOPE(I) MW	Total Return $
1	119.94	0.0	312.20	21.04	121315.62
2	277.25	0.0	525.99	59.88	538841.23
3	148.98	0.0	415.90	19.96	687989.39
4	157.23	0.0	439.89	30.50	846402.99
5	65.28	0.0	73.91	6.85	861608.64
6	67.99	0.0	250.46	0.0	905139.44
7	87.05	0.0	423.99	0.01	1230769.02
8	109.32	0.0	503.99	0.51	1617968.34
9	140.76	0.0	553.92	0.64	2043522.26
10	111.19	0.0	408.06	0.38	2346506.45
11	122.62	0.0	443.65	0.0	2671735.60
12	75.07	0.0	461.00	0.85	3025971.61
13	10.80	0.0	83.54	0.0	3056942.02
14	62.00	0.0	336.84	0.00	3341365.38
15	62.00	0.0	354.81	0.48	3584590.02
16	61.99	0.0	366.39	0.08	3835972.24
17	62.31	0.0	432.39	1.11	4168295.31
18	71.31	0.0	452.75	1.74	4516396.87
19	128.24	0.0	602.03	0.44	4978853.70
20	167.16	0.0	708.12	0.49	5522798.93
21	167.00	0.0	705.38	1.87	6064946.43
22	61.69	0.0	355.76	0.0	6273174.50
23	171.51	0.0	721.58	1.78	6827730.71
24	166.80	15.00	709.11	0.15	7372363.75
25	165.50	38.00	705.36	0.31	7914152.69
26	183.00	49.00	749.05	2.11	8498588.33
27	181.50	86.00	742.30	1.37	9060382.02
28	182.00	57.00	741.82	0.71	9630254.46
29	181.50	34.00	684.89	0.38	10156334.80
30	182.00	59.00	682.59	0.34	10680641.97
31	182.50	48.00	673.57	1.98	11198394.43
32	183.00	65.00	656.29	1.58	117[illegible]2768.32
33	183.50	66.00	687.83	1.55	12231390.28
34	184.00	98.00	701.24	1.29	12770228.45
35	184.00	98.00	695.79	0.49	13304700.26
36	185.50	89.00	719.41	2.33	13857700.89
37	132.50	108.00	526.15	1.99	14260932.18
38	185.50	81.00	704.23	1.80	14802153.13
39	186.00	103.00	696.37	1.70	15337314.72
40	186.00	71.00	693.41	0.66	15870004.34
41	88.50	86.00	390.05	0.64	16157298.99
42	186.50	91.00	683.86	1.08	16682736.19
43	186.50	120.00	677.95	0.97	17203624.76
44	187.00	70.00	662.85	1.49	17713026.22
45	186.00	97.00	655.51	1.49	18216808.08
46	185.50	56.00	644.22	1.83	18711966.23
47	186.00	39.00	630.63	3.88	19197171.25
48	174.50	55.00	511.54	10.20	19578033.39
49	228.50	66.00	606.30	95.24	20055574.66
50	288.00	67.00	527.57	303.17	20543913.14
51	360.01	0.0	524.77	339.79	21024390.19
52	299.49	0.0	404.32	285.48	21403062.75

IIASA DISCUSSION PAPER

E. Wood

The TVA's system contains many large, complex water resource systems subjected to various, often conflicting, demands. System outputs such as power and recreation have increased value owing to both their limited quantities and to increased demands. To plan and manage a system like the TVA requires more sophisticated procedures than have been previously needed.

In this paper the TVA describes a program to develop models to be used in the operation and planning of their system. Any management program implies this process of evaluating and choosing "optimal" decision acts. Such a decision making process contains certain elements such as:

1) the objective function. Before we can operate on the objective function, the objectives must be defined and appropriate measures of effectiveness found. Some measures of effectiveness for the objective function to "minimize flooding" could be: reduction of flood damages in monetary terms or the occurrence of floods that cause damages. Our measures of effectiveness affect how we evaluate and model various potential decision sets.

2) the system modelling. The purpose of the modelling effort is to gain a perspective into how the system reacts to various decision acts. The output of the modelling effort is a flow of information up into the decision making level. Modelling should not take place before the objectives and measures of effectiveness are completely analyzed since the type of model depends upon the first step.

Conceptually, a planning methodology can be viewed as a ierarchy. At the bottom there exists a set of models that 'describes" the system and the impact of various possible ecisions upon the system's outputs. These outputs, or measures f effectiveness, feed up into the decision making level whose utput is an "optimal" decision act. The "optimal" decision is ighly dependant upon the chosen measures of effectiveness and he modelling of the system.

With this simple view of a planning methodology, let me turn to the first part of the paper - the Browns Ferry impact study. In particular with this study and with the TVA's program in general I felt that there was a lack of overall planning methodology. It is my feeling that the TVA went too quickly into the modelling effort without understanding how or where the modelling output fits into the decision making process.

In the Browns Ferry study the TVA is interested in the impact of the proposed nuclear power plant on the economy (measured as total system generation costs), water quantity (measured by river discharge at Browns Ferry and the water level in some of the major tributary reservoirs), and water quality (measured by the resulting river temperatures at Browns Ferry and outflow temperatures from the reservoirs considered above). The decision set considered four modes of cooling: by rivers, by towers, by rivers and towers combined with and without upstream release scheduling.

Four models were used to perform the analysis: a weekly system scheduling model, an hourly subsystem scheduling model, a weekly temperature generation model, and a deep reservoir water temperature prediction model. Before commenting on these four models, there are a number of questions that come to mind.

a) How are decisions made, Maximizing expected net benefits subjected to various constraints? Maximizing system reliability subjected to some implicit cost constraints? Was this study used in decisions concerning Browns Ferry or was the study done after the fact?

b) In the study described here, should the decision set be limited to the four modes considered? I feel that the capacity of the plant is an important decision variable. Similarly, with the cooling tower capacity and its design for these parameters can affect the ecological impact of the plant as well as its operation. Another alternative to consider could be the siting of the plant to take advantage of the more favourable cold water releases from particular reservoirs.

With respect to the models I have a few comments. The weekly scheduling model tries to balance stream generation and hydrogeneration for a particular set of hydrologic and system conditions subject to predetermined constraints. The impact of Browns Ferry was determined for "a wet year, a dry year, and an average year." Since the operation model was significantly affected by these various inputs, it would be important to determine what the frequency and impact was, on the overall system of various hydrolic inputs. What is the frequency associated with a "dry year?" If the unit is cut back, can the hydro system pick up the demand? With what probability will the system have trouble meeting demands and how will the additional drawdown of reservoirs affect future performance. These kinds of basic statistical questions do not seem to be addressed.

In the case of the hourly scheduling model, I am not too clear on its role in providing information for a long range, impact study. Is the information too fine? Similarly, a model like the deep reservoir temperature prediction model should be used to study in detail some critical issue that may affect the operation. It should be considered as a submodel that feeds information into other system models. Does the use of the same inflow temperature and heat transfer data for all years negate the value of its outputs?

The weekly water temperature generation model is composed of two parts: a deterministic Fourier component and a linear regression on residual air temperature. Therefore, the "generation" model is really a deterministic predicition model for temperature. Such a model will predict the mean but will not maintain statistics such as the variance. This is not to imply that the prediction model is not useful: it may be very good but like all other models its role must be well specified.

The results of the Browns Ferry impact were very interesting. Even with the modelling problems encountered, insights into certain aspects of the system operation could be made. The feeling remains, though, that the decision space should include additional items, and that a more complete decision methodology be planned out which would include a more intensive statistical analysis.

Reservoir scheduling and operation is a problem faced by all large reservoir systems, and the TVA's work considers many of the latest techniques. Their objective function was, in essence, a fifth-order polynomial with respect to reservoir storage. They considered four deterministic optimization procedures: a linear network flow algorithm, discrete differential dynamic programing, dynamic programing by successive approximation, and a reduced gradient method.

It is understandable that owing to the nature of the objective function a linear programing technique was found to be unacceptable. The large dimensionality of the problem requires some dynamic programing techniques that restricts the trajectories of the solution. It is well known that such procedures as DDDP and DPSA may lead to local optima rather than global optima. The possibility of this increases with the complexity of the system: has the TVA investigated this aspect? Essentially it involves looking at particular properties of convexity for the constraint set. The local optimality problem can also arise with the reduced gradient method. It is recognised that scheduling is an extremely complex problem and that procedures which may give partial solutions are better than no solutions at all.

A number of additional questions arise concerning reservoir operating policies.

1) Has the TVA considered quadratic programing? One difficulty will be the size of the resulting problem: it may not be solvable without decomposition.

2) I think that we all recognize that stochastic effects must be included. Should this take the form of working with generated inflows or should some other measure such as "system resiliency" be incorporated?

3) How do the increased benefits from "better" operation compare with the forgone benefits from a better design, that is, the determination of better reservoir capacities and targets. What I am getting at is this: should more effort go into the design of a system component since, once constructed can only marginal improvements be made?

Many of the comments concerning the reservoir scheduling study also apply to the study of the long-range multipurpose reservoir release scheduling. I would like though to address a few comments and questions to the objective functions.

a) In the flood control objective function, relationships between storage space combinations and resulting hydrographs were determined. Would this not result in an extremely large set of simulation combinations? How did the TVA get around this problem?

b) It seems to me that finding the weekly probability density distribution for floods would suffer from a lack of data. If we assume three independent flood peaks of interest per year for the approximate forty years of record, then we would have, on the average, only seven events per three week period. Did the TVA estimate the uncertainty in their weekly flood frequency curves?

c) The assumption that "regulated crests retain the same probability as the original floods producing them" is unclear. Does it mean the probability distribution, $f(q)$, does not change? If so then the assumption is clearly wrong since $f(q)$ shifts part of its mass to the left. Does it mean that an unregulated flood, q, of probability $f(q)dq$ gets reduced to q' with probability $f(q)dq$? Then how is $f(q)$ established, considering the non-stationary aspects of the TVA water control system,

d) How should multiple objectives be incorporated, both in operation models and in planning models? In the present report they are handled, at best, as constraints. How does the TVA propose to address the question of trade-offs between different objectives--like water quality and hydropower, for example?

I would like to conclude my comments with two ideas. The performance of a complex system such as the TVA depends upon how the system reacts to stochastic elements such as inflow discharges. Long range planning models must reflect this uncertainty and I feel that the development of models based upon expected input data yielding fixed operating policies will not yield meaningful insights into system operation.

I return to my previous statements that planning models should start with an overall decision methodology and the role of planning and operation models is to provide information required for decisions. In many cases, especially with the Browns Ferry impact study, I feel that not enough thought was given to the role of the models or what information they were to provide.

The TVA has started a large project to develop planning aids The questions they want to address are extremely difficult, complex and of vital interest to water resource management.

TVA COMMENTS ON DISCUSSION BY E. WOOD

It is reemphasized here that the program to develop methods for operation planning and real-time operation of the TVA reservoir system consists of three steps and that only methods and results of the first two preliminary steps were reported in the paper presented to IIASA. The first step was to demonstrate how comprehensive systems analysis could contribute timely to a planning and operating problem arising with the addition of the large Browns Ferry Nuclear Plant to the TVA system. The second step was a feasibility study primarily aimed at optimization methods for water scheduling. The third step included the development of the proposed water management methodology over a ten year period. This reminder may be helpful in understanding some of the questions and assessing the comments made by the discussant. Answers to specific questions raised by the discussant will be given below.

The Browns Ferry study was not part of the plant siting or design process and was done after the fact. Therefore, the design variables mentioned by the discussant were not considered. The selection of our four cooling methods and of three specific years was made to cover the spectrum of possible cases by a small number of combinations. The probability of the selected years was not determined. The scheduling model considers Browns Ferry capacity reductions to meet environmental standards only in one mode when no cooling towers are available. This case, though academic, was included as a limiting case. If capacity must be reduced, remaining thermal units and the hydrosystem carry the load up to a specified cost limit and the excess load is shaved at a penalty. The study was limited to highlight the events per se wihout regard to the probability.

A comprehensive statistical analysis of the Browns Ferry study results would have been desirable but was not carried out for various reasons. Among others, it was thought that the demonstration purpose of the study would not warrant extensive model runs.

The weekly system model could only provide a picture of weekly average conditions in the system and in the Browns Ferry vicinity. The system load, the hydro-operations upstream and downstream from Browns Ferry as well as the meteorological conditions are continually changing. Therefore, an hourly subsystem scheduling model was devised to disaggregate the weekly schedules of the system-wide model into hourly schedules of the Browns Ferry subsystem to simulate the continually changing conditions at the plant as closely as reasonable and to demonstrate the use of short-range hydroscheduling as aid to Browns Ferry cooling water needs.

The simplifying assumptions with regard to input data for the deep reservoir temperature prediction model were based on extensive experience with such systems. Also, the location of the Browns Ferry site several hundred miles downstream from the tributary reservoirs eliminated in this case any feedback of release temperatures on Browns Ferry operations. It was hoped that the Browns Ferry study results would impress on planners that comprehensive systems analysis methods should be used in the early phases of future project planning and design.

Of the various mathematical programming methods tried on the six reservoir subsystems, DPSA was selected as most promising for expansion to the entire system. This work has now (August 1975) progressed to a stage which deals extensively with the problem of convergence. It should be noted that the objective function used on the six reservoir subsystem was of a preliminary nature and has been replaced in the expanded model by a more detailed objective function including power, flood control and navigation objectives.

Quadratic programming was not tried; but the reduced gradient approach exploited the network properties of the system and the linearity of the constraints and handled reasonably well the nonlinear and branching objective function. Alternatives to dynamic programming are being considered due to the non-Markovian processes that must be dealt with when travel time or water quality "memory" of deep reservoirs become issues.

Currently the deterministic approach to system modelling is followed since, with the exception of inputs and certain probabilistic elements in the objective functions, the transition between stages is deterministic. A method such as "Monte Carlo dynamic programming" may later be used to generate information on transition probabilities for use in operation policies. A later expansion of the present deterministic method to include stochastic elements seems feasible. The discussant's pre-occupation with stochastic aspects of the models at this time seems unwarranted.

The TVA water control system is essentially completed. Therefore, reservoir capacities are fixed. However, the use of the reservoirs will continue to change. To guide reservoir operations under such changing conditions will be an important task that the proposed methods can help to fulfill. Also, the expected monetary benefits from improved operation, even if marginal, are still substantial for a large system.

The development of the objective function for flood control in the weekly model required a large number of simulation combinations. The limitations necessary to keep this number down to a manageable size of 21,000 routings have been explained in our paper.

Some of the simplifying assumptions in establishing the flood control function were imposed by lack of data. For example, only seven documented flood events were used in the routings. Their weekly probability of occurance was modified according to the position of their peaks on the weekly distribution curves. The function as developed for the weekly model is considered a pilot study which can be improved by a more comprehensive data analysis at a later date.

The assumption was made that the regulated flood has the same probability as the unregulated flood. The probability of the unregulated flood was established by a graphical adjustment of unregulated flood peaks using the Gumbel distribution law. The unregulated flood peaks of all major floods occurring at the investigated site are routinely computed by the TVA under the assumption that no water control structures are present.

It is planned to develop objective functions for all operation objectives. In the subsystem models, constraints were used for flood control. In the present system model, no flood control constraints are used, except the physical maximum and minimum levels of storage reservoir. The weighted sum of power generation costs, average flood risk costs and navigation costs is used as overall objective function. Various weights have been used in preliminary trade-off computations for power generation and flood control.

We fully share the discussant's concern about the important role of uncertainty in the decision-making process. This problem has been with the TVA since the first water control operation was attempted. For a long time, expected input data and predesigned fixed operation rules were the only operation tools available. It is the very philosophy of the present effort that more flexible guides can now be developed. Emphasis will be placed on devising decision rules as function of various state, decision, and input variables. Input forecasting for the immediate and near future will be used to adapt these rules to the real-world situation. The discussant's conclusion that fixed rules and expected inputs will be used in the decision-making process is quite contrary to our intentions.

MANAGEMENT OF AN INTEGRATED WATER CONTROL SYSTEM

ABSTRACT

Sections 2 through 6 of this paper describe the TVA water control system, relate the plan of system operation to the hydrology of the region, explain the role of the streamflow prediction process in the daily operation of control facilities, briefly describe some operating principles and objectives, and explain system operations and management in terms of achieving objectives.

Section 7 evaluates the effectiveness of the water control system in terms of objectives achieved by past system operations.

Section 8 identifies some management tools and procedures which must be improved in order to meet the rapidly changing and increasing demands on the water control system, lists some preliminary work being done within the Division of Water Control Planning to meet these demands, and identifies other areas where technological developments by other agencies (or by industry) would greatly improve the capability to meet these demands.

Section 9 discusses TVA's past accomplishments in the field of water resources development; identifies constraints on present development efforts; and urges that TVA not rest on its laurels, but proceed now to improve management tools so that they will be ready in time to meet future demands on the system.

SECTION 1

INTRODUCTION

The Tennessee Valley Authority was a pioneer in the basin-wide development concept, for the TVA Act directing this Federal agency to develop all the water resources in the entire Tennessee Valley was the first authority ever granted to implement this concept. By demonstrating the practicality of operating reservoirs to achieve multiple purposes, TVA proved that, when the objectives and priorities are clearly defined, conflicts in demands can be resolved, and the increased benefits of multiple-purpose operations can be obtained. TVA also was a leader in the development of systems management of an integrated water control system, demonstrating that maximum control, efficiencies, and benefits can be secured through carefully coordinated systems management of an integrated reservoir system.

The Tennessee Valley Authority Act[1] requires development of the river for navigation, flood control, and power generation. It directs the TVA Board of Directors to regulate the streamflow primarily for promoting navigation by providing a navigation channel adequate for 9-foot draft (2.74-meter draft) vessels the year round, and controlling floods in the Tennessee and Mississippi River Basins, then, as consistent with these two top priority purposes, to provide facilities at any dam for the generation, distribution, and sale of electricity. It also provided for planning and development of the natural resources of the region. This provision has resulted in the evolution of such secondary objectives in the operation of facilities as recreation; control of vectors, aquatic plants, and water quality; fish spawning; and other special water-related needs.

Management of the water control system to attain primary and secondary objectives is a demanding daily task requiring not only adherence to general operating principles and objectives, but also close attention to and prompt allowance for daily developments. One especially important principle to be observed in water control operations is that each project must be operated as part of a carefully coordinated system in order to achieve all the system objectives. Another principle is that the volume of water arriving in each reservoir from its unregulated drainage basin must be predicted with considerable accuracy or the complexities of system operations become academic, and efficient scheduling of releases for multiple purposes becomes impossible.

This paper describes the TVA water control system, relates the plan of system operation to the hydrology of the region, explains the role of the streamflow prediction process in the daily operation of control facilities, briefly describes some operating principles and objectives, and explains system operation and management in terms of achieving objectives.

SECTION 2

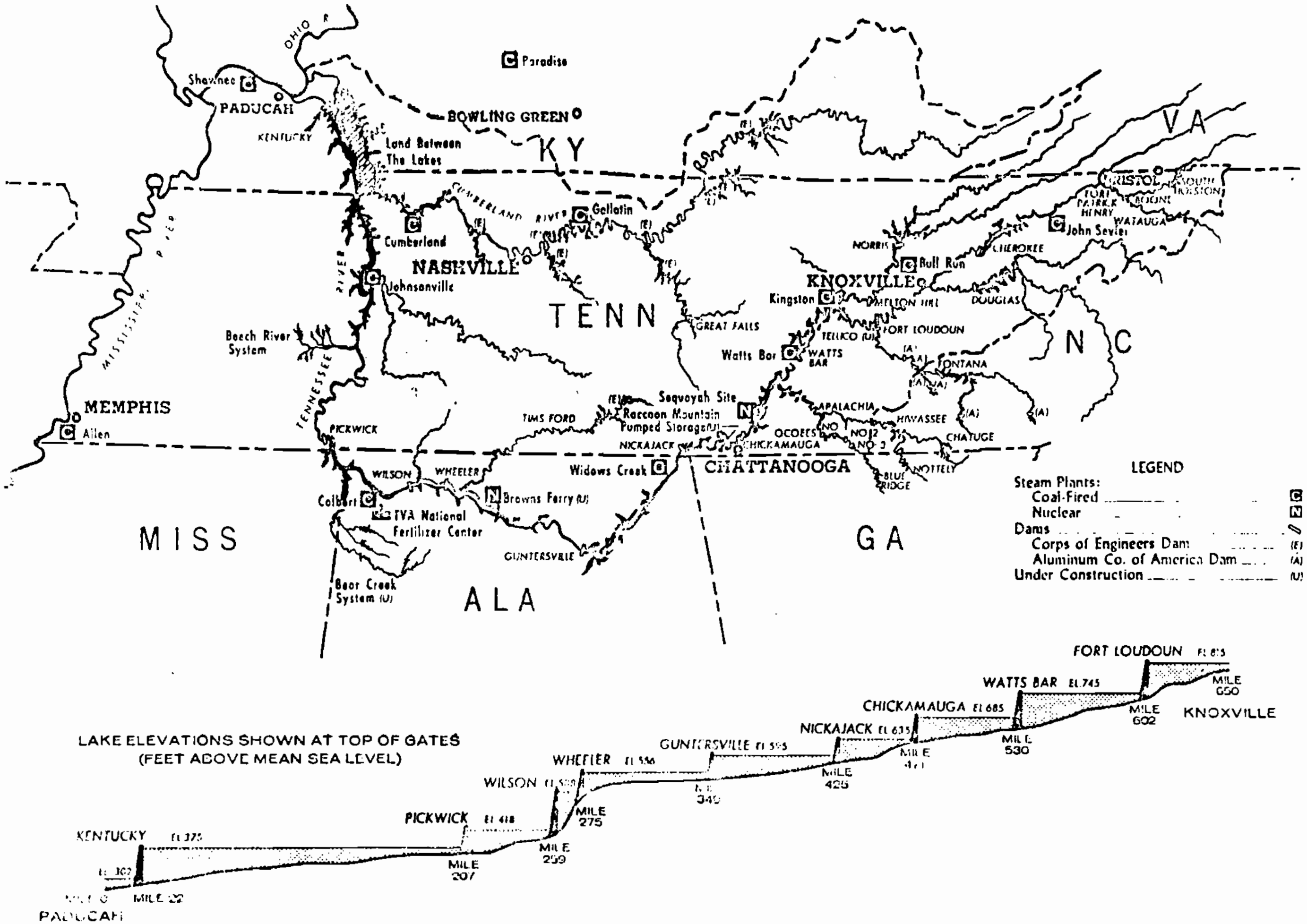
THE TVA WATER CONTROL SYSTEM

2.1 DESCRIPTION OF BASINS

The hydro- and steam-electric generating plants in the Tennessee Valley region that supply electrical energy to the TVA power service area are shown in Figure 2-1. The Tennessee River Basin comprises a drainage area of 40,900 square miles (105,900 km^2). Contiguous to its northern border is the Cumberland River Basin of 17,900 square miles (46,400 km^2). These basins lie in the southeastern portion of the United States. The topography of the Tennessee Valley is characterized by the rugged mountainous and dense forest regions of southwestern Virginia, eastern Tennessee, northern Georgia, and western North Carolina, where mountain tops are over 6,000 feet (2,000 m) above mean sea level. The terrain varies from these mountains to the rolling hills of middle Tennessee, the relatively flat lands of northern Alabama and Mississippi, to the open fields and woodlands of western Tennessee and Kentucky. The elevation at the mouth of the Tennessee River is about 300 feet (90 m). The Cumberland Valley is similar to the Tennessee Valley, having rugged mountains in the eastern portion but varying to a rolling, low plateau in the western portion of the basin. The elevations range from about 4,200 feet (1,300 m) in the headwaters in the Cumberland Mountains to about 300 feet (90 m) at the mouth.

2.2 TYPES OF RESERVOIRS AND LOCATIONS

The TVA water control system, shown in Figure 2-2, consists of 35 hydro power projects, including 21 multiple-purpose projects and 14 single-purpose power projects. Eleven of the multiple-purpose projects are on tributaries of the Tennessee River in the eastern half of the Tennessee Valley, one is on a tributary in the western half, and nine are on the main river. The 14 single-purpose power projects include 6 major projects owned by the Aluminum Company of America, 7 owned by TVA in the Tennessee Valley, and 1, Great Falls, owned by TVA in the Cumberland Valley. In addition to these 35 projects, 8 hydro projects of the Corps of Engineers are located in the Cumberland Valley, making a total of 43 major hydro projects in the combined system in the two river valleys. All 43 dams have power generating equipment and control works. Six minor hydro power projects owned by ALCOA, with a total installed capacity less than 1 percent of the installed hydro power capacity of the TVA system, also contribute energy to the system. In addition to the system of 43 major hydro projects, there are 2 tributary area development nonpower projects--the Beech River project in western Tennessee with eight small dams and reservoirs, and the Bear Creek project in northwestern Alabama with one small dam and reservoir completed of four planned. These dams and their reservoirs have among their principal operating objectives: flood control, recreation, water supply and water quality control, and some of them irrigation. There are also two flood protection dams and reservoirs near Bristol, Virginia,--Beaver Creek and Clear Creek.



PROFILE OF THE TENNESSEE RIVER (ALL MAINSTREAM DAMS HAVE NAVIGATION LOCKS)

TENNEESSEE AND CUMBERLAND VALLEYS REGION
FIGURE 2-1

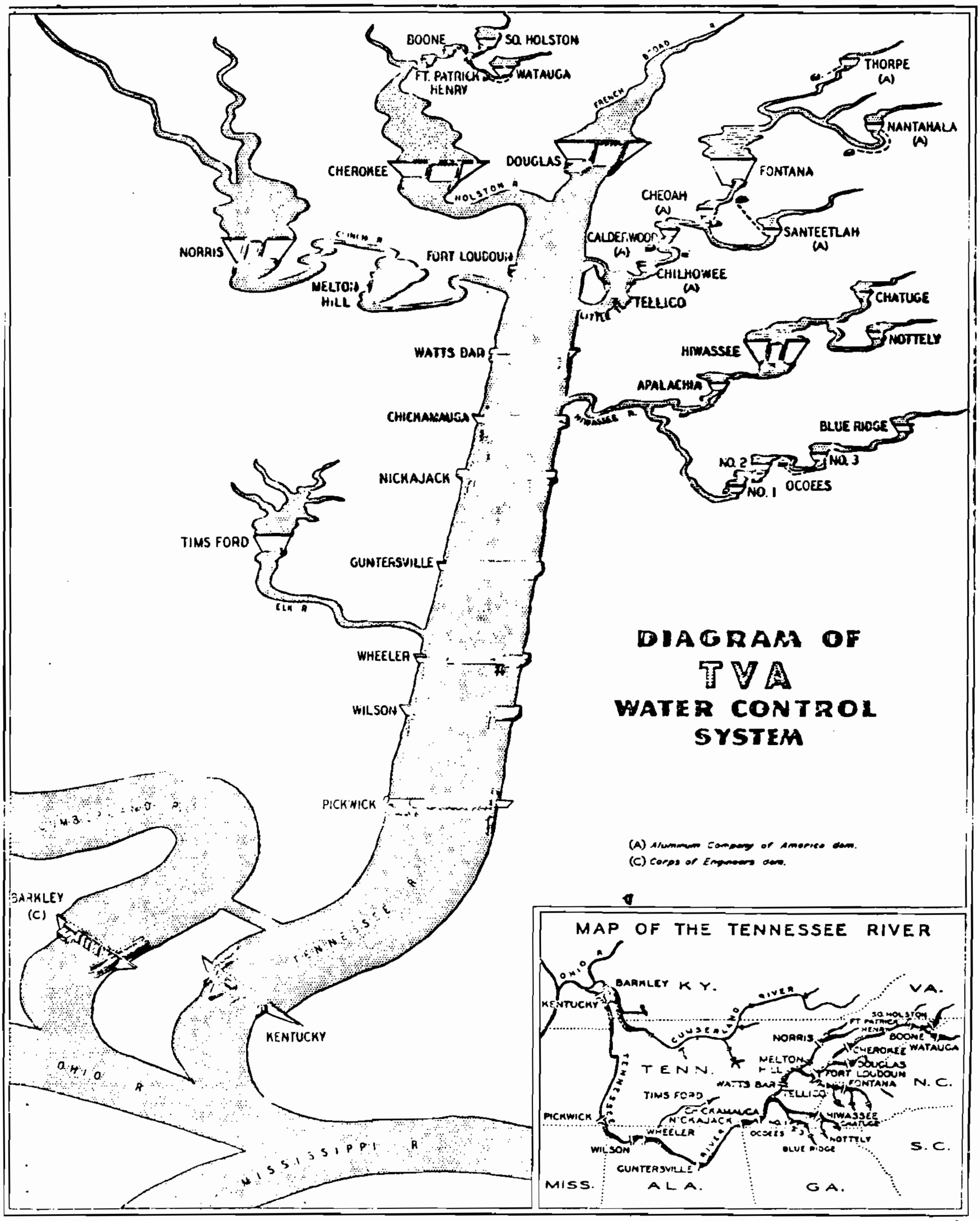


DIAGRAM OF
TVA
WATER CONTROL
SYSTEM
BOONE
SO. HOLSTON
FT. PATRICK HENRY
WATAUGA
THORPE (A)
NANTAHALA (A)
FONTANA
CHEROKEE
DOUGLAS
HOLSTON R
FRENCH BROAD R
CHEOAH (A)
SANTEETLAH (A)
CALDERWOOD (A)
CHILHOWEE (A)
TELLICO
NORRIS
FORT LOUDOUN
MELTON HILL
CHATUGE
NOTTELY
HIWASSEE
WATTS BAR
APALACHIA
CHICKAMAUGA
BLUE RIDGE
NO. 2
NO. 3
NO. 1
OCOEES
NICKAJACK
TIMS FORD
GUNTERSVILLE
ELK R
WHEELER
WILSON
PICKWICK
BARKLEY (C)
KENTUCKY
TENNESSEE R
OHIO R
MISSISSIPPI R
(A) Aluminum Company of America dam.
(C) Corps of Engineers dam.
MAP OF THE TENNESSEE RIVER
OHIO R
BARKLEY
KY.
VA.
KENTUCKY
CUMBERLAND RIVER
NORRIS
SO. HOLSTON
BOONE
WATAUGA
CHEROKEE
DOUGLAS
FORT LOUDOUN
FONTANA
TENN.
MELTON HILL
WATTS BAR
TELLICO
N. C.
TIMS FORD
HIWASSEE
CHATUGE
NOTTELY
PICKWICK
NICKAJACK
WHEELER
OCOEES
BLUE RIDGE
S. C.
WILSON
GUNTERSVILLE
MISS.
ALA.
GA.

FIGURE 2-2

SECTION 3

THE TVA POWER SYSTEM

3.1 POWER SERVICE AREA AND GENERATING CAPACITY

TVA power is distributed to about 2,300,000 consumers by 110 municipal electric systems and 50 rural electric cooperatives. The power service area comprises 80,000 square miles (207,000 km^2) lying in portions of seven states--Kentucky, Virginia, Tennessee, North Carolina, Mississippi, Alabama, and Georgia.

The total installed hydroelectric generating capacity of the TVA, Aluminum Company of America, and Corps of Engineers dams in the TVA power distribution system is 4,473 megawatts, or about 19 percent of the total installed system generating capacity of 23,319 megawatts. The other 81 percent, or about 18,846 megawatts, is provided by thermal power plants, including 12 coal-fired steam plants, 1 nuclear plant, and 2 gas turbine plants.

3.2 SCHEDULING GENERATION

The size of the power service area, the variability of the load, and the necessity for choice between hydro and various thermal power sources combine to complicate the task of scheduling generation to meet the load requirements. The electrical load is very sensitive to the weather conditions in the power service area. Light intensity and wind velocity have pronounced effects on the electrical load, but the sensitivity of the load to temperature conditions is most significant.[2] For example, a difference in temperature during winter peak hours of 1 degree Fahrenheit (0.5 degree Centigrade) produces a change in the heating load of about 100 megawatts at 40 degrees Fahrenheit (5 degrees Centigrade). During summer peak hours, the cooling load shows a similar sensitivity to differences in temperature. Additional information concerning the effect of weather on both the peak hour load and the daily total system load has been published in technical papers and journals /2, 3, 4/.

The complexity of scheduling generation for TVA's large mixed-source power system motivated development of computer programs to aid in the selection of the particular thermal and hydroelectric units to be used for meeting both demand and energy requirements. The objective of these programs, developed by the Office of Power, is to supply the load while maximizing efficiency in the use of available water at the hydro plants, minimizing production costs at the thermal plants, and simultaneously minimizing transmission losses from the various combinations. A description of the programs was presented to the World Power Conference in Lausanne, Switzerland, in September 1964.[3]

The program that schedules the total energy to be supplied by each hydro plant considers, in addition to the values of storage, the rainfall predictions, estimates of runoff, inflows from uncontrolled storage, the routing of storage releases through the river system for a period of several days, and load predictions for the same period. Power releases are coordinated with numerous variations in the flow requirements for other purposes, such as navigation, flood control, mosquito control, construction work, fish life, recreation, water supply, etc. The coordination of releases for all purposes is a primary responsibility of the River Control Branch.

With the hydro energy from each plant thus scheduled for each day, another computer program then is used to develop an advance 24-hour schedule, within the limits of any prescribed operation. This program schedules the most economical generation to fit the predicted hour-by-hour load for the next day. Detailed explanations of power scheduling to meet predicted loads are contained in published technical papers and transactions [3, 4, 5, 6].

Steam electric plant operation is most economical with a high load factor and as few starts and stops as possible; thus steam plants are operated on base load, and the hydroelectric plants supply the additional power demand of the peak loads. As the power demand decreases and the hydroelectric plants are not needed, they are shut down or reduced to the minimum consistent with the needs of navigation or as limited by other objectives. This results in large hourly and large daily variations in discharge from most reservoirs. The rapid response capability to meet unscheduled or emergency demands, and the flexibility to schedule large variations in power generation during a day makes the hydroelectric plants especially valuable.

SECTION 4

THE HYDROLOGY OF THE REGION

4.1 PRECIPITATION

The long-term annual precipitation for the Tennessee Valley averages nearly 52 inches (132 cm) and has varied between extremes of 38 inches (96 cm) and 71 inches (180 cm). Generally, the average in the western half of the Valley is fairly uniform and near the average for the whole basin. In the mountainous eastern half precipitation is quite variable, ranging from about 40 inches (102 cm) in some shielded areas to 90 inches (229 cm) in higher mountainous areas, as shown in Figure 4-1. The seasonal variation of monthly rainfall is not great. The drier months, however, usually are September, October, and November with monthly averages of 2.5 inches (6.4 cm) to 3.5 inches (8.9 cm). Other months average from 4 inches (10 cm) to 5.5 inches (14 cm). March is usually the month of heaviest rainfall. Snowfall averages about 8 inches (20 cm) annually and seldom remains on the ground for more than a few days except in the higher mountain areas. It rarely contributes significantly as a supply of streamflow.

4.2 STREAMFLOW

The variation in streamflow from month to month is in sharp contrast to precipitation. Figure 4-2 depicts this monthly variation of average rainfall and runoff. In the winter and early spring vegetation is dormant and lower temperatures reduce evapotranspiration. Consequently, more of the rainfall becomes streamflow during this period. A low-flow period occurs usually during the fall of the year. The long-term average annual discharge of the Tennessee River at its mouth is about 65,000 cfs (1840 m^3/s). Extremes have ranged from 4,500 cfs (127 m^3/s) during the drought of 1925 to over 500,000 cfs (14,200 m^3/s) during the flood of 1897.

4.3 FLOOD DISTRIBUTION

Although rainfall in the Tennessee Valley is well distributed throughout the year, streamflow records show a strong seasonal pattern in which the high flows of the winter and spring months stand out clearly. Occurrence of great Valley-wide floods fit the seasonal runoff pattern. Figure 4-3 illustrates the flood history for the city of Chattanooga, the city most vulnerable to flooding of any metropolitan area in the Tennessee Valley. At the top of the Figure, flood heights are plotted by years, beginning with 1867 on the left and progressing to the present day on the right. It shows the irregularity with which large floods occur. The largest flood on record occurred in 1867, and the second largest flood, if there had been no regulation, occurred in 1957. The lower part of Figure 4-3 shows the distribution of the same floods by months of the year. All of the large Valley-wide floods so far have been limited to the period from late December to early April, following the seasonal runoff pattern.

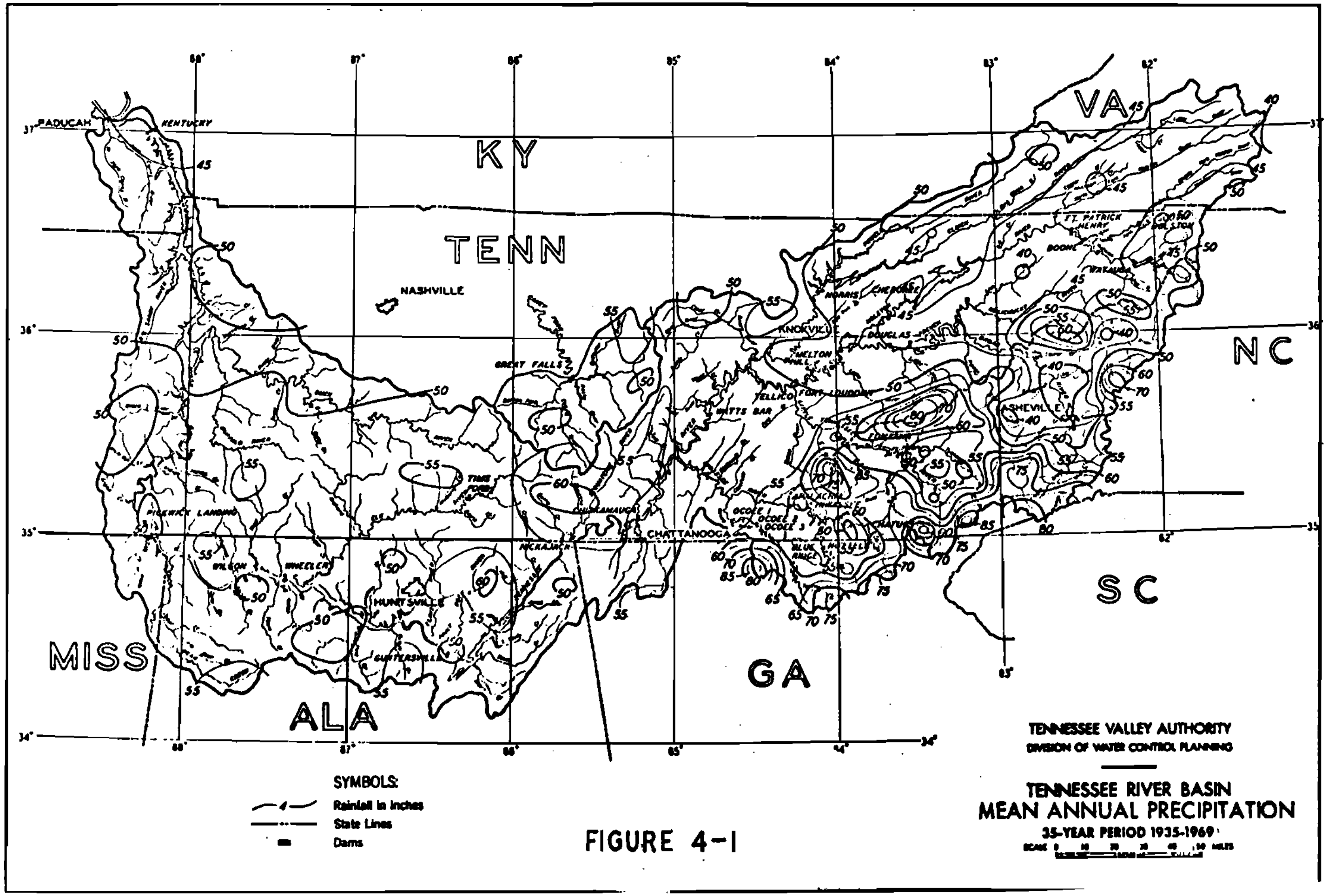
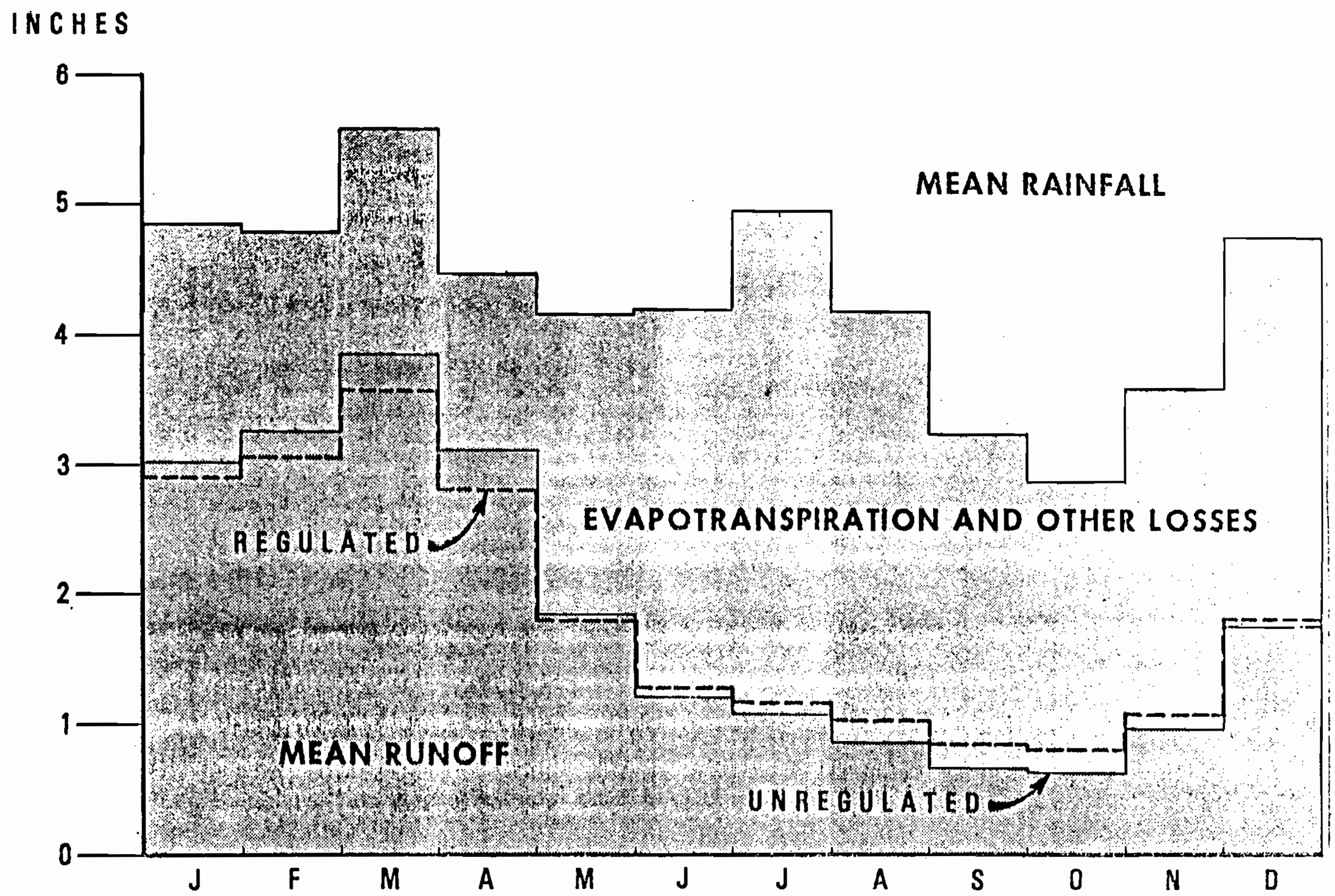
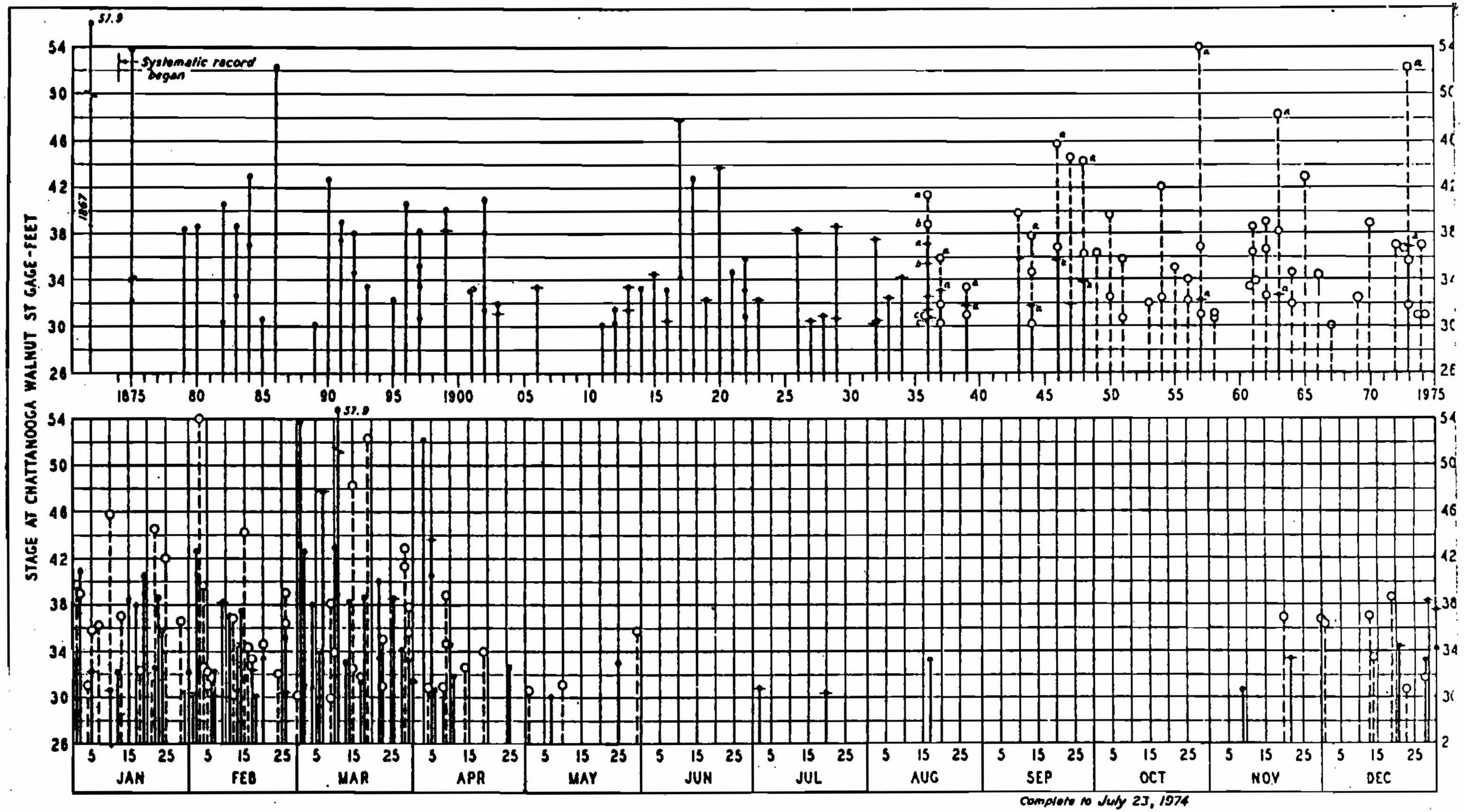

KY
TENN
VA
NC
SC
GA
ALA
MISS
PADUCAH
KENTUCKY
NASHVILLE
KNOXVILLE
CHATTANOOGA
ASHEVILLE
HUNTSVILLE
GREAT FALLS
TIMS FORD
PICKWICK LANDING
WILSON
WHEELER
GUNTERSVILLE
NICKAJACK
CHICKAMAUGA
WATTS BAR
TELLICO
FORT LOUDOUN
MELTON HILL
NORRIS
CHEROKEE
DOUGLAS
FONTANA
OCOEE 1
OCOEE 2
OCOEE 3
BLUE RIDGE
HIWASSEE
CHATUGE
NOTTELY
BOONE
FT. PATRICK HENRY
SOUTH HOLSTON
WATAUGA
SYMBOLS:
Rainfall in Inches
State Lines
Dams
TENNESSEE VALLEY AUTHORITY
DIVISION OF WATER CONTROL PLANNING
TENNESSEE RIVER BASIN
MEAN ANNUAL PRECIPITATION
35-YEAR PERIOD 1935-1969

FIGURE 4-1



TENNESSEE VALLEY MONTHLY RAINFALL AND RUNOFF
FIGURE 4-2



Gage zero = 621.12 (1929 geod. adj)
USWB flood stage = 30 feet
Drainage area = 21, 400 sq mi

LEGEND:
● Estimated
⌖ Observed
○ Computed
a, b, c, Corresponding flood

TENNESSEE RIVER AT CHATTANOOGA, TENNESSEE

DISTRIBUTION OF FLOODS
FIGURE 4-3

SECTION 5

RELATION OF PLAN OF OPERATION TO HYDROLOGY

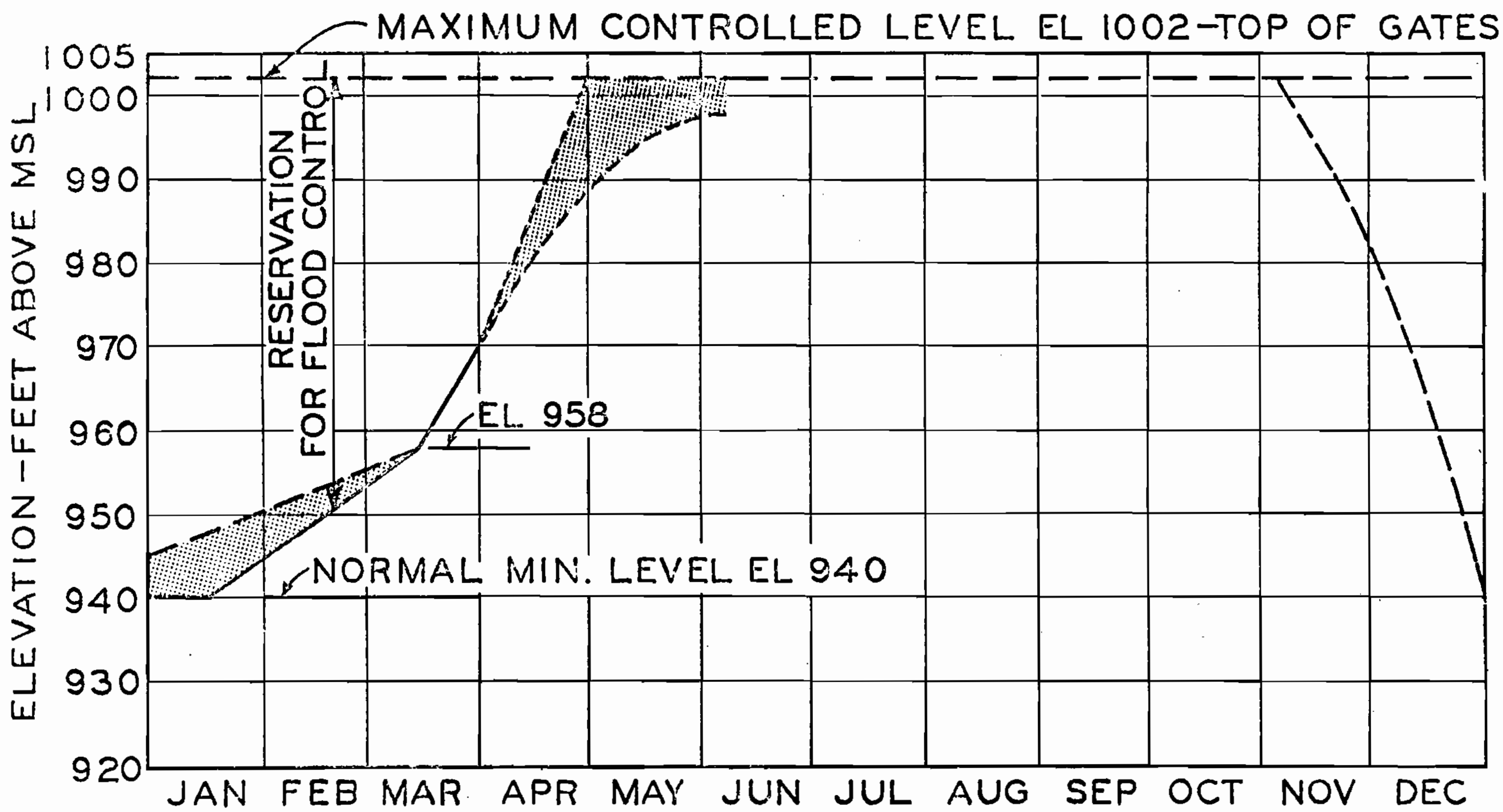
Planning for the operation of reservoirs is an essential feature of project design. The high priority assigned to flood control by the TVA Act ensured that the plan of operation for each reservoir would provide storage space for flood control. Initial investigations revealed that, within the Tennessee Valley, by far the greatest potential urban damage from floods was at Chattanooga. Planning of the reservoir system upstream from Chattanooga thus was primarily directed toward eliminating, or at least reducing, the potential flood damages in that city. Details of the development of the plan of operation of the TVA reservoir system for flood control can be found in TVA Technical Report No. 26 /7/.

In designing and developing the plan of operations of the TVA reservoir system, the seasonal occurrence of floods was an important factor. The definite seasonal pattern shown by long-term dependable records, illustrated in Figures 4-2 and 4-3, imply that the full amount of flood storage space need be reserved only during the indicated flood season.[8]

The reservoirs in the TVA system fall into two general groups--tributary multiple-purpose reservoirs, and main Tennessee River multiple-purpose reservoirs--which are greatly different as to method of operation, relative flood storage capacity, and effect at critical flood control points.

5.1 TRIBUTARY MULTIPLE-PURPOSE RESERVOIRS

As an example of an annual operation plan, Figure 5-1 shows a typical operating guide curve for a tributary multiple-purpose reservoir providing flood-control storage and conservation storage for power and navigation. The storage reservation for flood control on March 15 was determined as the amount necessary, in conjunction with other reservoirs and levees, for controlling the maximum probable flood at Chattanooga, a critical downstream location. The greater flood-storage reservation on January 1 gives assurance that the March 15 reservation will be available in event a series of floods make it difficult to draw down the reservoir to the March 15 level. Drawdown of the reservoir prior to January 1 provides useful water for meeting navigation and power production requirements during the drier months, and normally can be accomplished with greater assurance and efficiency than would be possible during the January 1-March 15 period. The lesser reservation on March 31 and thereafter makes allowance for the decreased chance of floods near the end of the Valley-wide flood season, as indicated by the flood record on Figure 4-3. After March 31 the reservoir is allowed to fill more rapidly dependent upon hydrologic conditions, and may be filled to normal maximum level if rainfall is abundant. Deficient



TYPICAL OPERATING GUIDE CURVE FOR A TRIBUTARY MULTIPLE-PURPOSE RESERVOIR

FIGURE 5-1

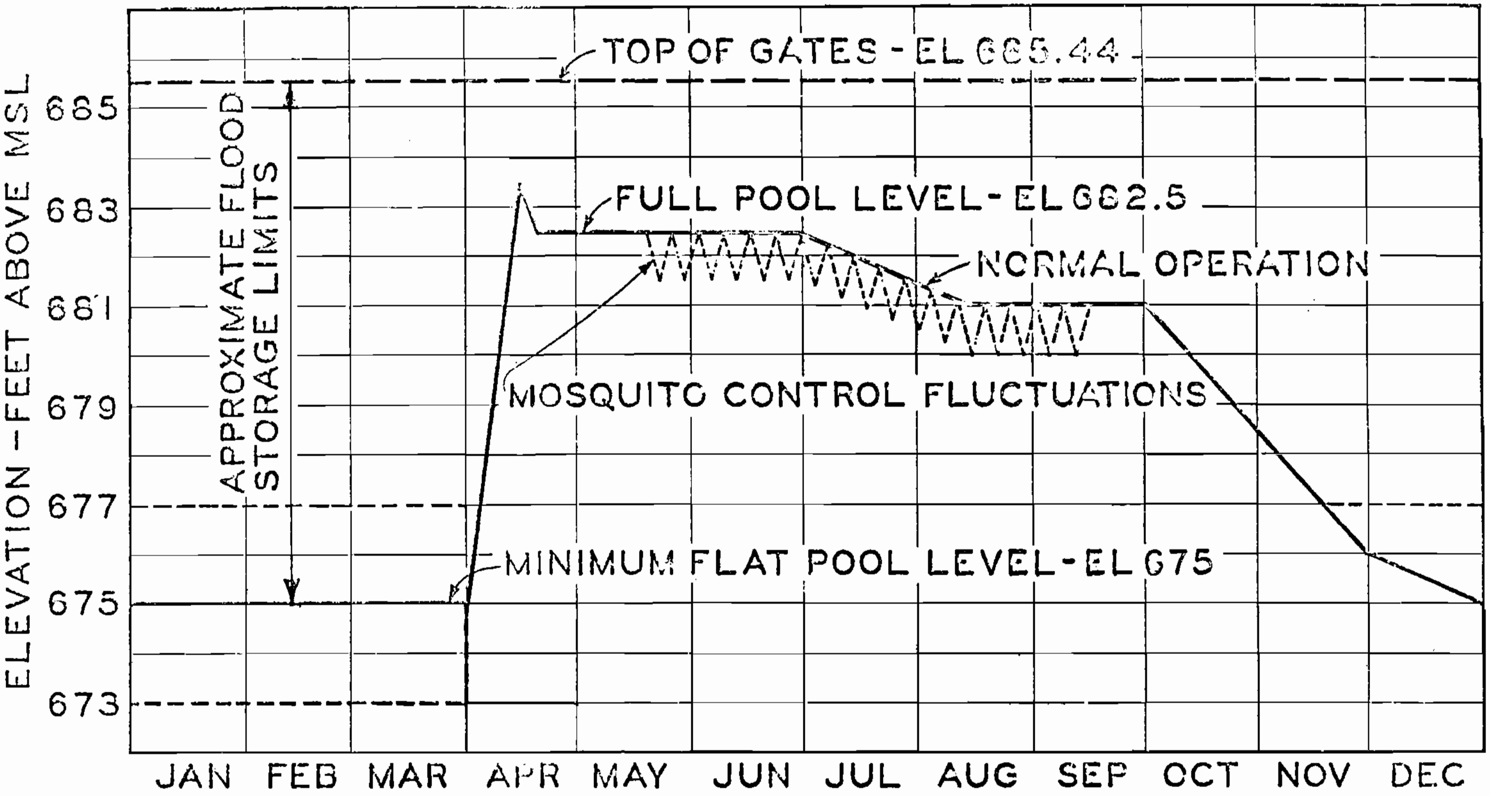
rainfall, combined with heavy demands for hydroelectric power production during the normal filling period, April 1 to June 1, will prevent filling of the reservoir, which then may remain substantially below top level through the summer. A small amount of flood detention capacity is reserved through the summer months as a protection against flood-producing storms over limited areas.

When heavy runoff occurs during the flood season, discharge from the dam is reduced or cut off and the reservoir may be temporarily filled above the operating guide curve, thus storing flood waters and reducing downstream flood crests. When flood danger has passed, the reservoir is returned to seasonal level by releasing water at rates that will not create or supplement downstream flooding. Sometimes this drawdown can be accomplished by operating the hydroelectric plant at turbine capacity until the necessary quantity of water has been discharged from the reservoir. Often, however, it is necessary to release additional water through sluiceways or spillways to lower the reservoir level more quickly and regain the detention space needed for future rains. Spilling of this water is stark proof that TVA places priority for flood control over that for power--a definite stipulation in the TVA Act.

Lowering of the reservoirs to prepare the system for the next flood season normally begins in early summer and accelerates during the relatively dry fall months. The water is withdrawn gradually, to supplement diminishing natural streamflow, for navigation improvement and power production. By late December, the reservoirs normally have been returned to low levels, completing the annual cycle, as shown by Figure 5-1.

5.2 MAIN TENNESSEE RIVER MULTIPLE-PURPOSE RESERVOIRS

An example of an annual operation plan for a multiple-purpose main Tennessee River reservoir, which also provides flood control storage and conservation storage for power and navigation, is shown in Figure 5-2. In addition to conservation storage, it provides a permanent pool for navigation. The minimum pool, elevation 675 (205.7 m), was determined by the specified navigation depth at critical points in the reservoir, and the maximum pool, elevation 685.44 (208.9 m), was determined by reservoir limitations and the location of the next upstream dam site. Flood control or conservation storage therefore was limited to the zone between these two levels, but during the usual Valley-wide flood season the full amount was reserved for flood control, except for minor fluctuations due to turbine operation. In order to retain storage capacity for flood control, drawdown to elevation 673 (205.1 m) at the dam is permitted provided navigation depths are maintained throughout the reservoir. After March 31 the reservoir is filled to elevation 682.5 (208.0 m), and the zone between elevation 682.5 (208.0 m) and elevation 685.44 (208.9 m) is the minimum reservation for flood storage during the summer.



TYPICAL OPERATING GUIDE CURVE FOR A MAIN TENNESSEE RIVER MULTIPLE-PURPOSE RESERVOIR

FIGURE 5-2

The fluctuating dashed lines show 1 foot (0.3 m) weekly changes in level for control of lake-breeding mosquitoes. These planned fluctuations of main river reservoirs usually begin in June and continue into September and are part of a yearly cycle of water level management. The main river reservoirs are fluctuated in tandem throughout the reservoir chain. The fluctuation cycle for sequential reservoirs is accomplished 180 degrees out of phase; thus when reservoir No. 1 is filling, reservoir No. 2 is drawing, etc. Alternating the fill-draw cycle throughout the reservoir chain makes possible the maintenance of a relatively constant volume of water within the main river reservoir system, thus expedites the fluctuations, reduces the impact on storage in the multiple-purpose tributary reservoirs, and minimizes the chances of spilling water at the main river dams in order to achieve the fluctuations. Kentucky Reservoir, on the lower Tennessee River, is so large that weekly fluctuations are impractical, thus treatment with insecticides and gradual lowering of the reservoir are used to reduce the production of mosquitoes.

The 1 foot (0.3 m) rise above elevation 682.5 (208.0 m), shown on Figure 5-2 about the middle of April, is a surcharge of the reservoir above normal summer level to strand drift and debris brought into the reservoir by winter floods. After the reservoir has been surcharged for about 24 hours, the level is drawn back to normal summer level within one day. Much of the floating driftwood and debris is stranded on the shoreline above the water level of the reservoir. This operation serves as a means of cleaning the reservoirs, thus reduces the hazards to recreational boaters and water ski enthusiasts, reduces the production of mosquitoes, and improves the aesthetic appearance.

The operating guides for the main Tennessee River reservoirs also require the lowest reservoir levels during January, but unlike the tributary reservoirs, available flood storage space is so small that low levels are held until near the end of the flood season before filling to summer levels. Reservoir levels provide channel depths adequate for navigation throughout the year. During a flood control operation, the main river reservoirs may be temporarily filled to top-of-gates level, if required, thus storing flood waters and reducing downstream flood crests. As flood danger subsides, the reservoirs are promptly returned to seasonal levels by releasing water at rates that will not create or supplement downstream flooding. Usually it is necessary to release excess water from the main river reservoirs through the spillways to lower the reservoir level more quickly and regain the detention space needed for future rains.

Lowering of the main Tennessee River reservoirs also begins during the summer and accelerates during the relatively dry fall months, thus pulling the water level away from the encroaching vegetation and preparing the system for the next flood season. The water is withdrawn gradually for navigation improvement and power production. By late December, these reservoirs also have been returned to low levels, completing the annual cycle, as shown by Figure 5-2.

SECTION 6

MANAGEMENT OF RESERVOIR SYSTEM

6.1 OPERATIONAL RESPONSIBILITY

The overall management of the reservoir system is delegated to the Division of Water Control Planning by the General Manager. The River Control Branch, located at division headquarters in Knoxville, Tennessee, is responsible for the day-to-day operational management activities. The River Control Branch directs the impoundment and release of water from the reservoir system for all purposes to obtain optimum use of the system in accordance with the requirements of the TVA Act and Board policies. One especially important principle observed in the direction and control of the reservoir system is that each project must be operated as part of a carefully coordinated system in order to achieve all the system objectives.

The Office of Power, located in Chattanooga, Tennessee, has the responsibility for the economic production of the hydroelectric energy potential of the system, within the statutory limits imposed by navigation and flood control priorities. Other programs, such as mosquito control, recreation, construction, fish and wildlife, water supply, and water quality, also compete for and impose conflicting demands on the water resources of the Valley, and thus influence the operation of the reservoirs. Although none of the possible uses of a reservoir are entirely compatible with any other use, under many circumstances it is possible to bring some uses into reasonably good agreement. The basic factors in the operation of a multiple-purpose reservoir system are compromise and coordination. Final decisions are made and instructions for operations are issued by the River Control Branch, after coordination with numerous other organizations whose program interests are affected by the operation of the reservoir system. The River Control Branch thus serves as the coordinating and control center for all operational requirements and demands on the reservoir system.

6.2 PURPOSES OF STREAMFLOW PREDICTIONS

Management of a multiple-purpose water control system requires not only current information concerning system demands and constraints, and adherence to general operating principles and objectives, but also a determination of the quantity of water to be controlled. Unless the volume of water arriving in each reservoir from its unregulated drainage basin can be predicted with considerable accuracy, the complexities of system operations become academic, and efficient scheduling of releases for multiple purposes becomes impossible.

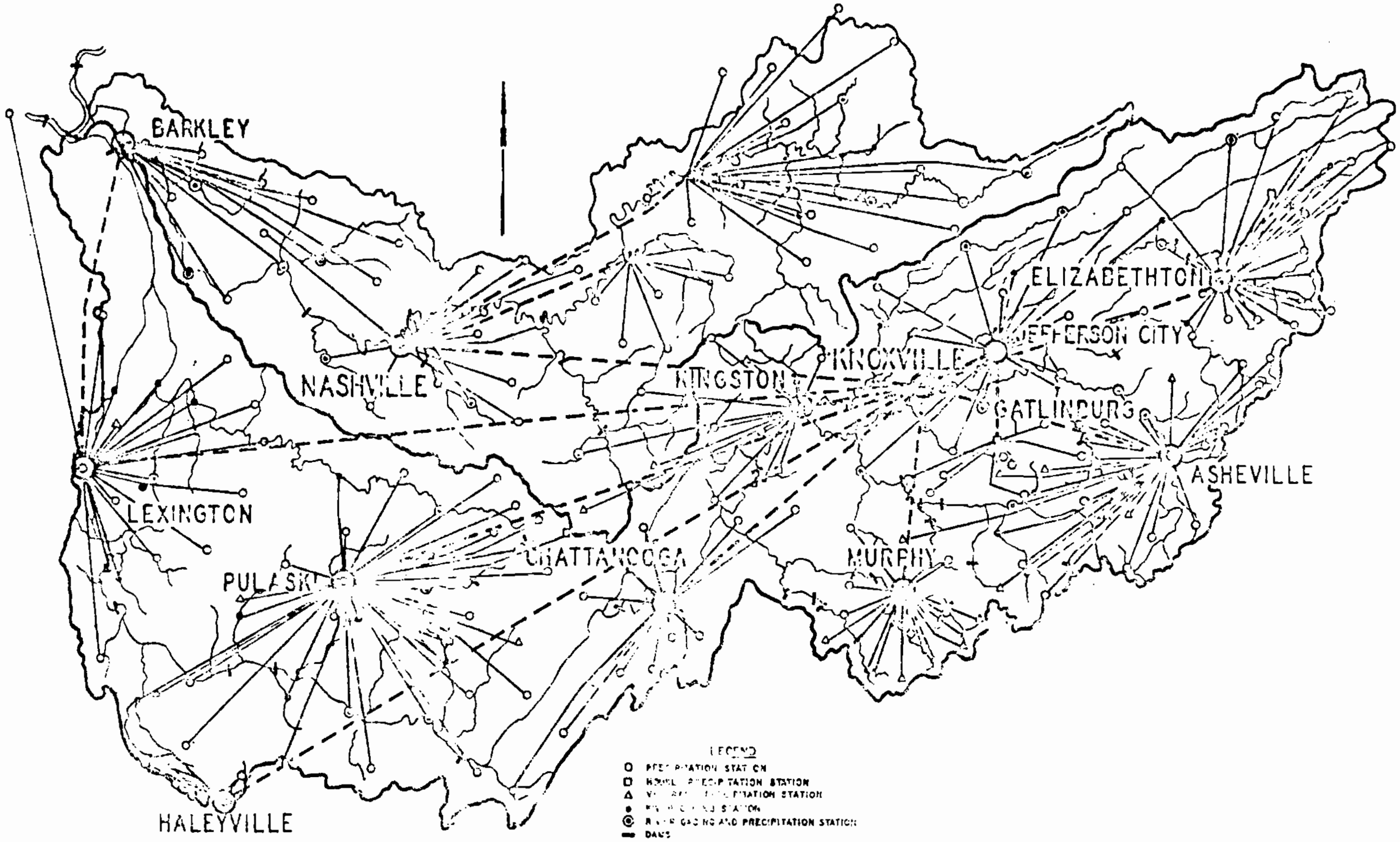
Since the directives of the TVA Act are specific, a knowledge of current and anticipated streamflows is essential for the efficient operation and control of the reservoir system. Inflow predictions are required, at the present time, for 43 reservoirs within the Tennessee and Cumberland River Basins. The primary purpose of streamflow predictions is to provide a base for planning the operation of the reservoirs while reserving the capability to regulate floods when they occur. For this reason it is important to know the streamflows which will be available at each plant for as long in the future as they can be reasonably and accurately predicted. With this information available, it becomes feasible to coordinate the water use at the hydro plants to achieve simultaneously many primary and secondary objectives. This procedure is more or less continuous, requiring revisions in predictions each day or, when precipitation is continuing, several times each day as streamflows and power demands change rapidly. Current practice is to predict streamflow for five to ten days in advance for use in planning short-term water control operations. Within ten days or less, increased runoff from additional rainfall can be expected to make the current prediction obsolete.

6.3 HYDROLOGIC DATA COLLECTION

The efficient operation of the reservoir system for the many and sometimes conflicting objectives requires (1) the collection of detailed precipitation and streamflow data on a day-to-day and sometimes on an hour-by-hour basis, (2) the forecasting of streamflows for several days in advance, and (3) a reliable system of communication by which the basic data can be received and operating instructions transmitted.

To provide the basic hydrologic data needed in making streamflow forecasts, which is the first step in scheduling hydro plant operations, a hydrologic network of reporting precipitation and streamflow stations has been devised.

At present there are 270 precipitation stations in and adjacent to the Tennessee and Cumberland River Basins reporting daily, Figure 6-1. Fifty-three of these gages are located at power plants and substations. The remainder, particularly those in the Tennessee Valley, are located to give a good sampling of precipitation on the respective drainage area contributing to the individual reservoir, with due regard for the character of the terrain. The location and type of some of these gages are determined by the availability of observers and a dependable means of communication. The observers of the standard can-type gages report daily by telephone to centrally located area offices, shown in Figure 6-1. Where observers or telephone communications are not available, automatic very-high-frequency (VHF) radio rain gages are installed which broadcast rainfall amounts every two hours. There are 27 of these gages from which



FIELD REPORTING HYDROLOGIC NETWORK

FIGURE 6-1

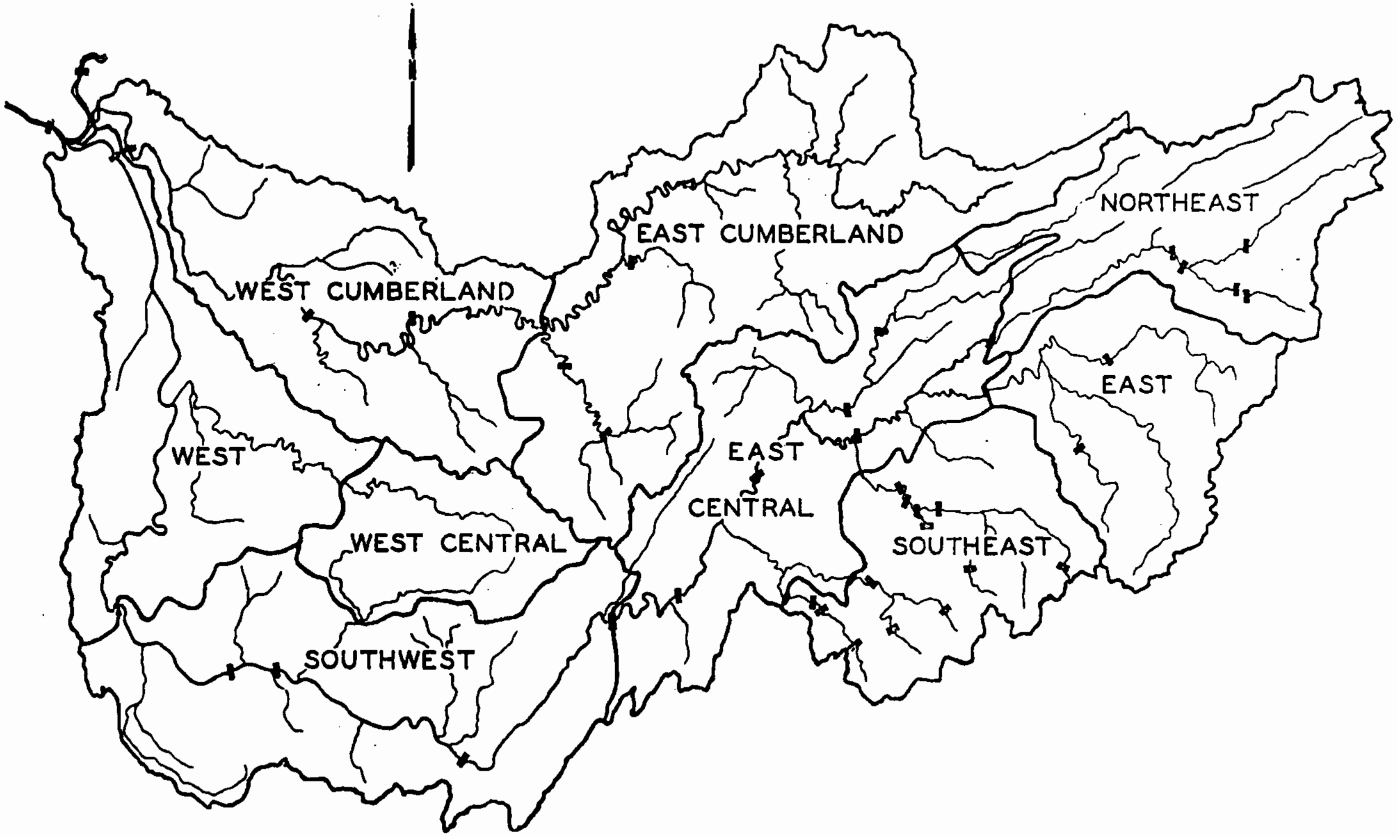
broadcast amounts are received and recorded in area offices located throughout the Valley. The rainfall reports received in the area offices within the Tennessee Valley are relayed by telephone to the River Control Branch in Knoxville. Those received in the Cumberland Valley by the Corps of Engineers in Nashville are relayed to TVA by teletypewriter or telephone. Rainfall reports from the gages located in power plants and substations are obtained by power dispatching personnel in Chattanooga and are relayed by facsimile equipment to the River Control Branch in Knoxville. Rainfall reports are also received by teletypewriter from the Knoxville airport office of the National Weather Service and from the NOAA Weather Wire Service.

Reports are received daily from 72 streamflow stations within the Tennessee and Cumberland River Basins, Figure 6-1. The majority of these reporting stations are located on principal tributary streams or on small areas to measure the discharge at points for which streamflow forecasts are made and/or for use as an index of runoff conditions. Automatic VHF radio gages are installed at 24 stations, which broadcast stages every two hours. The stream gage reports received in the area offices within the Tennessee Valley are relayed by telephone, with the rainfall reports, to the River Control Branch, while those received in the Cumberland Valley are relayed by the Corps of Engineers with the rainfall reports.

Observed reservoir elevations and discharges at the 43 hydro plants are obtained by dispatching personnel of the Office of Power in Chattanooga and are transmitted by facsimile equipment to the River Control Branch.

6.4 WEATHER FORECAST SERVICE

Under a personal service contract between TVA and the General Weather Center, a private meteorological service in Detroit, Michigan, forecasts of weather for the Tennessee and Cumberland Valleys are received on a regular daily schedule. Additional forecasts are furnished as frequently as changing weather conditions warrant. The forecasts include quantitative precipitation amounts for nine subdivisions of the two major basins, Figure 6-2, temperature and light intensity at selected locations, and wind velocities. The forecasts cover the current and the succeeding four days. At least three times weekly the meteorological service also gives a telephone briefing on weather conditions to key personnel of the River Control Branch. This service is supplemented by weather maps received on a facsimile machine, and by information on the Weather Wire Service teletypewriter installed in the office of the River Control Branch. These machines receive information from the National Meteorological Center of the National Weather Service in Washington, DC. These weather forecasts and other sources of meteorological information are used in scheduling water use at each plant in the system. Predicted temperatures, light intensity, and wind velocity are used by the Office of Power to aid them in the prediction of hourly and daily total power loads. Water use at the hydro plants then is scheduled to



SUBDIVISIONS FOR QUANTATIVE PRECIPITATION FORCASTS
FIGURE 6-2

aid in supplying the predicted load. The quantitative precipitation forecast is used by the River Control Branch in planning the operation of the reservoir system. Advance knowledge of the expected precipitation enables the branch to draw reservoirs down for flood control or power generation, in advance of the rain. Water, which otherwise would have been spilled, can be used for power generation; additional flood control storage space, provided in anticipation of the rain, can be used in regulating the system and reducing the flood crest downstream from the reservoir.

6.5 PREDICTING RESERVOIR INFLOWS

The prediction of inflows arriving in each reservoir from its unregulated drainage basin is the first step in preparing daily water dispatching schedules. Two types of reservoir inflow predictions are made: (1) predictions based on rain that has already fallen and been measured, and (2) predictions based on the rain expected to fall in the future, based on quantitative precipitation forecasts. Although the same procedures are used in predicting these two types of reservoir inflows, the response may be quite different, dependent primarily on the degree of confidence in the quantitative precipitation forecast.

6.5.1 PREDICTIONS BASED ON OBSERVED RAINFALL

The routine daily collection of hydrologic data is scheduled to begin at 8 a.m. Within one hour all reports of observed hydrologic data are received in the office of the TVA River Control Branch in Knoxville. The reported precipitation data and coded operating instructions for a computer program are keypunched on IBM cards, checked, and fed into one of TVA's electronic computers. "Previous condition" data (already stored on magnetic tape), and the reservoir inflow program (stored on a disk pack), also are fed into the computer. Volumes of uncontrolled inflows into each reservoir then are computed and the answers are printed out ready for use. The program usually is run on the IBM 360/50 computer located in TVA's Knoxville Computing Center, but the IBM 370/165 computer located in the Chattanooga Computing Center is used when the Knoxville computer is out of service. The printout includes, for each reservoir in the system: (1) predicted 6-hour average inflows for the first three days, and (2) predicted 24-hour average inflows for up to seven additional days.

This program, used to predict uncontrolled inflows into each reservoir in the TVA system, is <u>not</u> based on a mathematical model, but is based on a computerized version of methods and procedures developed for manual use. Some increased detail and refinements, not feasible when inflows were predicted manually, were incorporated in the program. (For additional information see reference number 9.) In coding the operating instructions for the program, several options are available to obtain increased accuracy and allow wider flexibility of use, such as:

(1) Seasonal adjustments of the rainfall-runoff relations can be made to compensate for deviations from a normal seasonal runoff pattern. Such deviations might occur during a late spring, or an early winter, etc.

(2) An option is included for routing flood flows, when required, in one of the main tributary streams which has large overbank storage. The routing procedure employs the Muskingum equation with variable values of the "C" coefficients.

(3) Another option is included in the program for computing additional inflows resulting from predicted rainfall for use in advanced planning of reservoir regulation.

The program is designed for daily (once-a-day) use, but may be used more or less frequently. The program is coded in FORTRAN IV.

Hydrologic relations used within the program are emperically derived relations based on useful hydrologic concepts already well documented in technical literature. A 2-component hydrograph separation method is used for simplicity and speed [9, 10, 13]. Inflow from direct rainfall on the reservoir surface is computed by multiplying rainfall by a factor for that particular reservoir [9]. Runoff from rainfall is computed by use of the antecedent precipitation index (API) method of Kohler and Linsley [11]. Hydrographs for unit runoff [12] of one inch (25.4 mm), both surface water and groundwater, are used for distributing in time the volumes of the respective runoff categories. Inflows during any period are composed of: (1) runoff from rainfall during that period, (2) water released from groundwater storage, and (3) water in transit in stream channels at the beginning of that period, which will arrive as streamflow during the period. Included in the "previous condition" data, stored on magnetic tape by the previous computer run, are: (1) the antecedent moisture conditions for each area (API), (2) groundwater flow recessions, and (3) surface water flows arriving from previous storm runoff.

Flows predicted by the computer program are compared daily with those flows being observed, and when a significant difference is noted on the recession limb of the hydrograph for any area, the antecedent flow data stored on magnetic tape for that area is adjusted to eliminate the difference. On the recession limb of the hydrograph the amount of streamflow available from uncontrolled ground and channel sources can be evaluated from recessions of flow from each source. Continued recessions are predicted separately for groundwater and surface water flows, using depletion curves developed for each of those components of flow. The total streamflow recession then is computed as the sum of the groundwater flow and surface water flow recessions. (For additional information see Chapter 15 and Figure 15-8 and 15-10 of reference number 13.)

In summary, inflows arriving from previous storm runoff (including the groundwater flows) are added to the inflows from the current precipitation, to obtain predictions of the total inflow into each reservoir. Additional information on the hydrologic relations and forecasting procedures used by TVA can be obtained from reference number 9, 10, 14, and 15. As previously stated, the manual procedures explained in the older reference have been computerized for increased speed and accuracy.

6.5.2 PRECIPITATION BASED ON QUANTITATIVE PRECIPITATION FORECASTS

In the efficient operation of a multiple-purpose reservoir system it is essential to know not only the current streamflows to be regulated but also the possible streamflows that may result from predicted precipitation. Most of the reservoirs on the main Tennessee River have a relatively small storage capacity; thus it is desirable to draw down these reservoirs for flood control and/or power generation in advance of significant increases in inflows. To estimate satisfactorily these potential inflows into each reservoir it is necessary to know where the precipitation will occur over the system of reservoirs, when it will start and stop over each significant subdivision, and how much precipitation will fall in specific time intervals and specific subdivisions. In addition, it is desirable to know the probability of development of predicted precipitation, preferably expressed quantitatively. This probability aspect helps to guide the river control engineer in making decisions as to whether to operate solely on observed rainfall, on observed plus predicted, or on some criterion between these two extremes. Telephone briefings by a General Weather Center meteorologist plus the availability of current and prognostic weather maps, give an idea of the relative probability of development of the forecast.

Streamflow forecasts based on predicted quantities of precipitation are made whenever the amounts are sufficient to produce significant increases in streamflow. These forecasts serve as a guide in planning water control operations. This systematic practice avoids having to wait until the precipitation is observed. Often it would then be too late to schedule the most efficient and economic operation of a reservoir system. Effective use of stored water for power generation can be made which may otherwise have had to be wasted by delaying the operation decision until the rainfall was observed. Reducing or stopping the discharge from tributary storage dams, while drawing down main Tennessee River reservoirs in advance of the storm runoff, provides for the maximum reduction in flood stages at vulnerable locations along the main Tennessee River. Prudence must be exercised in the event that all predicted precipitation does not materialize. Frequent evaluation of observed rainfall during the subsequent forecast periods, and as the storm progresses, minimizes difficulties and unanticipated restrictions on power generation due to main Tennessee River reservoirs approaching absolute minimum operating levels for navigation.

The predicted quantities of rainfall are treated as an extension of observed rainfall, and an option in the computer program is exercised to compute the additional inflows, into each reservoir in the system, from the predicted rainfall. Flows are routed through the reservoir system based on two separate sets of predicted inflows. One routing is based on observed rainfall; while the other routing is based on observed plus predicted rainfall. The two routings then are analyzed to determine (1) what operations are required because of the observed rainfall and (2) what operations will be required if the predicted rainfall develops. The actual operation planned initially is dependent upon the relative chance of development and the potential consequences; thus a third routing usually is required based on flows between these two extremes.

It is unusual to plan initial operations and establish a water dispatching schedule based upon observed rainfall plus all of the predicted rainfall for the full 5-day weather forecast period. The operations plan developed to include the predicted rainfall usually is based on the rainfall expected in the first 48 hours, since the science of weather forecasting has not advanced sufficiently to achieve verification of predicted quantities of rainfall beyond this 48-hour period. Long-term weather forecasts, such as 30-day outlooks, have not been sufficiently accurate to warrant using them, even for long-term advance planning.

6.6 RESERVOIR ROUTING

The method used to route water through a reservoir will depend on whether the reservoir is level or whether it has substantial slope, as under natural river conditions, and on the operation of control gates in the dam.[8] TVA's tributary reservoirs are deep reservoirs on relatively steep streams. Outflow from these reservoirs normally is completely regulated, and usually is not affected by the rate of inflow. For all practical purposes these reservoirs can be considered level pools; thus for each of these reservoirs a single curve represents the relation of headwater elevation to storage volume. Routing of flows through the tributary reservoirs is accomplished manually, using the following fundamental relation between inflow, outflow (discharge) and storage:

$$\frac{I_1 + I_2}{2} \; t \; - \; \frac{O_1 + O_2}{2} \; t \; = \; S_2 - S_1 \qquad (6.6.1)$$

Where I is the inflow rate, O is the outflow rate, S is the volume in storage, t is the length of the time interval, and the subscripts 1 and 2 refer to the beginning and end of the time interval, respectively. If the unit of flow is cubic feet per second, the time period is one day, and the storage volume is expressed in day-second-feet (a common unit of storage equal to 2,447 cubic meters) the equation can be reduced to:

$$\bar{I} - \bar{O} = \Delta S \qquad (6.6.2)$$

Where $\bar{I}$ is the average inflow during the day, $\bar{O}$ is the average outflow during the day, and ΔS is the change in storage. Equation 6.6.2 is the form normally used for daily routing of flows through TVA's tributary reservoirs. Appropriate changes must be made if time periods other than one day are used.

All main Tennessee River reservoirs except Kentucky can be considered level pools for flows of about turbine capactiy or less. For higher flows, however, the amount of storage between level pool and the backwater curve becomes appreciable and must be evaluated. In Wheeler Reservoir, for example, the controlled level storage space between the normal minimum level of elevation 550.0 feet (167.6 m), and the top of gates at elevation 556.3 feet (169.6 m), is 352,000 acre-feet (434 hm^3). With 250,000 cubic feet per second (7,080 m^3/sec) flowing through the reservoir, the difference in volume between total profile storage and level pool storage at top of gates, elevation 556.3 feet (169.6 m), is 419,000 acre-feet (517 hm^3). This profile condition is illustrated in Figure 6-3. The routing procedure used must account for this volume as it goes into storage on increasing flows and comes out of storage on decreasing flows.

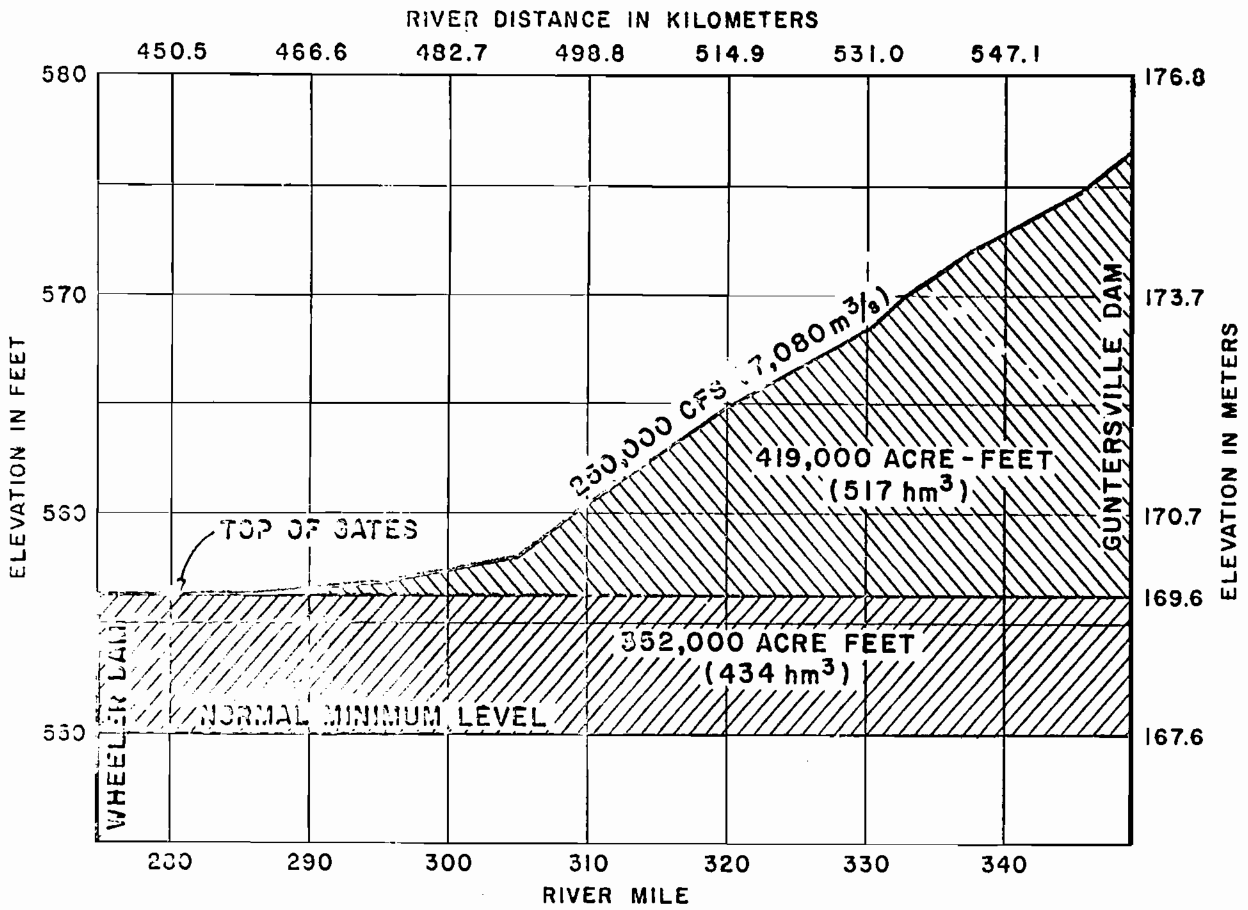
When profile storage exists, storage volume within the reservoir can not be related to headwater elevation by a single curve for all flow rates, as was done in tributary reservoirs. In the main Tennessee River reservoirs, profile storage volumes are correlated with headwater elevation at the dam and tailwater elevation at the upstream dam. A correction diagram was developed to adjust the profile storage, indicated for steady conditions, for changing stage at the upstream tailwater. These profile storage curves, and correction diagrams, were developed from profiles observed and flows measured during past floods. Reservoir routing using slope storage thus involves the use of a fourth variable, headwater elevation, in addition to those of inflow, outflow, and storage. After the observed storage volume has been determined from the profile storage relations, equation 6.6.2 can be rearranged as

$$\bar{I} = \bar{O} - \Delta S$$

and used to compute the observed inflow, since the average outflow $\bar{O}$ is a measured quantity.

Discharge curves, corresponding to the flow at the upstream tailwater, are superimposed on the storage curves. In routing predicted flows, the outflow from the upstream dam is used as a parameter to determine the profile storage volume. This parameter must be lagged in time to allow for the loop in the rating curve. Having thus determined the profile storage volume, and having already predicted the inflow into the reservoir, two quantities remain to be determined: (1) the ending headwater, and (2) the average outflow. Establishing either one of these quantities allows the other to be computed. System regulation objectives and constraints determine which quantity is established.

Routing through the 184 miles (296 km) of Kentucky Reservoir is a special problem. Treating the reservoir as a simple reach does not give sufficiently accurate results. In addition, forecasts at intervening



WHEELER RESERVOIR - PROFILE STORAGE
FIGURE 6-3

points in the reservoir are desired for navigation and public information. For routing purposes, therefore, the reservoir is divided into four reaches. The discharge at the end of each of the three intermediate reaches is determined from slope ratings, which are rating curves relating the discharge at the end of a reach to the elevation at that point and the elevation upstream at the start of the reach. These ratings were developed by the slope-area method, described in section 15 of reference number 8, and were correlated with open channel discharge measurements made at the ends of each reach during flood flows. Routing is then accomplished by a successive approximation procedure until a satisfactory profile and storage balance are achieved. The routing procedure through Kentucky Reservoir has been computerized for increased speed and to expedite consideration of alternative operations.

Routing of flows through all reservoirs except Kentucky continues to be performed by simple manual procedures, but a program is being developed to route these flows on an electronic computer as soon as a remote terminal is acquired for rapid access to a TVA computer.

In summary, the reservoir routing process requires a knowledge of the following: (1) total inflow, which may be the sum of several components such as the discharge from a dam at the upper end of the reservoir, the discharge of a contributing river within the drainage basin of the reservoir, and the discharge of all small creeks entering the reservoir (local inflow); and (2) the relationship between storage and other variables such as inflow, outflow, and headwater elevation. When these factors are known or can be determined, an outflow hydrograph can be obtained by the repetitive solution of the storage equation [8]. (For a more detailed explanation of reservoir routing methods see section 25 of reference number 8, and reference number 10.)

6.7 BASIS OF DAILY WATER DISPATCHING SCHEDULES

Daily water dispatching schedules are prepared in conformance with the priorities established by the TVA Act: (1) to promote navigation, (2) to reduce flood crests on the Tennessee River and its tributaries and on the lower Ohio and Mississippi Rivers, and (3) to obtain the most dependable and effective production of electric energy, consistent with those first two primary purposes. The daily schedules also provide for the operation of the reservoir system for secondary purposes provided they may be accomplished without significant detriment to the three primary objectives of navigation, flood control, and power. Thus the basis of all water dispatching schedules is the attainment of established objectives. Priorities have been assigned to various objectives to aid in resolving conflicting demands on the water resources of the region, and these priorities are complied with in developing the plan of system management.

6.7.1 NAVIGATION REQUIREMENTS

A navigation development must offer long-range dependability in order to attract shippers and promote the growth of terminals along the waterway. The navigation channel must be dependable in terms of depth and of the range of fluctuation of water levels, and it also should be reasonably free of wide variations in streamflow and the corresponding velocity changes. The objective of providing adequate depths for navigation from the Ohio River to Knoxville is attained by regulating reservoirs on the Tennessee River to ensure that levels are not drawn below planned minimum levels. Water levels sufficient to provide a minimum 11-foot depth (3.35 m) for vessels of 9-foot draft (2.74 m) are maintained in the Tennessee River between Knoxville and the mouth, and in the Clinch River between Clinton and the mouth.

The objective of limiting the variation in velocities and water levels in the reservoirs is attained by careful routing of discharges through the reservoir system and by imposing constraints on the rate of change of discharge from the dams. Flood discharges do create problems occasionally, but the reservoir system and navigation facilities are so designed that interruptions due to floods only occur during floods of such magnitude that the frequency of occurrence is once in 40 years.

6.7.2 FLOOD CONTROL REQUIREMENTS

The objective of all flood control operations is the regulation of damaging floods to minimize potential damages. Operation of the TVA reservoir system for flood control is accomplished by the regulation of flows and reduction of flood crests at places where an actual need exists.

Within the Tennessee Valley by far the greatest potential urban damage from floods is at Chattanooga, located just above the narrow constriction that divides the Valley into rather distinct upper and lower portions, Figure 2-1. The existing TVA reservoir system provides almost complete protection to large areas below the tributary dams, and a substantial degree of protection to the areas below the main river dams. Chattanooga, however, is the focal point for major flood control operations within the Tennessee Valley, for it is the location of greatest preventable damage in the basin.

The principal use of flood control storage in the Tennessee River reservoirs below Chattanooga is to regulate floods (1) below each of the dams on the Tennessee River, and (2) on the lower Ohio and Mississippi Rivers. Paducah, Kentucky, and Cairo, Illinois, are locations of particular interest in flood damage prevention on the lower Ohio River. The primary objectives in the operation of TVA reservoirs fo regulation of floods on the lower Ohio and Mississippi Rivers are: (1) to safeguard the Mississippi River levee system, (2) to reduce the frequency with which the Birds Point-New Madrid floodway is put to use, and (3) to reduce the frequency and magnitude of flooding of land not protected by the levee system. [17]

The 10 large flood storage reservoirs on the tributaries to the Tennessee River have a relatively large capacity with respect to flood volumes--equivalent to 6.4 inches (16.3 cm) over their drainage areas on March 15--and therefore are operated to store all, or almost all, of the flood inflow. The eight main Tennessee River reservoirs, which have a flood storage reservation, have a relatively much smaller flood storage capacity--equivalent to an average of about 1.8 inches (4.6 cm) over their drainage areas, excluding Kentucky--and therefore are operated to accelerate the preflood flows downstream, thereby reserving their flood control storage for use in reducing the flood crest, when optimum benefit can be achieved through use of the limited flood storage space.

During 40 years of planning, construction, and operating the TVA hydro projects, 10 flood control operating principles and objectives evolved. Detailed information on the development of these operating principles and objectives has been published in TVA Technical Report No. 26 [7]. Four typical examples of these operating principles and objectives are:

(1) The use of reservoirs between certain elevations for dual purposes is feasible in the Tennessee Valley because the annual critical flood season at Chattanooga is quite definite as to time of year, from about December 15 to April 15 of the following year.

(2) During periods of substantial flood flows, the operation of the reservoir system above Chattanooga will be primarily for reduction of flood stages at Chattanooga and other points in the upper Tennessee Valley, with incidental downstream benefits.

(3) An available capacity of at least 4,000,000 acre-feet (4.93 km^3), suitably distributed among the tributary reservoirs above Chattanooga, is to be reserved for flood control during the flood season through March 15, with a gradually decreasing reservation permissible between March 15 and April 15. This flood storage capacity to April 15 will be operated primarily for protection of Chattanooga. After this date, it will be largely for the protection of agricultural lands from the smaller, crop-season floods. Additional flood storage capacity will be available on January 1 to allow for multiple floods, with the amount decreasing from January 1 to 4,000,000 acre-feet (4.93 km^3) on March 15.

(4) The objective in the use of the reservoir system for flood control is for the regulation of damaging floods only, and the available capacity is to be reserved for that purpose.

Day-to-day operation of the reservoir system requires frequent and detailed advance scheduling of discharges from each reservoir because none of the outlet works are automatic. The following factors are considered in establishing a water dispatching schedule for flood control: existing reservoir levels with respect to the operating guides, predicted reservoir inflows, current runoff conditions, weather forecasts, areal distribution and timing of precipitation, the outlook for the current storm being followed by another and how soon, and stages at locations selected for maximum regulation. In compliance with the multiple-purpose reservoir operating guides, storage space in the reservoirs is reserved, and during flood runoff periods, is used to reduce downstream flood crests. During periods of substantial flood flows, flood control requirements always have top priority over <u>all</u> other objectives of system operation.

Although the primary objective of flood control operations is the reduction of flood crests to nondamaging levels, a secondary objective of providing timely flood warnings also is important. When the flood cannot be regulated to prevent all damages, timely flood warnings can result in substantial lessening of the flood damage, and may prevent loss of life. To meet this need, information is disseminated by several means. Predicted flows and reservoir elevations are furnished to the National Weather Service for radio and television broadcasts, and for publication by newspapers. A Daily River Bulletin is published and distributed by mail. Special bulletins and warnings are issued for critical locations during flood periods. Flood wall superintendents, barge line operators, river terminals, city officials, county agents, etc., are alerted and warned as the flood develops, and revised predictions are issued if the operation schedule is changed during the day or night.

6.7.3 POWER PRODUCTION REQUIREMENTS

During periods of normal to low flows, when navigation and flood control requirements are not governing the operation of the system, hydroelectric power loads are distributed among hydro plants to make the most efficient use of available water. The proposed generation schedule for each hydro plant, received each morning from the scheduling section of Power System Operations, is used by the River Control Branch for tentatively scheduling the releases at each dam. Inflows into each reservoir, including runoff from the uncontrolled drainage basin plus releases from upstream dams, then are routed through the reservoir to determine whether the proposed operation will conform to the limits allowable for achieving current water control objectives. Proposed releases from various dams are adjusted to keep the available storage space approximately in balance within each type of reservoir system--that is, within the tributary multiple-purpose reservoir system, within the tributary power reservoir system, and within the main Tennessee River reservoir system. A balanced distribution of the storage space within the reservoir system provides balanced flood control capabilities, and minimizes public complaints of preferential treatment as the reservoirs are drawn down below the most desirable levels for recreational pursuits. Other factors considered in establishing the daily water dispatching schedules include: scheduled maintenance and projected duration of unit outages at a hydro plant, discharge constraints at each plant, rate-of-change-of-discharge constraints at some plants, and secondary operating objectives--such as those listed in section 6.7.4. Close coordination between the River Control Branch in

Knoxville and the Office of Power in Chattanooga usually makes it possible to operate the reservoir system to meet the demand for hydroelectric power while attaining many other objectives.

The objective of the daily water dispatching schedule for power production is to make the most efficient use of available water when generating electricity to meet the power demand. The procedures used in scheduling generation, and the value of the hydroelectric plants in meeting peaking and emergency load demands, have been described in section 3.2.

6.7.4 SECONDARY OBJECTIVES

When reasonably consistent with the three primary objectives, water levels and streamflows are regulated to achieve numerous secondary objectives, including the following:

(1) To control mosquitoes and other vectors.

(2) To control aquatic growth.

(3) To enhance recreational use of the waters by providing favorable pool levels, minimizing fluctuations during the prime recreation season, and providing adequate discharges from some dams to expedite boating and/or fishing activities downstream.

(4) To stabilize reservoir levels during fish spawning season, and thus to encourage the propagation of desirable species of fish.

(5) To provide a suitable environment for desired species of fish life downstream from the dams by making special releases to (a) provide adequate volumes of water, (b) control the water temperature, and ( ) increase the level of dissolved oxygen.

(6) To provide a water supply for domestic, industrial, or agricultural use.

(7) To produce water quality benefits for the public health and public use of the reservoirs by minimizing detrimental pollution effects through (a) dilution, (b) dispersion, and (c) removal (flushing) from critical locations of the polluted water.

(8) To assist, upon request and when feasible, individual navigators, ferrymen, farmers on river islands and shore lands, and others who experience emergency needs or who may otherwise suffer discomforts or inconveniences.

(9) To expedite necessary construction, repair, or maintenance activities, in or adjacent to the reservoirs or regulated streams.

(10) To avoid or relieve emergency situations involving hazard to human life or health.

An example of regulating the reservoirs to achieve secondary objectives is the stabilization of reservoir levels during fish spawning season. Fish biologists know that spawning of most game and pan fish in TVA lakes takes place when water temperatures rise in the spring. During the spawning period the change in water level must be limited so that the eggs are not left high and dry by a falling lake, or covered too deeply by a rising lake. When water temperatures reach 60 to 65 degrees Fahrenheit (15.6 degrees Centigrade to 18.3 degrees Centigrade) the reproduction process starts. As the water warms above 65 degrees Fahrenheit (18.3 degrees Centigrade) the fish lay their eggs. Observations of reservoir temperature are taken each spring, in most reservoirs, to provide data for scheduling a period of stable reservoir levels. The trend of rising water temperature is monitored, and as soon as the temperature exceeds 65 degrees Fahrenheit (18.3 degrees Centigrade) each reservoir is regulated to hold relatively stable reservoir levels for about two weeks. Since the critical spawning temperature does not occur simultaneously in all reservoirs, it is unnecessary to stabilize all reservoir levels simultaneously. Successive stabilization of levels in various reservoirs reduces the potential detrimental effect on power system operations. Fortunately the need for stabilization of reservoir levels occurs during a period of reduced demand for electric power--the period between the heating season and the air conditioning season--thus permitting achievement of this secondary objective without significant detrimental effect on power system operation

6.8 DISPATCHING OF WATER FROM THE DAMS

After the amount of water expected to arrive in each reservoir is determined for the required period, a plan of operation for the reservoir system over the next several days is prepared. Primary and secondary objectives, outlined in the preceding section, provide the basis for the daily water dispatching schedules. Instructions governing the storage and release of water in the reservoirs are transmitted to the Office of Power in Chattanooga which, through its dispatching system, instructs the operator to perform the required operation at each dam.

Regulation of the reservoir system for multiple uses requires detailed daily attention to the operations. Flood control operating procedures require current predictions of inflows to reservoirs, supplemented by predictions of unregulated streamflow at downstream control points. Because of the dynamics of the river, decisions are necessary on a round-the-clock basis during flood control operations, to vary upstream releases for attaining nondamaging stages downstream. Since storage is not adequate for complete protection from very large floods, competent personnel must be available to determine when the objective of the regulation should be changed from complete protection to that of minimizing damage, or in extreme floods, to ensure safety of the regulating structure.

Prompt attention to the regulation of the reservoir system is equally essential to the economical use of stored water for power, both on a daily and long-range basis. Increases in streamflow which would have no significance for flood control may be extremely significant for power operations. Unless power releases from upstream storage reservoirs are reduced in time, the combined flow may exceed turbine capacities at downstream run-of-river plants. Thus, to obtain the most effective operation of the reservoir system and to ensure the attainment of all objectives, prompt revisions in the operating plan are necessary in response to changing streamflow and weather conditions.

Forecasting and water dispatching for the TVA reservoir system is a continuous process. Complete forecasts for the system are made five days a week. Main river forecasts are revised on Saturdays. A check on the observed elevations and discharges at each tributary and main river dam is made on both Saturday and Sunday and the operating plan revised when necessary. During rapidly changing streamflow periods, or with rapidly changing hydro power load conditions, revisions to the plan of operations are often necessary during the day, and sometimes at night, especially during prolonged periods of runoff-producing rainfall. During major flood periods forecasting and water dispatching for the reservoir system becomes a round-the-clock, seven-day-per-week, job.

SECTION 7

EFFECTIVENESS OF THE WATER CONTROL SYSTEM

In evaluating the effectiveness of the TVA water control system, the question arises--"Is the system effectively performing the functions for which it was developed?" That first question might logically be followed by two additional questions: (1) "How is the effectiveness evaluated?", and (2) "How are the benefits measured?" Some benefits of the three primary objectives--navigation, flood control, and power--can be partially measured in terms of monetary units. Other benefits of the three primary objectives are similar to the benefits obtained from the secondary objectives, in that, although these programs improve the quality of life in the Tennessee Valley region, the benefits cannot be measured adequately in terms of monetary units. Agreement has never been reached on a monetary value of a human life saved by flood control. Citizens of the region expect--and often they demand--the benefits of the various objectives even though they cannot be evaluated in terms of monetary units.

7.1 NAVIGATION BENEFITS

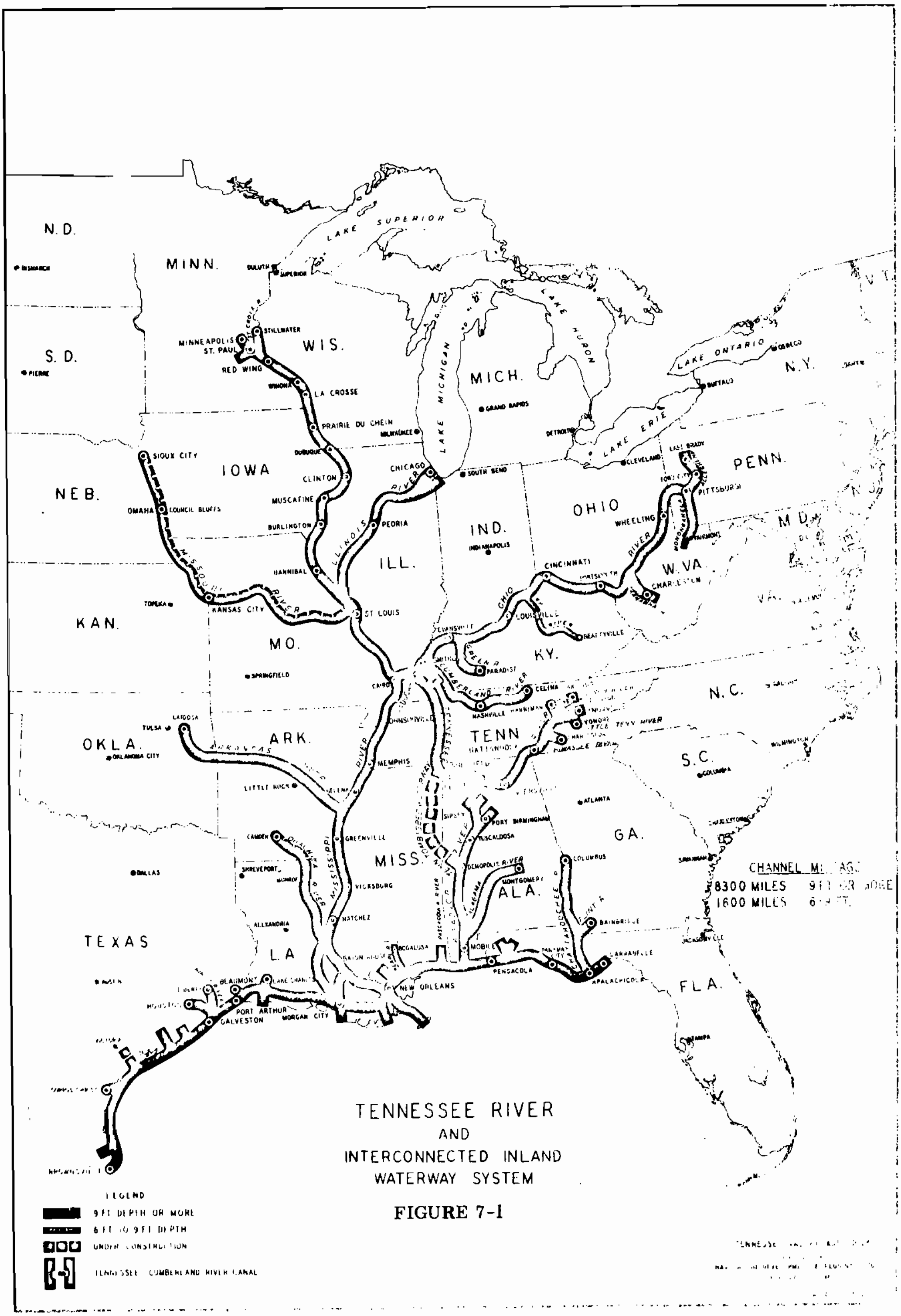
Nine TVA dams create an unbroken chain of lakes and locks for river tows, extending navigation 650 miles (1,046 km) up the main stream of the Tennessee River from the mouth to Knoxville, Tennessee. The region thus is linked with an inland waterway system extending from the Gulf Coast to Minnesota and Pennsylvania, Figure 7-1. Barge traffic totaled 29 million tons (26 Gg) of freight and saved users of the Tennessee River waterway almost $72 million in transportation costs during 1973 alone. Since 1933 when construction of the TVA system of dams began, shipper savings have totaled $755 million, while total Federal operating costs have totaled $167 million, including depreciation. Accumulated savings by shippers thus total over 4-1/2 times the accumulated Federal costs of the navigation facilities.

Private industry has invested more than $2.4 billion in Tennessee River waterfront plants, terminals, and distribution facilities since 1933. Over 41,000 area residents are employed directly by waterfront industry.

Obviously, the navigation objective has been attained, as the TVA reservoir system provides a dependable, year round, channel from Knoxville to Paducah, Kentucky, and thence via the inland waterway system, to ports in 21 states.

7.2 FLOOD CONTROL BENEFITS

The success of the TVA water control system in the regulation of floods is known throughout the world. Operation of the TVA reservoirs for flood control began in early March 1936 with the closure of Norris Dam, the first multiple-purpose project completed. Construction



TENNESSEE RIVER
AND
INTERCONNECTED INLAND
WATERWAY SYSTEM

FIGURE 7-1

of additional dams during the ensuing 38-year period has increased the capability of the flood control system and numerous large floods have been effectively regulated. The second largest flood on record at Chattanooga would have occurred in January-February 1957 had it not been regulated by the reservoir system. The regulated crest stage of the 1957 flood was 32.2 feet (9.8 m) at Chattanooga, about 22 feet (6.7 m) lower than the computed natural (unregulated) crest. Although the regulated crest stage was 2.2 feet (0.7 m) above the official National Weather Service flood stage, only minor damages and inconvenience occurred. Regulation of the 1957 flood crest reduced flood damages at Chattanooga by $66 million (this value was based on a 1953 survey of the city, and the dollar values of 1957.)

During fiscal year 1973 the Tennessee Valley experienced potential flood situations of record proportions. The water control system regulated three floods on the Tennessee River, and assisted in lowering three flood crests on the lower Ohio River and five on the Mississippi. Flood damages averted during 1973 alone are estimated at $574 million, which is more than twice the capital cost of all TVA flood control facilities, plus the cost to date of operating and maintaining them. Figure 7-2 shows the reduction in stage at Chattanooga during the March 1973 flood. Damages averted at Chattanooga in this one flood were estimated at $465 million.

At Chattanooga the March flood lasted about three days and reached a level about 6.9 feet above flood stage. Without regulation by TVA's reservoir system, the same flood (broken line) would have gone 22.4 feet above flood stage, inundating about half the city and causing more than $500 million in damages.

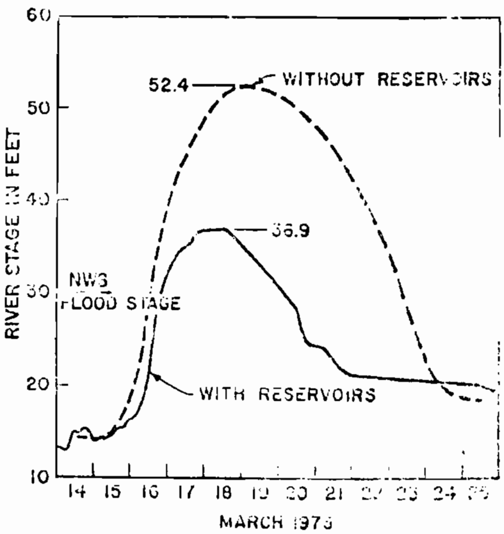
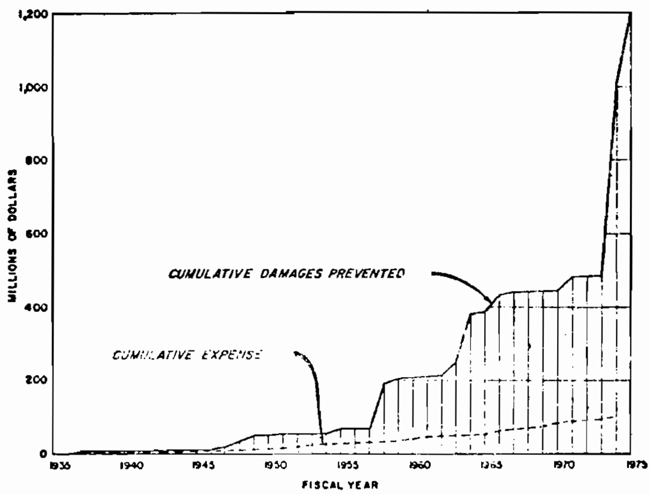


FIGURE 7-2 CHATTANOOGA STAGE

Flood control benefits attributable to the TVA flood control system now total over $1.2 billion. This is over six times the $197 million capital investment in flood control facilities, and is 12 times the $101 million accumulated flood control expense. Figure 7-3 shows the cumulative flood damages prevented by the TVA multiple-purpose reservoir system since 1936, and the cumulative flood control expense during the same period.

With the major flood control operation of 1974, the estimated total for damages prevented through the years by the TVA multipurpose system rose to more than 1.2 billion dollars, not including $150 million in enhanced land values along the lower Ohio and Mississippi Rivers. The accumulated cost of flood control operations over the same period was about $101 million.



PREVENTED FLOOD DAMAGES - TVA MULTIPLE-PURPOSE SYSTEM

FIGURE 7-3

Although the investment in the flood control system has been more than recovered, the system will continue to regulate floods for many years into the future. Obviously the original flood control objectives also have been attained; additional flood control projects are being constructed for the benefit of some tributary areas where actual needs exist.

7.3 POWER GENERATION BENEFITS

The economic growth of the Tennessee Valley has been greatly stimulated by abundant supplies of electricity at low cost. When TVA was created in 1933 only one farm in 30 had electric service, and most city homes used electricity only for lighting. Today almost every home in the Valley has electric service. The average home in this area now uses nearly 15,000 kilowatt-hours a year, or 25 times as much as in 1933. Despite inflation and environmental protection costs, the average cost per killowatt-hour for residential electric service is only about one-third of the 1933 cost.

During 1973 hydroelectric generation at dams in the TVA power system amounted to 24.5 billion kilowatt-hours, or 22.5 percent of the total generation of the system. The value of the hydroelectric system is enhanced by its ability to respond rapidly to varying power loads and the large percentage of the power produced "on-peak". Obviously, the hydroelectric plants are a dependable, low-cost, nonpolluting source of electricity. The system will continue to produce hydroelectric power for many years to come, its generation cost unaffected by the rapidly rising costs of fuels.

The reservoir system also benefits the thermal generating plants by providing a dependable and plentiful supply of condenser cooling water, and by reducing the transportation costs of coal shipped to many of the plants by barge via the Tennessee River waterway.

The power generation objectives, stated in the TVA Act--as (1)"to promote and encourage the fullest possible use of electric light and power," (2) "to provide and operate facilities for the generation of electric energy in order to avoid the waste of water power," and (3) to distribute and sell the power generated, equitably, for the benefit of the people of the section as a whole, and particularly the domestic and rural customers, at the lowest possible rates, and in such manner as to encourage increased domestic and rural use of electricity--have been achieved beyond the fondest dreams of the founders of TVA.

7.4 RECREATION BENEFITS

The TVA reservoirs, with their 11,400 miles of shoreline and 650,000 acres of water surface, are one of the greatest recreation resources of the Tennessee Valley. These reservoirs and the scenic beauty of the region have made the Tennessee Valley one of the most popular vacation areas in the United States.

Many benefits accrued to the region from 61 million recreation visits, by vacationers and sportsmen, to TVA reservoirs during calendar year 1973. Private investments in recreation facilities and improvements along TVA lakeshores now total about $437 million, and are growing steadily. Dealers in boats and motors, fishing tackle and supplies, recreational vehicles, and camping equipment have also established thriving and profitable businesses throughout the Valley. Visitors to the reservoirs and streams of the Valley depart with pleasant memories, and the money they spend at motels, restaurants, gasoline stations, and other businesses provides employment for thousands of area residents.

7.5 OTHER BENEFITS

Benefits of the TVA water control system extend far beyond those evaluated above. The regulated river and reservoir system has provided immense opportunities for water-based recreation, expanded fish and wildlife resources, abundant water supplies for cities and industries, and sites for industries along the shorelines protected from floods.

SECTION 8

OUTLOOK FOR THE FUTURE

Plans, procedures, and tools developed by TVA for management of the reservoir system have proven satisfactory and effective and have met the needs of the Tennessee Valley during the past 41 years. They will not, however, meet future sociological, economic, and technical needs. Increased emphasis on improving the quality of the environment in the region, the anticipated continuation of the energy crises, growing demands on water-based recreation resources, expanding industrial demands, and population growth within the region are establishing new needs and priorities. These new needs and priorities will require revised plans, improved procedures, and sharper tools to satisfy the increasing demands on the water resources of the region.

Some plans can be revised internally within TVA in response to the changing needs of people in the Valley. Existing statutory objectives and priorities established by the Congress can be changed only by the Congress.

Work is in progress within TVA's Division of Water Control Planning to provide improved procedures, including:

(1) Establishment of an automated data collection network that will permit continuous receipt, processing, and analysis of hydrologic data.

(2) Development of a mathematical model for continuous streamflow forecasting that will provide accuracy and reliability greater than that obtained by present methods, for all ranges of flow.

(3) Development of a practical, reliable, and economical mathematical model for the rapid and accurate routing of unsteady flows through open river channels and through reservoirs. Use of this model with a scheduling program to route water through the entire reservoir system, on an iterative basis, to optimize system benefits, makes it imperative that the routing model be of much greater efficiency and speed than any now available.

(4) Development of a computer program for use in scheduling the release of water from each reservoir to obtain optimum system benefits. All objectives of the operation of the reservoir system, and all constraints on the components of the system, must be included in order to obtain a realistic schedule.

Improved capabilities are required also in the following areas in order to increase the efficiency of utilization of the regional water resources. Work in these areas is being performed by other Federal agencies, other divisions within TVA, and by research staffs in the universities and colleges. Urgent needs include:

(1) Equipment for obtaining a more timely and representative sample of areal rainfall over each basin.

(2) Equipment and procedures for consistently obtaining greater accuracy in measuring discharges in open channels, over spillways, and through turbines throughout the full range of discharge obtainable.

(3) Improved weather forecasts, especially quantitative precipitation forecasts that are more reliable and of greater accuracy with respect to quantity, areal coverage, and distribution with time. Accurate long-range forecasts would be invaluable in increasing the efficiency of utilization of the water resources.

(4) Evaluation and assignment of an accepted value to the various items included in the category of secondary objectives of reservoir regulation, such as recreational benefits, water quality improvement, stabilization of water levels for fish spawning, etc.,--for use in optimization procedures.

Hard work, initiative, and innovation by planners, scientists, and engineers have produced acceptable solutions to the difficult problems of the past 41 years. These same qualities, along with the fullest research and development programs, will be required to solve the complex problems of the future.

APPENDIX

REFERENCES

1. U.S. Congress, "Tennessee Valley Authority Act of 1933, Public Law 17," 73rd Congress, 1st Session, approved May 18, 1933, as amended.

2. Cooper, Alfred J. "The Role of Weather Forecasts in TVA Reservoir Operations," Meeting Preprint 773, paper presented at ASCE Annual Meeting and National Meeting on Water Resources Engineering, New Orleans, Louisiana, February 3-7, 1969.

3. Brudenell, Ross N., and Gilbreath, Jack H., "Scheduling Generation on the TVA System With a Large General Purpose Computer," paper presented at World Power Conference, Sectional Meeting, Lausanne, Switzerland, September 13-17, 1964.

4. Wessenauer, G. O., Dean, W. E., Jr., and Gilleland, J. E., "Some Problems on a Large Power System with Large Generating Units," Paper 82 III. 0/7, Sixth World Power Conference, Melbourne, Australia, October 20-27, 1962.

5. Brudenell, Ross N., and Gilbreath, Jack H., "Economic Complementary Operation of Hydro Storage and Steam Power in the Integrated TVA System," AIEE Transactions, 1959, Vol. 78, Part III-A, pp. 136-156.

6. Brudenell, Ross N., Gilbreath, Jack H., and Dobson, W. A., "Computer Scheduling of Generation," paper presented at American Power Conference, Chicago, Illinois, March 1963.

7. TVA - 1961, "Floods and Flood Control," Technical Report No. 26, Knoxville, Tennessee, Chapters 7, 8, 9, and 13.

8. Handbook of Applied Hydrology, edited by Ven Te Chow, McGraw-Hill, Inc., New York, 1964, Section 15-X-A, and Section 25 Part III.

9. Cooper, Alfred J., "TVA's Method of Forecasting Reservoir Inflows for Water Control Operations," unpublished paper, TVA River Control Branch, Knoxville, Tennessee, Revised October 1972.

10. Engstrom, Le Roy, Wilkinson, Jackson H., and Blickensderfer, Alfred, "Streamflow Forecasting and Water Dispatching for TVA Reservoir System," paper presented at Knoxville Convention, American Society of Civil Engineers, Knoxville, Tennessee, June 8, 1956.

11. Kohler, Max A., and Linsley, R. K., "Predicting the Runoff from Storm Rainfall," U.S. Weather Bureau Research Paper 34, Washington, D.C., September 1951.

12. Sherman, L. K., "Streamflow from Rainfall by the Unit-graph Method," Engineering News Record, Vol. 108, pp. 501-505, 1932.

APPENDIX

REFERENCES

13. Linsley, Ray K., Jr., Kohler, Max A., and Paulhus, Joseph L. H., Applied Hydrology, New York, McCraw-Hill Book Company, Inc., 1949, Chapter 15.

14. Cooper, Alfred J., "Short-Term Streamflow Forecasting for Reservoir Operations," paper presented at 44th Annual Meeting of American Geophysical Union, Section of Hydrology, Washington, D.C., April 17, 1963.

15. Cooper, Alfred J., "Water-flow Data Keep Hydro Plants Efficient," Electrical World, March 20, 1967.

16. Mitchell, John T., Jr., "A Perspective on the Use of Operation Rules," Meeting Preprint 1096, paper presented at ASCE National Water Resources Engineering Meeting, Memphis, Tennessee, January 26-30, 1970.

17. Tucker, Russell L., "The Role of TVA Reservoirs in Reducing Flood Crests on the Lower Ohio and Mississippi Rivers," Proceedings, Mississippi Water Resources Conference, Water Resources Research Institute, Mississippi State University, State College, Mississippi, April 1970, pp. 47-74.

WATERSHED STREAMFLOW QUALITY AND QUANTITY MODELING IN TVA

Background

The roots of the TVA watershed models are buried in a history of small watershed research dating back 40 years (TVA, 1961 and 1962, and TVA and NCSU, 1963 and 1970). These watershed studies, as many others in the world have done, established that significant changes to streamflow quality and quantity could result from land-use changes. There is a problem inherent in small watershed studies, however, in that the results cannot be quantitatively transferred to other areas where the meteorology, geomorphology, geology, land use, or even catchment size may be different. It was evident by 1960 that if the results from the research studies were to be made transferable so that they could be used in planning, hydrologic modeling would have to be undertaken.

A project was undertaken in 1962, located in Upper Bear Creek in northwestern Alabama, with the express purpose of developing hydrologic planning models (Betson, 1965). The goal was to develop mathematical models for streamflow quality and quantity that could be calibrated using a wealth of hydrologic data already available in the Valley and used to provide information where data were unavailable. They were also to be sufficiently simple to use so that they could be readily used in planning applications. During the 10-year span of the project, there were changes in the mathematical models, the optimization techniques used, and some of the modeling concepts, based upon project findings (TVA, 1973a). The basic goal, however, remained as is reflected in the hydrologic system models described herein.

The Modeling Approach

The TVA hydrologic models are basically parametric (Snyder, 1971). This means a model is adjusted to observed watershed data using optimization or multiple regression techniques to obtain a value for each model parameter. The particular value obtained will result because of unique physical and hydrological characteristics of the watershed involved. When the model is adjusted to a variety of watersheds with a range of physical characteristics, a range of values will be obtained for each parameter. Generally a relationship will exist between variations in some physical measure(s) among watersheds and variations in the values obtained for each parameter.

It was found, however, that there are some problems that complicate the parametric hydrology approach (TVA, 1973a). These problems are associated with adjusting a particular model to data. The adjustment typically involves minimizing the error of prediction. The parameter values obtained are those associated with a minimum error, often the sum of squared error. One of the well-known constraints in linear regression is that the model variables must be independent. This constraint also exists in nonlinear optimization although the existence of interdependent variables is often more difficult to detect and avoid. The consequence in either case, however, of interdependent variables is less reliable parameter values. In other words, the values obtained for interdependent parameters will vary considerably among data sets on a single watershed and thus become difficult to relate to watershed characteristics. Because hydrologic processes are interrelated in nature, interrelated model variables are difficult to avoid. Regarding this problem, Nash (1967) observed that "the postulation of too complex a model in the first instance may render difficult or impossible the extrapolation of results obtained at one basin to another or the recognition of relationships between physical characteristics and parameters of the model--relationships which must be recognized if the postulation of a suitable conceptual model for ungaged basins is to be achieved."

The goal in designing the hydrologic models was simplicity and independence. Generally this was achieved by limiting number of parameters to be obtained through adjustment and thus the problems associated with interdependence.

Because the TVA hydrologic models are to be used in planning activities requiring relatively prompt results, they are designed to be applied using data readily available in the Tennessee Valley. For model calibrations only published hydrologic data are used and no field measurements are required. Model parameter values are related only to watershed characteristics that can be determined from maps, such as topographic and geologic, or other published data. As a consequence, the models can be applied at locations that have not been visited.

The TVA hydrologic models have been defined as first-generation models (Betson, 1974) because they use only existing published data. They are regionalized and can be applied generally throughout the Tennessee Valley. Their direct applicability to other areas in the world has not yet been demonstrated; however, they should be applicable in other areas with reasonably similar conditions and data. In any case, however, they do demonstrate the application potential of first-generation models, in general, once they are regionalized.

TVA Watershed Models

There are presently three component models in the system of watershed hydrologic models--a continuous flow model, a water-quality model, and a storm-hydrograph model. These models were developed to be used separately because typically only a single model is needed in an application. They can, however, be applied in combination and examples will be provided.

Continuous Daily-Streamflow Model (TVA, 1972a)--This model is the nucleus of the system of watershed models. It has a variety of applications by itself. In addition, however, it is used as a vehicle for transporting water-quality constituents. It can also be used to provide storm runoff volumes for the companion storm-hydrograph model in applications where flood information is needed

The continuous daily-streamflow model, in concept, is similar to other flow models as shown in Figure 1. Daily rainfall is budgeted among a series of conventional compartments or reservoirs. It differs from some flow models in that interflow is not included and there is only one soil moisture reservoir. These simplifications were made to minimize the number of parameters and intercorrelations among parameters.

One significant departure of the TVA model from other continuous flow models such as the Stanford Model (Crawford and Linsey, 1966) and the U.S. Department of Agriculture model (Holtan and Lopez, 1971) is that the process of infiltration is not included. Infiltration has been found to be highly variable across even apparently uniform hillslopes (TVA and NCSU, 1970). Haan (1972) in an attempt to evaluate the diffusivity equation for describing infiltration and moisture movement under field conditions concluded that the treatment of soil water flow on a watershed scale as a one dimensional process appeared to be a poor approximation to reality. If the areal variability of infiltration across a watershed must be accounted for, modeling becomes complicated and data requirements increase rapidly. To simplify the TVA model, the algorithm used allocates precipitation to storm runoff in proportion to the amount of moisture stored in the model's soil moisture and ground-water reservoirs. This algorithm is consistent with the present concept of partial catchment area runoff responses (for example, see Hewlett and Nutter, 1970) and the manner in which storm runoff occurs in humid areas. This algorithm is an adaptation of a rational storm runoff model (Betson et al, 1969) and uses three model parameters.

The yield of remaining moisture to the ground-water reservoir in the model is made in proportion to the yield of storm runoff. This algorithmic definition uses only one parameter.

There is one remaining basic model parameter. It allocates the portion of storm runoff that will occur on the day of the storm. One of these model parameters is used to assure continuity during model calibration. This parameter is not optimized per se; rather it is determined continuously during optimization to be a value such that the total predicted streamflow equals the observed. This latter parameter is one of those used in the storm runoff algorithm.

There are thus five basic parameters in the daily-streamflow model which must be obtained by optimization, all of which control the allocation of daily rainfall. These parameters are determined by adjusting the model to several years of continuous daily streamflow and rainfall using the Pattern Search Optimization Technique (Wilde, 1964). Typically, four years of continuous data can be analyzed on an IBM 360/50 computer to obtain parameter values in less than 30 minutes of computer time. In addition to the basic parameters, there are a series of constants and descriptors used by the model. These involve such measures as conventional flow recession constants, interception constants, percent of the area impervious (for urban studies), and phenological phasing measures, all of which can be obtained from existing data or by using estimated values which can be improved based upon the results obtained.

The input data used to calibrate the model consist of mean daily streamflow, daily precipitation, and monthly evapotranspiration. Because of a general lack of actual evapotranspiration data, land-pan evaporation is used in the model. Long-term monthly pan evaporation is modified by a growth index factor (Glymph et al, 1971) which is the ratio of current evapotranspiration to that at plant maturity, and the annual summation is they adjusted with a factor to equal long-term watershed loss. This factor is then applied to monthly observed evaporation data. The technique was described in a paper by Betson (1973). Using no parameters it does adjust evapotranspiration for land use in the watershed, allow for monthly variations from year to year, and assure that long-term evapotranspiration will approximate the expected watershed losses.

There are a variety of uses for a continuous streamflow model on watersheds where data are available even when it is short-term data. A study that was conducted on an urbanizing watershed in west Knoxville illustrates some of the potential planning applications. During the winter of 1973, two large floods occurred in the urbanizing 41 km^2 Ten Mile Creek catchment. What made these floods a problem was the fact that the floodwaters exceeded the capacity of the sinkholes into which they drain, forming a sizable lake that inundated a pumping plant. A question arose as to the effect that further urbanization will ultimately have on the stream.

The only stream gage data available on the stream were collected for three years in the early 1940's, when the area was rural. The TVA continuous streamflow model was adjusted to these data. It was found that far more flow was observed at the site than would be expected from the topographic divide for the drainage area above the gage (34.7 km^2). This indicated that the geologic drainage area, due to the carbonate rocks and subterranean solution channels present, was larger than the topographic drainage area and it was estimated to be 63.7 km^2. Figure 2 shows predicted and observed flows for 1944 using this adjusted drainage area.

Using aerial photographs and Knoxville Planning Commission urbanization projections, the present and planned percent of the area impervious was determined both within and outside the watershed (in the assumed contributing area). Twenty-five year daily-flow simulations were then made for rural, present, and future conditions using a stochastic rainfall generator (Wyrick, 1974). Figure 3 shows the simulated effect of urbanization on the flow duration relationship. The results indicate that urbanization will ultimately result in reduced flows ranging from some 0.05 m^3/sec at low flows to 0.11 m^3/sec at moderate flows. The reason, of course, is because increased imperviousness causes higher flood flows and results in lower soil moisture and ground-water storage. Figure 4 shows the simulated effect of urbanization on flood flows. There will be a very significant increased incidence of future flooding as a result of urbanization. The magnitude of the 100-year daily flow, however, will be increased only slightly.

The parameters for the daily-streamflow model have each been graphically related to various meteorologic or watershed measures although at this point the relationships are preliminary since the model has been calibrated at only a limited number of watersheds (TVA, 1972a). Still, they do permit prediction of the model parameters at locations where the model has not been calibrated. As a consequence the model can be used at locations where no data are available.

To illustrate the kinds of results that can be obtained at ungaged watersheds, two water years of observed and simulated daily flows for the 287 km^2 Caney Fork in middle Tennessee are shown in Figure 5. This watershed is about 130 km west of Knoxville, Tennessee, in the Cumberland Plateau physiographic province (Fenneman, 1938), an area of shallow sandy soils underlain by sandstone and shale rocks. The model had not been previously calibrated with data from a watershed in this province. This example is an actual test of model to simulate flows in this physiographic province, since the model is to be used at a nearby ungaged watershed to simulate flows in connection with a study to determine the effectiveness of a reclamation program in improving the quality of water from an area that had been strip mined. The simulations shown on Figure 5 were based upon predicted model parameters and the observed streamflow did not influence the simulations nor was the watershed ever visited. Observed rainfall was used for these simulations, however. The correlation coefficient for the two years was 0.87, and the simulated runoff was within 3 percent of the observed runoff of 146.8 watershed-cm.

Each time the model is calibrated using data from an additional watershed, flows are first simulated using estimated model parameters. The purpose is to test this simulation capability and at the same time check for errors in input data and problems the parameter estimates. Table 1 shows the results obtained for the first two years simulated on each of five watersheds as reported by Betson (1974). The Caney Fork results are also shown.

Buffalo Creek is an agricultural area, 32 percent forested, 25.7 km^2 in size, about 24 km north of Knoxville. The watershed is in the Valley and Ridge physiographic province which has many areas underlain by carbonate rocks. There are sinkholes in the lower portion of Buffalo Creek watershed. The effective drainage area was therefore reduced to 20.3 km^2 to account for lost drainage bypassing the gage. For the two years simulated, the correlation coefficient was 0.83.

The second watershed shown in the table is also in the Valley and Ridge physiographic province. Sewee Creek near Decatur, Tennessee, is about 100 km southwest of Knoxville, and the watershed is a larger agricultural area with 46 percent forest. The correlation coefficient obtained for the two years simulated was 0.83.

The third set of simulations shown in Table 1, that for the Tellico River located about 75 km south of Knoxville, is partially in the Valley and Ridge

TABLE 1

OBSERVED VERSUS SIMULATED MONTHLY FLOWS

All Values Are Watershed Inches

Year		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Buffalo Creek near Norris, Tennessee (9.92 sq miles [25.7 km^2], 82 percent forest)														
1948	O	.11	.27	.69	1.20	8.22	4.33	1.10	.26	.11	.46	.23	.08	17.08
	S	.11	.47	1.05	2.25	7.16	5.32	2.23	.33	.02	.35	.09	.01	19.39
1949	O	.10	3.69	4.44	7.14	2.84	2.46	1.07	.50	.26	.96	.22	.11	23.78
	S	.09	4.09	6.17	7.88	3.79	3.00	1.97	1.12	.17	.62	.19	.01	29.09
Sewee Creek near Decatur, Tennessee (114 sq miles [295 km^2], 46 percent forest)														
1964	O	.20	.36	.47	2.97	3.15	5.21	4.71	1.62	.46	.53	.71	.24	20.62
	S	.01	.17	.53	1.64	2.51	4.99	5.78	2.13	.24	.10	.16	.05	18.32
1965	O	.42	.54	1.98	2.07	2.13	7.95	3.56	.87	1.16	1.30	.40	.33	22.71
	S	.24	.38	2.04	2.65	2.19	7.42	5.55	1.33	1.25	1.12	.19	.06	24.40
Tellico River near Vonore, Tennessee (271 sq miles [702 km^2], 75 percent forest)														
1949	O	.32	3.67	4.48	6.03	4.01	2.80	3.33	2.19	1.25	3.61	1.46	1.47	34.63
	S	.22	2.13	6.91	7.38	3.63	2.93	3.56	2.25	.71	1.66	1.35	1.47	34.20
1950	O	1.72	2.60	2.63	5.96	4.61	5.95	2.08	1.70	3.08	1.33	0.88	0.83	33.37
	S	1.92	2.94	2.39	5.69	6.47	5.79	1.73	1.65	1.74	2.24	1.51	1.00	35.07
Caney Fork near Clifty, Tennessee (111 sq miles [287 km^2], 74 percent forest)														
1945	O	.52	.84	3.72	4.38	6.17	3.82	3.17	5.54	.38	.78	.31	.03	29.67
	S	2.28	.63	1.89	4.21	5.62	3.22	3.50	4.14	1.10	1.18	.48	.09	28.33
1946	O	.05	2.23	5.04	6.43	5.38	3.02	2.28	2.14	1.29	.09	.01	.14	28.12
	S	.30	1.54	5.10	6.04	5.51	2.67	2.63	1.35	2.19	.10	.04	.26	27.76
Calfkiller River near Sparta, Tennessee (175 sq miles [453 km^2], 75 percent forest)														
1964	O	.16	.17	.17	2.11	3.18	6.51	6.46	1.46	.60	.58	.69	.73	22.71
	S	.08	.18	.46	2.09	2.95	5.90	6.51	2.63	1.52	.76	.66	.55	24.49
1965	O	1.47	1.98	5.12	4.20	2.75	7.80	4.63	1.75	1.65	2.74	.53	.43	35.04
	S	1.48	1.49	4.83	4.04	1.80	5.69	5.60	1.90	2.94	2.13	1.28	.77	33.94

physiographic province, but the upper half of the area is in the mountainous Blue Ridge province. The upper portions of this watershed reach an elevation of some 1500 m. The model had been calibrated on only one watershed in the Blue Ridge province. The simulated results shown in Table 1 were obtained using two rain gages, one near the stream gage at an elevation of 239 m and the other on a mountain knob at an elevation of 1400 m. The daily-flow correlation coefficient for the two years was 0.79.

The remaining watershed shown in Table 1, that for Calfkiller River near Sparta, is located about 140 km west of Knoxville in the Highland Rim province, an area underlain by carbonate rock. The model had not been previously calibrated on a stream in this physiographic province and in fact the nearest stream to which the model had been previously calibrated was some 145 km away. The correlation coefficient for the two years shown was 0.82.

The results shown on Figure 5 and in Table 1 indicate that streamflow can be simulated at ungaged watersheds of varying sizes once the model is regionalized. Although these results were obtained using preliminary relationships between model parameters and watershed characteristics, as additional calibrations are made these results will improve. The spin-off from regional modeling therefore lies in the fact that each time a simulation is made or the model calibrated, the experience gained improves future results. In effect, data are converted to knowledge through models.

Mineral Water-Quality Model--A nonpoint source mineral water-quality model has been developed for natural areas in the Tennessee Valley (Betson and McMaster, 1974). Natural areas are defined as having normal land-use practices but without any known significant sources of pollution. This regionalized model is also first generation since it was developed using only published data.

The basis for the model is a rating curve between constituent concentration and streamflow. This approach has been used for some time with suspended sediment; for example, see Campbell and Bauder (1940) or Leopold and Maddock (1953). It has also been used for other water-quality constituents; for example, see Durum (1953) and Ledbetter and Gloyna (1964). Gunnerson examined dissolved load relationships for 99 stations throughout the United States using an inverse hyperbolic function and Walling (1971) developed curves for a number of solutes.

Generally these ratings have been of the form:

$$\text{Conc} = a\,Q^b \qquad \text{Equation 1}$$

where: Conc is the constituent concentration
Q is streamflow
a and b are coefficients

Constituent rating curves developed using Equation 1 would not be applicable at other locations on the same stream since, in general, flow is proportional to drainage area. A steady-state rating curve applicable to various locations on a stream can be obtained by dividing the discharge by the drainage area as was done by Campbell and Caddie (1963).

$$\text{Conc} = a\left(\frac{Q}{DA}\right)^b \qquad \text{Equation 2}$$

The two coefficients in Equation 2 will vary from watershed to watershed as a function of land use, soils, the quality of rainfall, and other factors. Data for most of these are not generally available. As a matter of fact, about the only continuously mapped data that are generally available for use in models are topography, geology, and percent forest (from topographic maps). Solute transport has not been found to be directly related to topography, but it has been found to be related to geology and percent forest. For example, studies by Hack (1960) in Virginia, Miller (1961) in New Mexico, and Pasternack (1963) in Poland indicate that solute dynamics vary among rock types. And several studies have shown, Tamm (1953), for example, that the movement of solutes from a watershed is affected by forest vegetation.

An equation for predicting the two coefficients in Equation 2 was devised using as independent variables measures of the forest and geology present:

$$a, b = N_1F + N_2C + N_3S + N_4I + N_5U \qquad \text{Equation 3}$$

where: a, b are the two coefficients in Equation 2
$N_1 \cdots N_5$ are regression coefficients
F is the fraction of the watershed area that is forested
C is the drainage area fraction underlain by carbonate rock
S is the drainage area fraction underlain by shale-sandstone rock
I is the drainage area fraction underlain by igneous rock
U is the drainage area fraction underlain by unconsolidated rock

The four geologic independent variables simply allocate the drainage area among the rock types present and must sum to one.

A total of 66 watersheds across the Tennessee Valley was selected for calibrating the model from published data (TVA, 1972b). At least 10 sets of concurrent flow (daily or instantaneous) and quality data had to be available and no significant upstream pollution could be present. Equation 2 was evaluated for 15 standard mineral constituents or measures. A total of 880 separate regression analyses was ultimately made. Equation 3 was next evaluated using as dependent variables the two coefficients in Equation 2. Table 2 shows the resulting coefficient prediction equations. To use these equations the flow in Equation 2 must be expressed in cubic feet per second per square mile.

The equations in Table 2 were tested on a group of watersheds not used in calibrating the model because there was an insufficient number of samples available. Two watersheds were selected in each of the six physiographic provinces in the Valley. The geomorphologic conditions range from the Blue Ridge province in the eastern Valley with up to 200 cm of precipitation annually to the Mississippi Embayment province on the west, an area of low hills underlain by deep unconsolidated material and rainfall averaging 125 cm. Constituent concentrations for the sample taken at the highest and lowest flow were simulated with the model. These were actual samples that had been taken some 5 to 15 years ago.

To obtain some idea of the confidence with which the mineral constituents can be simulated with the equations, the absolute error for each simulation was summed and averaged. Expressed as a percent of the average observed value for each constituent, it was found that average prediction errors of some $\pm$30 percent should be possible for silica, calcium, bicarbonate, total dissolved solids, hardness, and specific conductance, with errors of $\pm$10 percent for pH (see Rainwater and Thatcher, 1960, for definitions). Average errors will be in the $\pm$40 to 50 percent range for sodium, potassium, sulfate, and chloride, and in the $\pm$50 to 60 percent range for magnesium. For iron, which is affected by erosion and chemical buffering, and nitrate and color, both of which are affected by biologic processes, the average error will be some $\pm$100 percent. In general, these results are within the range of variability of the observed data on the watersheds.

The test results obtained are indicative of the results that can be expected at unsampled watersheds. In addition to simulating concentrations at

TABLE 2

TVA MINERAL QUALITY MODEL--

REGRESSION WITH FOREST AND GEOLOGIC VARIABLES

		N	Percent Forest	Regression Coefficients C	S	I	U	Statistics R	Sd	F
SiO_2	a	64	-1.26	5.42	6.78	10.2	8.95	.64	1.6[illegible]	8.1[illegible]
	b		-.135	.051	.099	0	-.029	.40	0.114	2.2[illegible]
Fe	a	29	.035	.020	-.009	-.008	.387	.95	0.004	42.2[illegible]
	b		-.173	.272	.104	-.125	.397	.38	.432	.80
Ca	a	66	-8.52	53.9	13.4	8.32	8.41	.85	9.0	31.4[illegible]
	b		.064	-.116	-.203	-.229	-.005	.32	0.153	1.3[illegible]
Mg	a	66	-2.81	11.4	3.41	3.05	2.45	.75	2.62	15.5[illegible]
	b		-.148	-.145	-.074	-.104	.513	.67	0.197	9.9[illegible]
Na	a	44	-1.79	2.23	2.84	3.00	3.74	.74	0.50	9.45
	b		-.318	.079	.122	.110	-.007	.48	0.138	2.3[illegible]
K	a	44	-1.08	2.51	1.94	1.58	1.80	.72	0.47	8.1[illegible]
	b		-.152	-.195	-.061	.033	-.158	.20	0.254	.3[illegible]
HCO_3	a	66	-22.8	200.	35.3	26.8	21.8	.86	32.1	34.3[illegible]
	b		.110	-.156	-.294	-.355	-.139	.35	0.132	1.7[illegible]
SO_4	a	66	-7.41	9.15	12.5	7.90	9.56	.39	5.35	2.19
	b		-.302	.103	.155	.272	.592	.49	0.274	3.69
Cl	a	66	-1.86	3.21	2.95	2.58	3.81	.60	0.93	6.6[illegible]
	b		-.171	.010	.088	.099	.067	.24	0.14	.72*
NO_3	a	63	-1.13	3.52	1.02	1.30	.84	.80	0.71	20.11
	b		-.70	.262	.899	1.063	.297	.26	0.671	.84*
TDS	a	66	-39.0	195.6	68.5	55.5	57.7	.84	30.6	28.42
	b		.016	-.094	-.146	-.142	0	.26	0.14	.38*
$CaCO_3$	a	66	-33.4	182.8	48.1	34.3	31.5	.86	29.3	33.06
	b		.033	-.150	-.176	-.222	.131	.49	.151	3.78
Spec. Cond.	a	46	-145.	357.	180.	142.	128.	.88	54.	26.74
	b		-.015	-.078	-.134	-.095	.051	.43	0.106	1.62*
pH	a	65	-.573	8.37	7.32	7.33	6.86	.73	0.42	13.53
	b		-.003	-.010	-.003	-.013	-.003	.16	0.021	.32*
Color	a	63	-1.79	2.50	9.17	9.75	10.8	.23	8.65	.62*
	b		-.376	.211	.339	.204	.448	.32	.364	1.26*

***Not significant at 0.9 level.**

unsampled sites, there are a series of other potential applications such as simulating concentrations below pollution sources where no prepollution samples were taken with which to assess pollution impacts. Several examples are presented in the paper by Betson and McMaster (1974).

Equation 2 is the water-quality algorithm used in the continuous daily-streamflow model for applications where continuous daily constituent transports are needed. Since both models can be applied at unmeasured sites, some interesting applications become possible. An example will be presented where the model was used to simulate the total dissolved solid (TDS) load in a reservoir.

The TDS concentrations have been found to be a primary variable in explaining biologic productivity among TVA reservoirs. To test the capability of the hydrologic models to simulate TDS transport, a test was made at Melton Hill Reservoir on the Clinch River. Although most of the TDS load originates at the upstream Norris Dam (7542 km^2), simulations for the 1094 km^2 local area were expected to illustrate the capabilities and provide a degree of verification (McCarthy et al, 1974).

The continuous daily-streamflow model was calibrated on a 174 km^2 watershed within the local area. It was assumed that the calibration model parameters would apply for the entire area because most of it is similar physiographically and the time of travel for tributary streams would be similar. Adjustments were made in the model to account for the larger drainage area. The two parameters in the water-quality model for TDS were predicted using geology and forest covers for the entire local area.

At Norris Dam a relationship was developed between daily flow and TDS using 25 available samples. Below Melton Hill Dam only seven samples were available with which to develop the relationship. Using these relationships daily TDS loads were determined using observed discharges for 1967. The flow model was used to simulate local area contributions.

For the year the sum of the observed flows at Norris Dam added to the sum of the simulated local inflows was within 3 percent of the observed flows at Melton Hill Dam. This is well within the accuracy of the turbine and sluice ratings used to measure flows through the dams. The simulated TDS loads for Norris Dam added to the simulated local area contributions were within 8 percent of the loads simulated for Melton Hill Dam. A check within 8 percent constitutes verification and is well within the accuracy needed for estimating biologic productivity.

However, since only seven samples were available for determining the relationships between flow and concentration at Melton Hill Dam, a further check was made. Using 58 samples that were taken at a site 18 miles downstream from Melton Hill Dam, another relationship between flow and concentration was developed. This latter relationship indicated that because of the paucity of data at Melton Hill Dam, the sum of the simulated loads for Norris Dam and the local area are probably closer to reality than were the simulations made at the dam that were used for verification.

Storm-Hydrograph Model--The third model in the system of watershed models is a storm-hydrograph model (TVA, 1973b, and Ardis, 1973). This model is based upon the unit-hydrograph principle (Sherman, 1932), but it does have some major differences.

The TVA storm-hydrograph model uses, in effect, a double triangle to represent a unit hydrograph as shown in Figure 6. The model has four parameters, the three time parameters T1, T2, and T3 and the unit hydrograph peak parameter UP. The ordinate at the inflection point, UR, is determined so that the area bounded by the function is unity.

The model was adjusted to 140 storm hydrographs on 11 catchments in the Tennessee Valley ranging in size from 12.2 km^2 to 43.5 km^2 and from the mountains in western North Carolina to the Mississippi Embayment in west Tennessee. Figure 7 shows an average adjustment of the model to a storm hydrograph, in this case from a 37.3 km^2 mountainous watershed located in western North Carolina. The range in parameter values obtained from these analyses was considerable. Next the parameters were related to meteorological and watershed measures using an equation of the form:

$$PAR = WF(1) * PE^{WF(2)} * NPE^{WF(3)} \qquad \text{Equation 4}$$

where: PAR is a model parameter
PE is precipitation excess, or storm runoff
NPE is the storm duration
WF(1), WF(2), and WF(3) are watershed factors

The watershed factors are a function of a possible eight watershed characteristics in a product form:

$$WF(I) = C1 * A^{C2} * Sc^{C3} * Sh^{C4} * W^{C5} * DD^{C6} * Si^{C7} * So^{C8} * Ti^{C9} \qquad \text{Equation 5}$$

where: A is the drainage area

Sc is the channel slope

Sh is the main stream channel length squared, divided by the area

W is the percent forest present

DD is the drainage density

Si is a measure of sinuosity or main stream channel length measured in 1.61 km (1 mile) chords divided by the main stream length

So is a surrogate measure of the effect of watershed soils on streamflow, defined as the streamflow exceeded 70 percent of the time

Ti is a measure of main channel flow time through the watershed and is the length of the main channel divided by the square root of the channel slope

C1 - C9 are coefficients

Not all of the possible eight independent variables shown in Equation 5 are used to predict each parameter. To determine the final equations, Equation 4 was first solved for each watershed, assuming WF(1), WF(2), and WF(3) to be constants. This yielded 11 values for each WF(I) for each model parameter. Next, log-transformed stepwise linear multiple regression was used to develop a prediction equation for each WF(I) to account for variation among watersheds. This step identified the significant watershed measures to be included. The coefficients for the WF(1) term were then determined using the Pattern Search Technique (Wilde, 1964), holding the WF(2) and WF(3) terms constant with values determined from the stepwise regression analyses. Finally, the coefficients for the WF(2) and WF(3) terms were determined, holding the WF(1) term to computed values. This complex solution procedure was necessary because of the nonlinear nature of the model. The final model allows for variation in the unit hydrograph shape among storms and for this relationship to vary among watersheds, a phenomenon observed by many researchers. The parameters of the model can be readily determined for ungaged watersheds.

To test the validity of the parameter-prediction equations, two storms were selected at random from each of the 11 study watersheds. The average correlation coefficient obtained was 0.94.

Two very different watersheds not used in developing the models were used to test the capability of the prediction equations for use at ungaged watersheds. Eleven storm hydrographs were simulated on one and only four on the other due to poor rainfall data. The average correlation coefficient obtained was 0.88 for the 15 events and ranged from 0.72 to 0.98. Figure 7 shows simulated storm hydrographs for the Beech River watershed. This is a 41.1 km^2 agricultural catchment located in west Tennessee, and the model had not been calibrated using data from this watershed. Figure 7 shows the best and poorest simulations obtained for 11 storms.

The TVA watershed models are designed to operate as a system. They can be used to study the effect of land-use changes upon streamflow. Land-use changes can result in complex alterations to the streamflow regime, to the flooding situation, and to water quality. These changes are difficult to quantify by conventional methodologies. One reason is because the components in the system interact and these interactions are difficult to handle when an individual component is studied. In the TVA hydrologic system models, these hydrologic interactions are handled by the system models.

The effect of system component interactions can be illustrated by an example showing the effect of forest cutting on a 36 km^2 Upper Bear Creek catchment. This is a drainage area where both the continuous daily-streamflow and the storm-hydrograph models had been calibrated. Land use on the area consisted of 85 percent forest and 15 percent pasture. For the illustration it was assumed that these land-use percentages were reversed, i.e., 85 percent pasture and 15 percent forest. The effect of such a land-use change on daily streamflow would be far from constant. During the late winter and spring when soil moisture is high, the differences to daily streamflow would be slight. During the late summer and fall, however, when potential evapotranspiration is higher than rainfall, periods of plant moisture stress develop under pasture cover in the permeable sandy soils present. Evapotranspiration under a forest cover remains relatively high because of the deeper root system so that under forest cover during the fall and early winter there is less moisture in the soil. Consequently under the forest cover there is a delay in the buildup in soil moisture that causes the typical high runoff yield winter storms.

Simulations with the continuous daily-streamflow model were made for both land-use conditions at the catchment. A large storm that occurred during the critical late fall, early winter was selected to demonstrate the maximum effect that this land-use change could have on streamflow. The storm occurred on December 22, 1968, with a rainfall of 6.78 cm and storm runoff of 2.57 cm. The volume simulated for this storm with the continuous streamflow model under existing land-use conditions was 2.49 cm. Figure 8 shows the observed storm hydrograph along with that simulated by the storm-hydrograph model using the 2.49 cm simulated volume from the daily-streamflow model. Under the condition of 85 percent pasture and 15 percent forest, the continuous daily-streamflow model simulated a storm runoff volume of 4.27 cm, an increase of 71 percent. But this land-use change would also result in changes to the shape of the storm hydrograph which can be accounted for by the storm-hydrograph model. Figure 7 shows that the combined effect of higher runoff volumes along with a more flashy hydrograph results in a flood peak over 2-1/2 times that under existing conditions.

This example illustrates how complex interrelationships between land use and streamflow can be studied with hydrologic models. Complex changes to water-quality constituent transport resulting from changes to both land use and the flow regime could also have been simulated. In fact, far more information can be readily generated using the models than it is possible to use in planning.

The results obtained with the hydrologic system models, such as in the examples presented, particularly those involving land-use changes, are not easily verified. It is not usually practical to actually alter land use except on research watersheds. The results can be checked in a qualitative manner since they must be reasonable. The use of models, however, does help to understand the complex effect of land-use changes upon the hydrology of a watershed. They also help to identify components in the hydrologic system where additional knowledge is needed. For example, the paper by Betson (1973) explores evapotranspiration information needs from the viewpoint of hydrologic modeling. As the results from research studies become available, they can be brought to bear on problems through the hydrologic models.

Conclusions

Three hydrologic system models have been presented. They are first-generation models designed to be readily regionalized and applied using only published data. They can be and have been used in the Tennessee Valley for a variety of applications involving land-use planning. Since the models are parametric, their reliability increases as additional model calibrations are made. Thus through the models maximum use is made of existing data and the results from research watersheds to provide information at locations and under conditions where data are lacking.

The capabilities of these models need to be extended. The continuous daily-flow model must be calibrated to data from watersheds with a range of features. The water-quality modeling capabilities must be extended to include additional constituents. And the storm-hydrograph model must be extended to include a greater range of drainage areas and the effect of urbanization. However, these additional capabilities can be developed without additional research effort by using existing data.

Ultimately these watershed models will be linked with aquatic biological productivity models currently under development in TVA. When this is accomplished, the capability will exist to perform detailed studies of the environmental impact resulting from land-use changes.

REFERENCES

Ardis, C. V., "A Double-Triangle Model for Generating Storm Hydrographs," Presented at the First World Congress on Water Resources, Sponsored by Int. Water Res. Assn., Chicago, Illinois, September 1973.

Betson, R. P., "Upper Bear Creek Experimental Watershed, Research in Hydrologic Analysis - Synthesis," Int. Assn. Sc. Hyd., Pub. No. 66, Symposium of Budapest, pp. 178-184, 1965.

Betson, R. P., R. L. Tucker, and F. M. Haller, "Using Analytic Methods to Develop a Surface-Runoff Model," Water Resources Research V5 N1, February 1969.

Betson, R. P., "Evapotranspiration Information Needs from the Viewpoint of Hydrologic Models," Presented at the Fall Annual Amer. Geophysical Union Meeting, San Francisco, California, December 1973.

Betson, R. P., "First-Generation Models for Water Quantity and Quality," Presented at an Amer. Soc. Civil Engrs. Irrigation and Drainage Speciality Conference, Biloxi, Mississippi, August 1974.

Betson, R. P. and W. M. McMaster, "A First-Generation Nonpoint Source Mineral Water-Quality Model," 47th Annual Meeting, Water Poll. Cont. Fed., Denver, Colorado, October 1974.

Campbell, F. B. and H. A. Bauder, "A Rating Curve Method for Determining the Silt Discharge of Streams," Trans. AGU 21, 603-7, 1940.

Campbell, A. P. and G. H. Caddie, "Erosion Rate Coefficients for Some New Zealand Catchments," J. Hyd. (N.Z.) 2, 1963.

Crawford, N. H. and R. K. Linsley, "Digital Simulation in Hydrology - Stanford Watershed Model IV," Stanford University Dept. of Civil Engg. Tech Rept. No. 39, 1966.

Durum, W. H., "Relationship of the Mineral Constituents in Solution to Streamflow, Saline River near Russell, Kansas," Trans. Amer. Geophy. Union 34, 435-42, 1953.

Fenneman, N. M., "Physiography of Eastern United States," McGraw Hill, New York, 1938.

Glymph, L. M., H. N. Holtan, and C. B. England, "Hydrologic Response of Watersheds to Land Use Management," ASCE Jour. of Irr. and Drainage No. IR2, June 1971.

Gunnerson, C. G., "Streamflow and Quality in the Columbia River Basin," J. ASCE San. Eng. Div. (93) SA6, 1967.

Haan, C. T., "Characterization of Water Movement Into and Through Soils During and After Rainstorms," Univ. of Kentucky Research Rept. No. 56, 1972.

Hack, J. T., "Relation of Solution Features to Chemical Character of Water in the Shenandoah Valley, Virginia," U.S. Geol. Surv. Prof. Paper 400B, 1960.

Hewlett, J. D. and W. L. Nutter, "The Varying Source Area of Streamflow from Upland Basins," Proc. of a Symposium on Interdisciplinary Aspects of Watershed Management, pub. by Amer. Soc. Civil Engrs., August 1970.

Holtan, H. N. and N. C. Lopez, "USDAHL-70 Model of Watershed Hydrology," U.S. Dept. of Ag. Agricultural Res. Service, Technical Bull. No. 1435, November 1971.

Ledbetter, J. E. and E. F. Gloyna, "Predictive Techniques for Water Quality Inorganics," ASCE J. San Engr. Div (90) SA1, February 1964.

Leopold, L. B. and T. Maddock, "The Hydraulic Geometry of Stream Channels and Some Physiographic Implications," U.S. Geol. Surv. Prof. Paper No. 252 (56 pp.), 1953.

McCarthy, M. M., R. C. Durfee, H. H. Shugart, C. W. Craven, Jr., R. Strand, R. Betson, T. L. Cox, J. A. Holbrook, R. B. Honea, D. Huff, W. C. Johnson, M. Mills, R. K. Screiber, D. H. Sharpe, T. C. Tucker, and C. W. Voightlander, "Regional Environmental Systems Analysis: An Approach for Management," Presented at First International Congress of Ecology, Hague, Net., September 9-13, 1974.

Miller, J. P., "Solutes in Small Streams Draining Single Rock Types, Sangre de Cristo Range New Mexico," U.S. Geol. Surv. Water Supply Paper 1535F, 1961.

Nash, J. E., "The Role of Parametric Hydrology," Jour. of the Institute of Water Engineers, vol. 21, pp. 435-474, 1967.

Pasternak, K., "Sklad Chemiczny Wody Rzek i Potokow o Zlewniach Zbudowanych z Roznych Skal i Gleb," Acta Hydrobiol. 10, 1963.

Rainwater, F. H. and L. L. Thatcher, "Methods for Collection and Analysis of Water Samples," U.S. Geol. Surv. Water Supply Paper 1454, 1960.

Sherman, L. K., "Streamflow from Rainfall by the Unit-Graph Method," Engg. News - Rec. vol. 108, pp. 501-505, April 7, 1932.

Snyder, W. M., "The Parametric Approach to Watershed Modeling," Nordic Hydrology 2, 1971.

Tamm, C. O., "Growth Yield and Nutrition in Carpets of Forest Moss (Hylocomium Splendens)," Skogstorskn Inst. Stockholm Medd. 43, 1953.

Tennessee Valley Authority, "Forest Cover Improvement Influences Upon Hydrologic Characteristics of White Hollow Watershed, 1935-1958," Knoxville, Tennessee, May 1961.

Tennessee Valley Authority, "Reforestation and Erosion Control Influences Upon the Hydrology of Pine Tree Branch Watershed, 1941-1960," Knoxville, Tennessee, 1962.

Tennessee Valley Authority and North Carolina State College, "Parker Branch Research Watershed - Project Report 1953-1962," Knoxville, Tennessee, 1963.

Tennessee Valley Authority and North Carolina State University, "Watershed Research in Western North Carolina," Knoxville, Tennessee, June 1970.

Tennessee Valley Authority, "A Continuous Daily-Streamflow Model," Research Paper No. 8, Knoxville, Tennessee, 1972a.

Tennessee Valley Authority, "Mineral Quality of Surface Waters in the Tennessee River Basin," Hydraulic Data Branch, Knoxville, Tennessee, May 1972b.

Tennessee Valley Authority, "Summary Report on the Upper Bear Creek Experimental Project," Knoxville, Tennessee, January 1973a.

Tennessee Valley Authority, "Storm Hydrographs Using a Double-Triangle Model," Research Paper No. 9, Knoxville, Tennessee, January 1973b.

Walling, D. E., "Streamflow from Instrumented Catchments in South-east Devon," In K. J. Gregory and W. L. D. Ravenhill (eds.) Exeter Essays in Geography Exeter, G. B., 1971.

Wilde, D. J., "Optimum Seeking Methods," Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964.

Wyrick, R. G., "A Daily-Stochastic Precipitation Generator for Continuous Streamflow Models," Presented at 55th Annual Meeting, Amer. Geophysical Union, Washington, DC, April 1974.

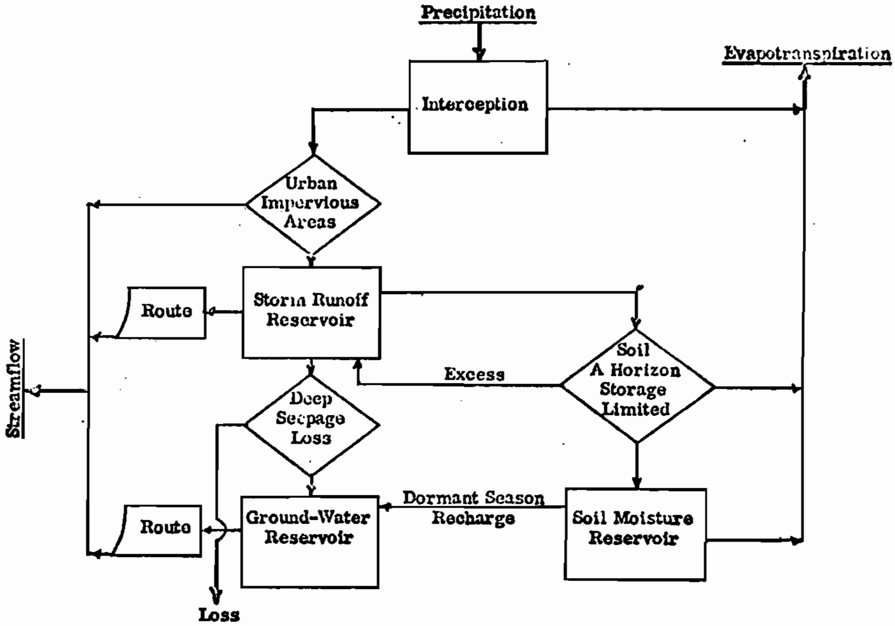


Figure 1. --SCHEMATIC DIAGRAM OF TVA CONTINUOUS DAILY-STREAMFLOW MODEL

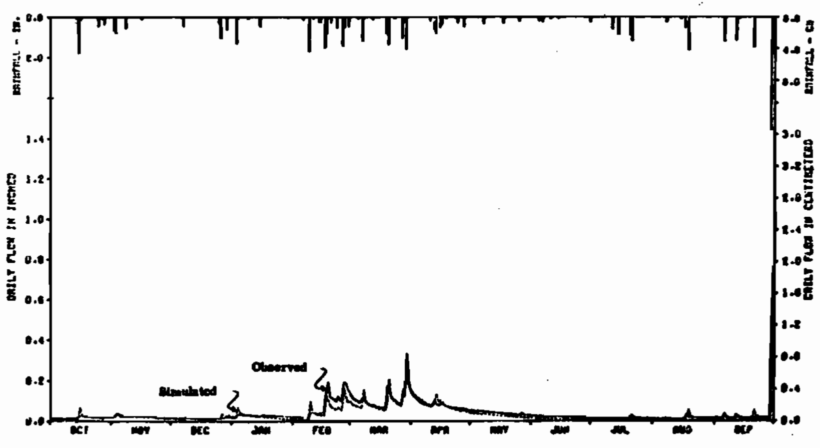


Figure 2. --CALIBRATION ADJUSTMENT OF CONTINUOUS DAILY-STREAMFLOW MODEL TO TEN MILE CREEK DATA - WATER YEAR 1943-44

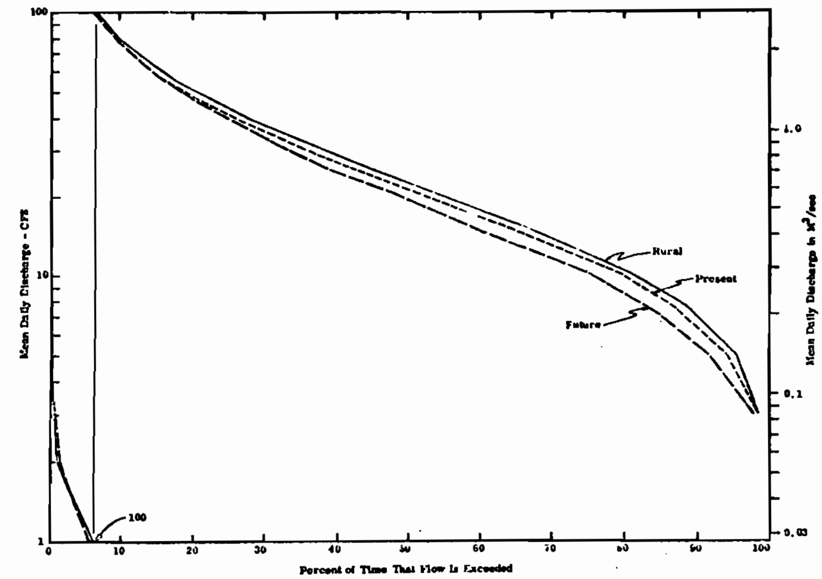


Figure 3. --TEN MILE CREEK FLOW DURATION RELATIONSHIPS BASED UPON 25-YEAR SIMULATED DAILY FLOWS

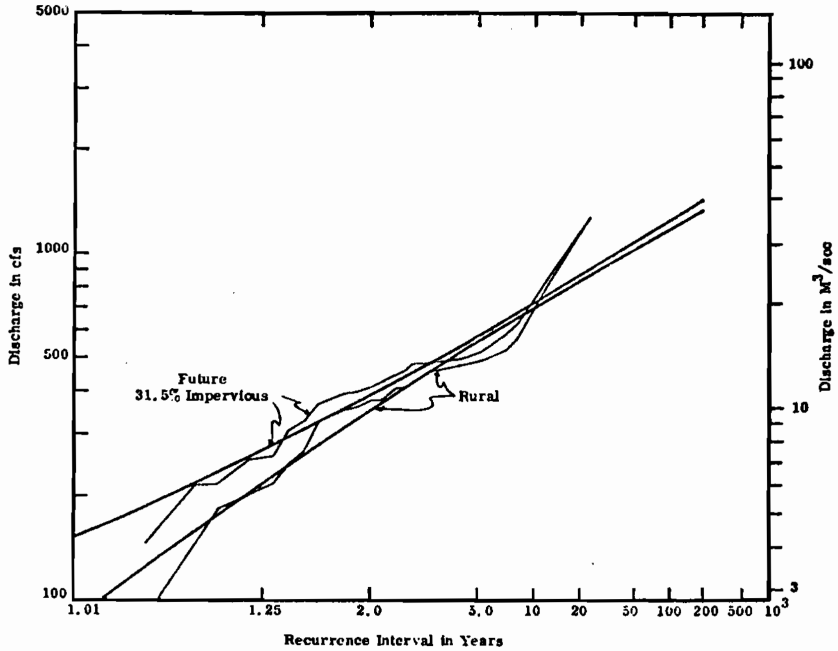


Figure 4. --TEN MILE CREEK SIMULATED MAXIMUM DAILY FLOW FREQUENCIES AND LOG PEARSON TYPE II CURVES

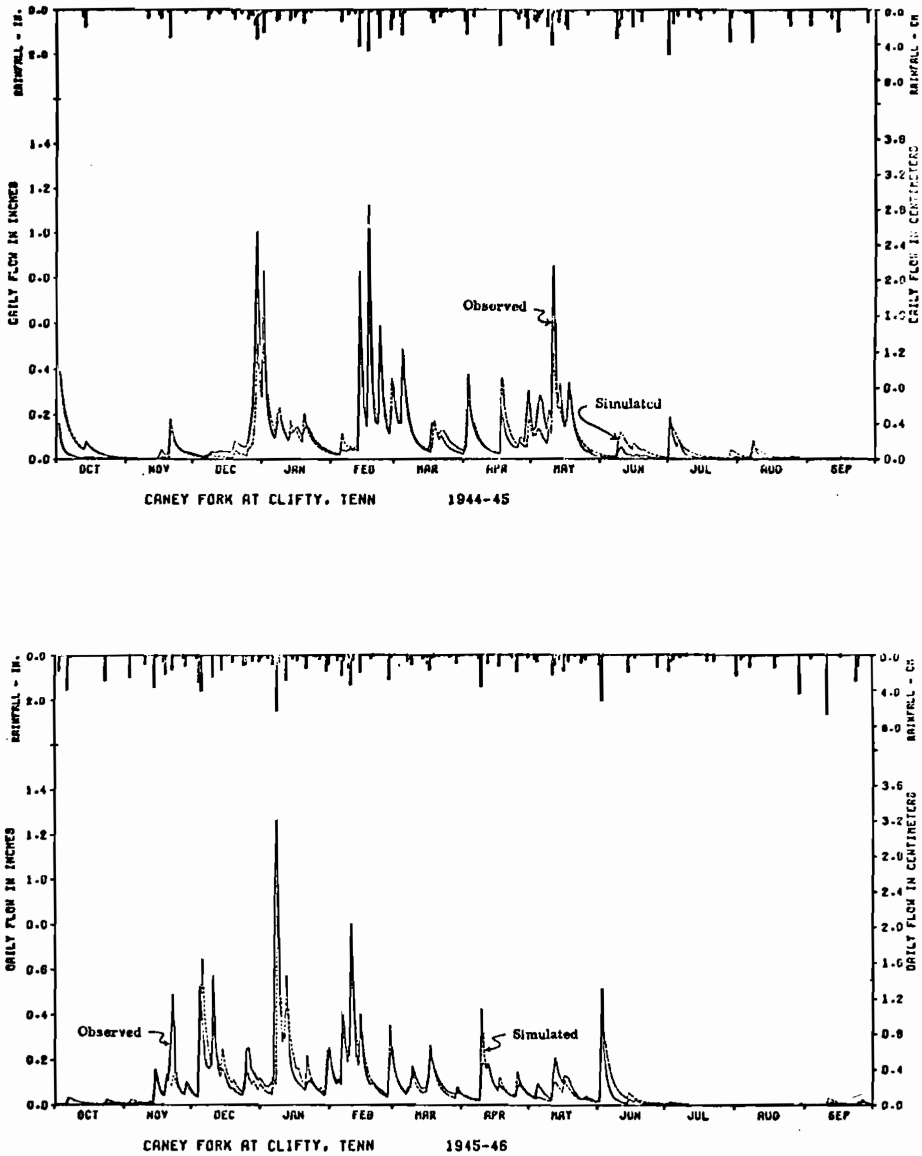


Figure 5.--OBSERVED DAILY FLOWS VS. SIMULATIONS WITH PREDICTED MODEL PARAMETERS--CANEY FORK AT CLIFTY, TENNESSEE, 1944-45 AND 1945-46

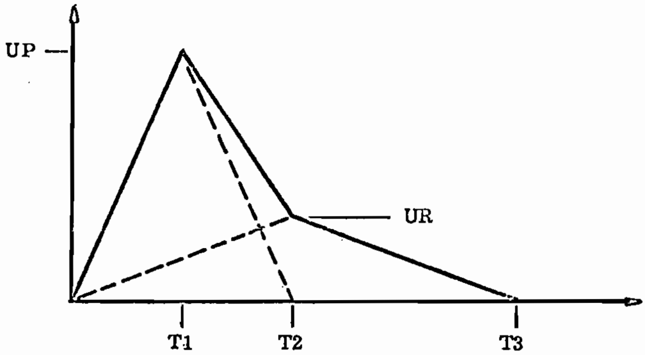


Figure 6. --DOUBLE-TRIANGLE MODEL REPRESENTATION OF UNIT HYDROGRAPH

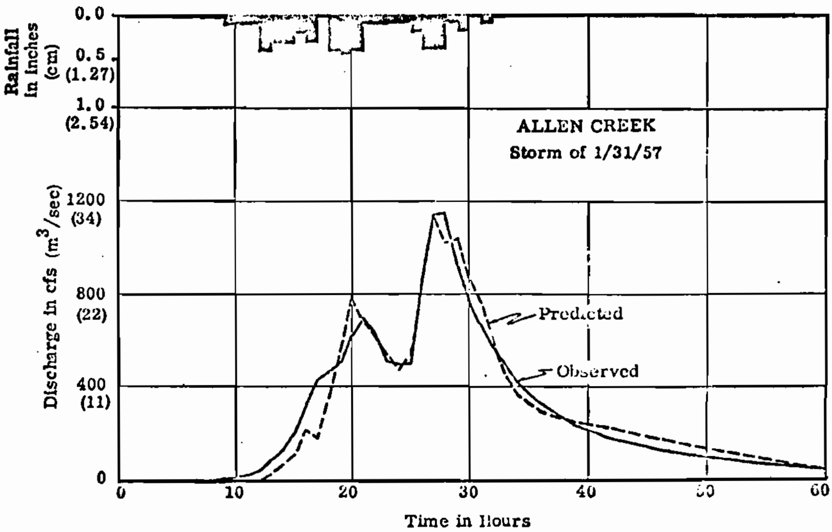
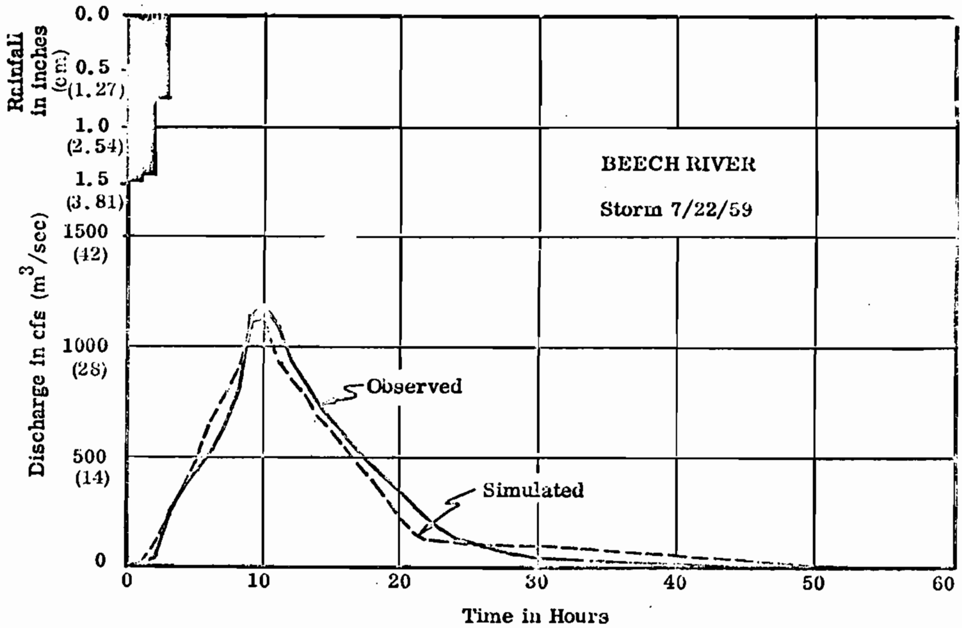


Figure 7. --AVERAGE ADJUSTMENT OF DOUBLE-TRIANGLE MODEL TO STORM HYDROGRAPH--ALLEN CREEK NR. HAZELWOOD, N. C.



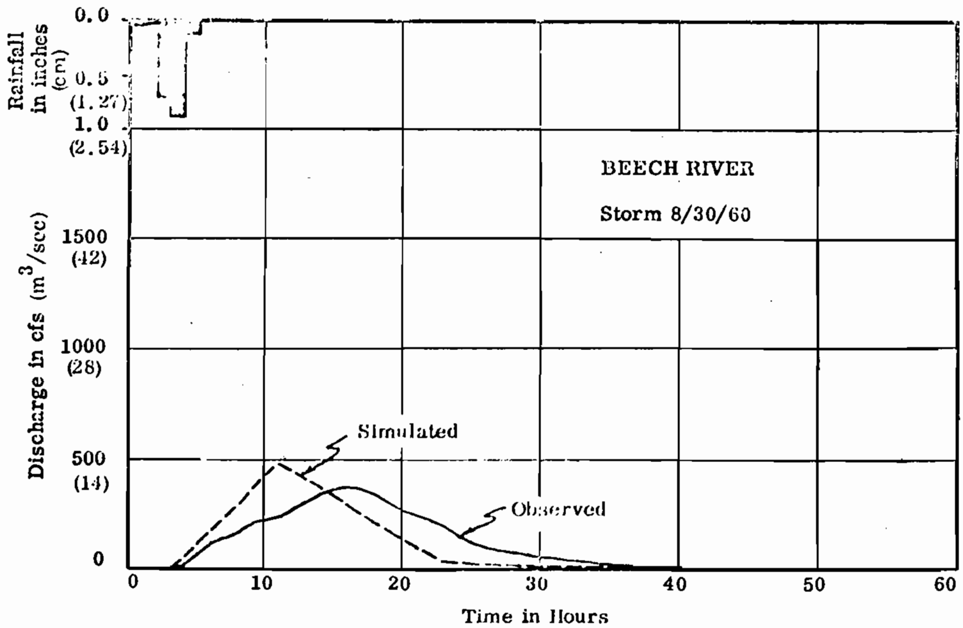


Figure 9 --OBSERVED STORM HYDROGRAPHS VS. SIMULATIONS WITH PREDICTED MODEL PARAMETERS--BEECH RIVER NR. LEXINGTON, TENNESSEE

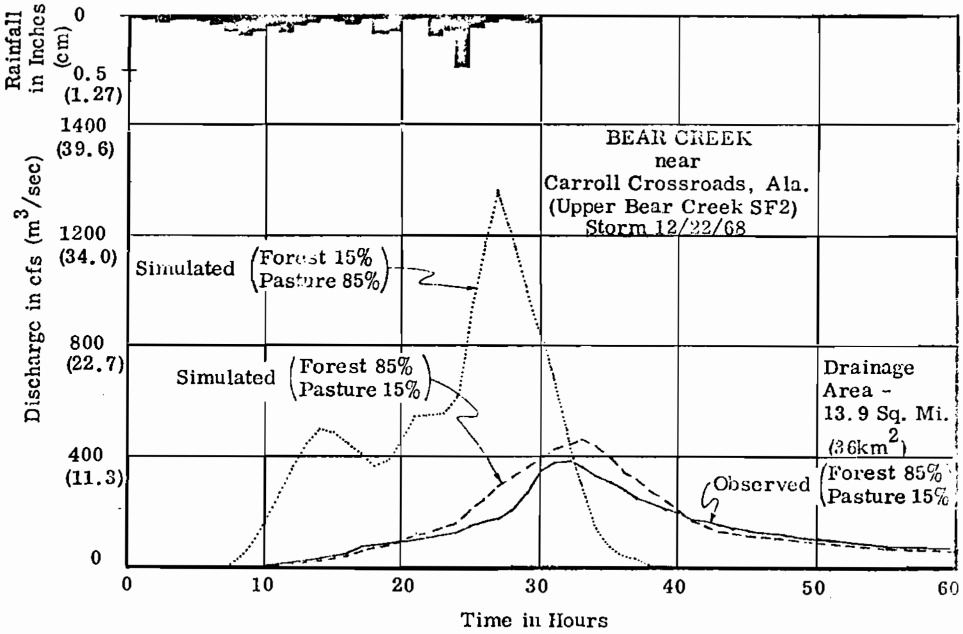


Figure 9. --SIMULATED EFFECT OF FOREST CUTTING AT BEAR CREEK WATERSHED FOR STORM OF DECEMBER 22, 1968

IIASA DISCUSSION PAPER

I. BELYAEV

The TVA controls the basins of two of the Ohio's tributaries: the Tennessee River (105,900 km^2) and the Cumberland River (46,600 km^2) where the population is about four million. Altogether, fifty-two multipurpose hydrotechnical structures are situated there. The strongest point of the TVA is that it uses computer processing of a highly developed hydrological and metheorological stations network for planning and system control. For this purpose it applies a great number of computer models. The use of these models provides the information which cannot be obtained through direct measurements.

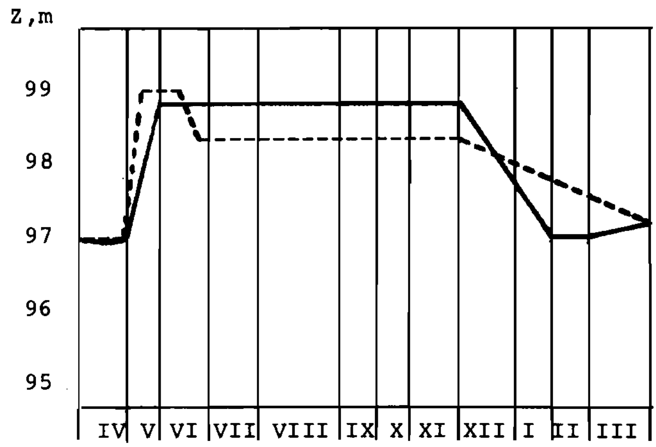
The rational use of water resources under TVA conditions essentially consists of effective seasonal regulation of runoff through the hydrotechnical structures system with the purpose of:

- flood protection,
- electric power generation,
- meeting the requirements of navigation,
- water supply for developing towns and agriculture,
- providing conditions for recreation,
- mosquito and water verdure control.

I would like to mention some interesting points of the TVA material. Detailed description of operation guide curve schedules of regulating multipurpose water reservoirs seems to be an important part of the "Management of an Integrated Water Control System," Figure 5.1 and 5.2.

For comparison I can demonstrate guide curve schedules of the Gorky reservoir in the Volga cascade (Figure 1) designed decades ago and still being investigated today with the purpose of developing the fishing industry.

It is fairly easy to see the analogy and the difference between the guide curve schedules of TVA and the above mentioned reservoir. So it is desirable that the authors should throw light upon the theoretical basis, structure and calculation order of a guide curve schedule--especially at the peak time in the middle of April. It is very interesting to know what the theoretical and biological basis of forming mosquito control fluctuations are, what the practical ways of calculating their parameters are, and, especially, the interaction of two or more reservoirs.



Operating guide curves for the Gorky storage (Volga River)

——— Projecting (designing), decades ago

------- Discussing

Figure 1.

Methods of evaluating the efficiency of a water control system are of great importance in the world water economy practice. The benefits of navigation and electrical power generation can be easily evaluated directly. Evaluating the efficiency of flood protection and the measures connected with realization and exploitation of biological systems (mosquitoes and water verdure in the Tennessee Valley, fish-breeding in the Volga) seems to be very complicated. Detailed explanation of the methodology of estimating direct and indirect losses and benefits connected with flood protection and mosquito control would be very useful and I ask authors to give this information. One of the models which is widely applied to efficient (operative) complex structures management and to land-tenure planning is the continuous daily streamflow model. The water balance equation is the basis of this model.

In the USA and in the USSR several models of this kind are known. The TVA materials show that the present computer program may be used for many engineering-hydrological calculations (computations) and for evaluation of such complicated phenomena as urbanization and intensification of agriculture. The authors could probably elaborate the mathematical expression of the model algorithm to show the mechanisms of the model parameters adaptation as new original data are received, illustrate the concrete ways of accounting the results of the program operation in managing the system and give two or three examples.

The model of water mineral quality is based on using the well-known interrelation between the contents of different (separate) components and water discharge in the river. Unfortunately, such interrelationships are not true of the rivers with a large number of mineral springs, for example, the Terek in the USSR, and of rivers with large sediment discharges. This kind of interrelation corresponds to the assumption that the change of components in the water is in proportion to a certain degree of the stream discharge

$$\frac{d(\mathrm{Conc})}{dQ} = ab\ Q^{b-1},$$

This dependence does not take into account chemical interaction and the biological structure of the stream. At the same time this model positively differs from other known models in the number of considered components (15) and the wide encompassing of geographical factors. Its practical application gives the TVA the opportunity to evaluate the changes of water chemical composition which take place in the system. The basis of a rainstorm hydrograph model is the principle of a "unit hydrograph" and the TVA took the road of applying a type hydrograph as a double triangle.

A complicated decision was used to determine the parameters and coefficients of the model (the structure of which is essentially nonlinear). The structure of decision is a combination of multiple regression methods, seeking for standards and eliminating. Perhaps, it is the most interesting procedure from the methodological point of view. The unit hydrograph models have a very wide application and, therefore, it would be very useful to listen to a more detailed explanation concerning the methodology of specifying conventionally bordering regions, the scheme of hydrograph alteration from one rainstorm to another, the procedure of parameters evaluation and model calibration.

In conclusion, I would like to emphasize that whatever questions have arisen from the TVA materials, whatever scientific arguments were carried on about the TVA models, the most important thing is that these models operate and are of use to planning and managing the complicated water economy system and provides the information which cannot be obtained through direct observation.

The TVA experience is of great value because this organization by its practical activity has proved the high efficiency of applying computer modelling to solution of the most complicated water economy problems. It gives hope that IIASA methodological developments will be widely adopted all over the world if they are aimed at creating a complex of interrelated models giving the solution of water economy problems under the conditions of developing complex economic and social systems, such as large river basins, regions and whole states.

TVA'S RESPONSE TO DISCUSSION BY I. BELYAEV

To show the theoretical basis, structure, and calculation order of a guide curve is beyond the scope of this paper. However, one can refer to TVA Technical Report No. 26 entitled "Flood Control." Chapters 7, 8, and 9 of this report give a detailed account of the basis for the development of the operating guide curves. The special question raised on the "peak" in April refers to the surcharge of levels above normal summer level on main river reservoirs. Unless the reservoirs have been filled above normal summer level in regulating winter floods, they are raised about one foot above these levels to strand floating debris on the shoreline. This aids in cleaning trash from the lake and cleans the shoreline where the summer water level is generally held.

Water level management is the most important measure used by the TVA to control mosquitoes. For a number of years, water level management alone has very satisfactorily controlled malaria mosquito production in most TVA reservoirs. Fluctuating water levels create ecological conditions unfavorable to malaria mosquito production (eggs, larvae, and pupae are stranded, destroyed, or exposed to natural enemies.) Other supplementary control measures, such as drainage, plant growth control, or larviciding, are required on some reservoirs. To accomplish the weekly cycle of fluctuations on main river reservoirs with the least disruption to the generation of power, alternate reservoirs are drawn or filled Monday through Friday and Saturday through Sunday.

The direct and indirect losses and benefits connected with flood protection and mosquito control are again beyond the scope of this paper. Again, the "Flood Control" report would explain the flood control benefits of the TVA system of reservoirs. Cumulative flood control benefits to the TVA system of reservoirs to date now total over $1.5 billion. The benefits owing to water level management for mosquito control can best be explained by the fact that there have been no cases of malaria attributed to mosquitoes bred in TVA reservoirs since water level fluctuations began.

References

Tennessee Valley Authority. "Flood and Control." Technical Report No. 26, Knoxville, Tennessee, 1961.

Tennessee Valley Authority. "Vector Control Program." Environmental Statement, Chattanooga, Tennessee, 1974.

TVA'S RESPONSE TO DISCUSSANTS' COMMENTS ON THE PAPER WATERSHED STREAMFLOW QUALITY AND QUANTITY MODELING IN TVA

Roger P. Betson*

A complete development of the mathematical expression of the TVA Continuous Daily-Streamflow Model is beyond the scope of the present paper, and it has been presented in a publication (TVA, 1972.) Perhaps the main feature that sets this model apart from many other continuous flow models is the algorithm used to apportion storm (surface) runoff. This algorithm will be presented to indicate generally how empirical expressions are used in the model.

The storm runoff algorithm for the TVA streamflow model was developed originally to be a simple parametric mathematical representation for relatively complex graphical coaxial rainfall-surface runoff relationships that were then being used in TVA's reservoir operations (Betson et al., 1969.) With some further simplification to eliminate two of the original parameters, the modified algorithm as used in the continuous streamflow model is

$$RI = (A + (D - A) * SI)e^{-B(SMI+GWR)}$$
$$SRO = (RF^2 + RI^2)^{1/2} - RI$$

where

- RI is a retention index (inches),
- A is a parameter associated with winter storms (inches),
- D is a parameter associated with summer storms (inches),
- B is a parameter used to force continuity (inches^{-1}),
- SI is a season index associated with phenological changes and is equal to one in summer and zero in winter with externally controlled phasing,
- SMI is a soil moisture index, in inches, or the amount of moisture stored in the soil moisture compartment,
- GWR is the volume of moisture, in inches, stored in the ground-water reservoir,
- SRO is the daily storm runoff to be routed (inches),
- RF is the daily rainfall minus interception (inches).

* Head, Hydrologic Research and Analysis Staff, Knoxville, Tennessee.

Mathematically the two equations allow for the yield of storm runoff to be proportional to the amount of moisture stored in the system. Conceptually, this algorithm is thus consistent with the present understanding of partial watershed area runoff responses and, more important, the manner in which storm runoff occurs in humid areas.

The structure of the two equations is designed to assure reasonable estimates of storm runoff. For large values of the retention index (dry conditions) the storm runoff will be small while for small values of the index (relative to the rainfall) the yield of storm runoff can approach 100%. The relative yields can vary among seasons because of the season index and the yields can vary among watersheds as a result of variations in the two parameters "A" and "D."

The parameter "B" in the model is determined to be a value such that the predicted total runoff for the entire period of an analysis equals the observed value. Because each parameter is capable of adjusting the predicted total runoff, the role of the parameter "B" is recomputed each time an adjustment is made to one of the other model parameters, and this is not optimized directly. However, since the amount of remaining moisture that cascades to the ground-water reservoir is proportional (as determined by an additional parameter) to the yield of storm runoff, the parameter "B" also effects the ground-water yield and thus the yield of total runoff.

The two components of flow, storm and ground-water runoff, are routed from storage components or reservoirs using conventional recession contants of the form

$$Q = RES \times (1 - K)$$

where

Q is either storm or ground-water runoff in inches,
RES is either the storm or ground-water reservoir in inches,
K is a daily recession constant.

Further details on the mechanisms of the model parameters can be found in TVA (1972).

As new information is received improvements have been made in the model. Most of these have centered around the effect of urbanization. A research project presently being concluded has disclosed several effects that are being included in the model to handle losses in potential pervious and impervious area runoff that occurs in highly soluble carbonate terrain. Although the algorithms to handle these losses are still being developed, the general approach used to modify the model when new information is received can be illustrated by describing the impervious area algorithm currently used in the model.

As originally presented (TVA, 1972) the model did not contain provisions for urbanization since all model development work had been confined to rural areas. An equation was presented by Miller and Viessman (1972) that appeared to predict the volume of impervious area runoff based upon the impervious area present

$$ISRO = 1.165 \ (IA - .17) * RF$$

where

ISRO is the impervious area storm runoff,
IA is the impervious fraction of the watershed,
RF is storm rainfall.

The applicability of the algorithm was tested using urban rainfall-runoff data available in the Tennessee Valley and was found to apply. This equation was therefore adopted directly as the urbanization algorithm in the continuous steamflow model. As such it becomes a deterministic feature since the impervious fraction of a watershed is a measurable quantity.

There have not been a large number of applications for the continuous streamflow model because it is still being developed and improved. The paper did describe an application to investigate the effects of urbanization (section on TVA Watershed Models) and to provide simulated flows in a study to determine the effectiveness of strip-mine reclamation on water quality. The model has also been used, along with the water-quality component, to estimate sediment transport at proposed water supply reservoir site (Betson and McMaster, 1974) and to estimate daily total dissolved solids transport for a large reservoir in connection with a reservoir fish yield model (Betson and Huff, 1975).

The observation that the water-quality model may not be applicable in rivers with a large number of mineral springs present is certainly valid. This nonpoint source water-quality model has such broad geologic groupings that it appears to be valid in many parts of the world, which is not the case. The model has been regionalized to the geomorphologic conditions of the Tennessee Valley and would be applicable elsewhere only under very similar conditions. Even in the Tennessee Valley it must be used with caution. For example, there is a relatively small formation of gypsiferous shale in the east-central portion of the Valley where the model does not apply (Betson and McMaster, 1974).

The purpose in developing these first-generation models is to provide a relatively simple nonpoint source modeling capability that uses only published data. Certainly the chemistry of water quality is more complex than is implied in the TVA nonpoint source model. For example, constituent rating curves have been found to display hysteretic effects with season (Gunnerson, 1967) and with rising and falling stage (Toler, 1965). Variations in relationships among watersheds are also influenced by soil characteristics, erosion rates, the relationship of ground waters to storm waters, the ion content in precipitation (Junge, 1958), land use, biological activity and chemical buffering mechanisms (Johnson et al., 1969), and so on. However, such factors are not easily modeled and requisite input or calibration data are sparse indeed. The first-generation modeling approach presented can readily provide information adequate for many planning applications and does represent a base modeling capability with which to compare the effectiveness and utility of future more detailed models that will account for some of the additional complexities inherent in the system.

Regarding the double-triangle unit hydrograph model, as I understnad the question about specifying conventionally bordering regions, the answer is that this is a lumped-parameter model. as such, for catchments that traverse, for example, two physiographic provinces, watershed characteristics would be used in Equation 5 that are averaged across the entire watershed. This has not been a particular problem because this model has been calibrated using data from watersheds generally 260 km^2 or less in size and these smaller catchments usually do not traverse physiographic regions. Certainly, should the need arise, a catchment can be subdivided and the upper area contributions lag routed and combined with downstream subarea hydrographs. This approach could be taken, for example, in a study to determine the impact upon stormflow of urbanizing only a portion of a watershed.

The technique for allowing the storm hydrograph model to vary from storm to storm can be seen in Equation 4 in the paper. For a given watershed, the three watershed factors (as determined from basin characteristics) become constants. Each of the model parameters therefore will vary depending upon the volume of precipitation excess and the duration of the storm. In other words, on a given catchment the shape of the unit hydrograph varies according to the size and duration of the storm.

The procedure for determining the four parameters of the model (shown in Figure 6) uses the nonlinear pattern search optimization technique described by Wilde (1964) and formalized in a computer program by Green (1970). This basic technique is also used to determine the coefficients in the watershed factors shown in Equation 5 although in this case the solution was accomplished in two steps as described in the Storm-Hydrograph Model. In subsequent work we have simplified the form of the parameter prediction equations essentially by setting WF(2) and

WF(3) in Equation 4 to constants. This allows for the equation to be solved in a single step using a log-transformation and stepwise multiple-regression. While this simplification does not allow for the relationship between the two storm variables and the model parameters to vary from watershed to watershed, the loss in predictability does not appear to be very large. The big advantage lies in the fact that the relationships can be readily updated as new data become available, and as new variables are introduced, such as the amount of impervious surfaces for urban areas. And, of course, the relationships become easier to apply.

References

Betson, R.P., and Huff, D.D. "Hydrologic Transport Modeling." Presented at an ERDA-Wide Conference on Computer Support of Environmental Science and Technology. Albuquerque, New Mexico, July 1975.

Betson, R.P., Tucker, R.L., and Haller, F.M. "Using Analytic Methods to Develop a Surface-Runoff Model." Water Resources Research, 5, 1 (February 1969).

Betson, R.P., and McMaster, W.M. "A First-Generation Nonpoint Source Mineral Water-Quality Model." Presented at 47th Annual Conference of the Water Pollution Control Federation. Denver, Colorado, October 1974.

Green, R.F. "Optimization by the Pattern Search Method." Tennessee Valley Authority, Research Paper No. 7, 1970.

Gunnerson, C.G. "Streamflow and Quality in the Columbia River Basin." Proc. ASCE J. San. Engg. Div., 39, 1967.

Johnson, N.M., Likens, G.E., Bormann, F.H., Fisher, D.W., and Pierce, R.S. "A Working Model for the Variation in Streamwater Chemistry at the Hubbard Brook Experimental Forest, New Hampshire" Water Resources Research, 5 (1969), 1353-1363.

Junge, C.E., and Werby, R.T. "The Concentration of Chloride, Sodium, Potassium, Calcium, and Sulfate in Rainwaters Over the United States." J. Meterol., 15 (1958).

Miller, C.R., and Viessman, W. Jr., "Runoff Volumes from Small Urban Watersheds." Water Resources Research, 8, 2 (April 1972).

Tennessee Valley Authority "A Continuous Daily-Streamflow Model." Research Paper No. 8. Knoxville, Tennessee, 1972.

Toler, L.G. "Relation Between Chemical Quality and Water Discharge in Spring Creek, Southwestern Georgia." U.S. Geological Survey Prof. Paper 525c, 1965.

Wilde, D.J. Optimum Seeking Methods. Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1964.

A MATHEMATICAL MODEL FOR TRANSIENT OPEN CHANNEL FLOW: A WATER RESOURCE PLANNING AND MANAGEMENT TOOL

INTRODUCTION

Effective management and the efficient use of the Tennessee Valley's abundant water resource has always been a primary purpose of the Tennessee Valley Authority. The years have seen the three basic multiple purpose uses of flood control, navigation and power generation expand to include other uses dictated by the needs of the region. Included among these uses are recreation and environmental considerations such as dissolved oxygen content, thermal effects, water supply, liquid waste disposal and many others. The industrial growth of the region - with its consequent demand for electrical energy - has caused the hydroelectric power system to change from a primary base load system to a power peaking system. Thus the nearly steady hydroelectric power releases of earlier years have given way to the intermittent power peaking operations which are characteristic of TVA's water control system today. These operations cause a continuously varying movement of the waters - both in time and space - in the separate reservoirs and connecting river links which make up the total TVA system. Research efforts over the past several years have led to the development of a computer solved mathematical model which accurately describes this movement of the water in a reservoir or river link as it responds to the multipurpose operations of the bounding facilities. On the one-hand these water release operations may be as rapid as the near instantaneous come-ons and shut-downs associated with the operation of the turbines for hydroelectric power generation or the flow resulting from a postulated dam failure - associated with the safety analysis studies required for nuclear-fueled generating plants. On the other hand these operations may be as gradual as the slowly varied flow associated with the flood control operations of the system or as gradual as evaporation from or rainfall on the surface of the river or reservoir. Regardless of the type of operation either rapidly, or slowly varied or a combination thereof the model quite accurately gives the transient water behavior as it responds to these operations. The model thus becomes an invaluable water management tool. With the continued and increased emphasis being placed on maintaining and improving our water resources through better water quantity and quality management practices, the ability to trace transient water behavior becomes the key for attacking the more complex problems of water transport. It is these continuously moving waters which transport life-sustaining dissolved oxygen, the heated effluent from nuclear and conventional generating plants, and pollutants of all types from industrial and municipal sources. Such a mathematical model is the only method available which provides the detailed spatial and temporal data on water movement necessary to attack the complex planning, operational and water management needs of TVA today.

This paper briefly describes the mathematical model, its verification and application to a variety of complex transient flow problems associated with the planning and management operations of the TVA water control system.

SUMMARY OF MATHEMATICAL MODEL

The mathematical model for unsteady flows in open channels is assumed to be one-dimensional in the sense that the flow characteristics such as depth and velocity are considered to vary only in the longitudinal (x) direction and with time. The channel geometry is three-dimensionsl.

The following items are consequences of the one-dimensional assumption.

1. The velocity is uniform across the cross section, so that the water particles in a moving section remain in that section.

2. The transverse water surface is a horizontal line in any cross section.

3. The axis of the river can be considered to be a straight line.

In the development of the mathematical model, the following assumptions are also made.

4. The flow is gradually varied so that the vertical acceleration of the water particles may be neglected, and that the pressure distribution in any cross section is hydrostatic.

5. The bottom slope of the channel is small.

6. The resistance coefficient, as determined for uniform turbulent flow at any given channel cross section, is the same for the given water surface elevation and mean velocity regardless of whether the flow is uniform or nonuniform, steady or unsteady.

7. The mass density ρ is a constant, i.e., no stratification exists.

The two equations of unsteady flow, the continuity equation and the equation of motion are

$$\frac{\partial(AV)}{\partial x} + B\frac{\partial h}{\partial t} - q = 0 \tag{1}$$

$$g\frac{\partial h}{\partial x} + V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} + gS_f + \frac{q}{A}V = 0 \tag{2}$$

in which A = flow area; V = mean velocity; x = distance; B = surface width; h = water surface elevation; t = time; q = lateral local inflow per unit distance and time; g = the gravitational constant; and S_f = the energy gradient given by:

$$S_f = \frac{n^2 V|V|}{2.21\ R^{4/3}} \tag{3}$$

in which n = Manning's resistance coefficient and R = the hydraulic radius. The terms $\partial A/\partial x$ in the expanded form of Eq. 1 can be expressed as a function of $\partial h/\partial x$. Therefore, these equations make up a system of two nonlinear, first order, first degree partial differential equations with two independent variables x and t, and with two unknowns h and V. No analytical solutions to this system of equations exist. They may be solved numerically, however, by writing them in finite difference form for digital computer manipulation.

In finite difference methods the differential equation is replaced by an approximating difference equation, and the continuous region in which the solution is desired is replaced by a set of discrete points called a net. A variety of net schemes for approximating the differential equations of unsteady flow have been studied by various investigators (1, 2, 3) (numbers in parentheses refer to references listed at the end of the paper). A characteristic computation net has several apparent advantages over other schemes, particularly in the stability and convergence of the solution and in optimization of net size. However, this computation scheme has the disadvantage that the net of points in the x-t plane is determined as the computation proceeds. It is therefore necessary to compute x and t in addition to h and V, and to use an interpolation procedure if it is desired to otain results at regular or specific distance and time intervals. The main advantage of fixed-net schemes is that the net of points in the x-t plane can be selected prior to computation, so that only h and V need to be computed. The major disadvantage of most explicit fixed-net computation schemes is the difficulty in finding a net size that will give a stable and convergent solution. Based on basic studies of many different explicit fixed-net schemes, a centered difference scheme proposed by Stoker (3) was found sufficiently stable and convergent for the unsteady flow computations if the relation

$$\left(V + \sqrt{g\frac{A}{B}}\right)\frac{\Delta t}{\Delta x} \leq 1 - \frac{gN^2|V|}{2.21\, R^{4/3}} \qquad (4)$$

is satisfied, in which Δt = the time interval and Δx = the distance interval (4).

The centered differences net used by TVA is shown in Figure 1.

In the solution of the partial differential equations of unsteady flow, it is necessary to specify boundary and initial conditions. Boundary conditions are conditions specified at fixed values of x at various times. Initial conditions are conditions specified at fixed values of time at various spatial locations.

The boundary conditions may be given as discharge or water surface elevation versus time, or as a stage-discharge relationship. A steady-flow profile, a flat pool-zero flow profile or a transient flow profile from previous computations may be used as the initial conditions.

In addition to boundary and initial conditions, input data on local inflows, channel geometry, and boundary resistance must be prescribed. From these input data the computer determines flows, mean velocities, and water surface elevations at any number of desired locations and times for the channel reach under study.

A typical reservoir or river link geometric representation is shown schematically in Figure 1. As this figure illustrates the mathematical model approximates the actual channel geometry by a series of adjacent prisms. Channel geometry data are determined by interpolations from tabular values of area, (hydraulic radius)$^{2/3}$ and storage width, all versus water surface elevation for each station. Off-channel storage in a reach i.e., embayments or tributaries, is accounted for in the mathematical model by adjusting the width B in the equation of continuity to give the correct volume in the reach. Storage width is generally different from the flow width upon which the cross-sectional area and hydraulic radius are based.

Tributary inflows are distributed over a reach length x in one version of the mathematical model or may be entered as point sources using a junction version of this model.

Typically TVA has used a computational time interval Δt ranging from 0.5 to 3.0 minutes with a longitudinal spacing of net points Δx ranging from 0.1 to 2.5 miles. Using a computational interval Δ t of 1.5 minutes and a Δx spacing of 2.1 miles requires about 1 minute of computer time for each day of real time in an average 75 mile long reservoir or river reach. The computer output may be obtained in either tabular or graphical form, for any set of desired locations and times. An IBM system 360, model 50, or an equivalent system, is required to accomodate the program used by TVA.

MODEL VERIFICATION

The validity of mathematical modeling rests upon the ability of the model to reproduce, within a study reach, actual transient conditions which have occurred in response to known time varying boundary and local inflow conditions of stage and/or discharge or velocity. For a controlled river such as the Tennessee these model verification data are readily available from the records required for the daily multipurpose operations of the system. These necessary data may also be obtained by special field tests.

That the model accurately reflects the water behavior in response to the operations involved, is illustrated by the following examples. Figure 2 shows the location of the projects for which examples are being cited.

RESERVOIRS

Normal Power Operations - Browns Ferry (5, 6, 7, 17) and Sequoyah Nuclear Plant Cooling Water Studies (7, 17).

Some degree of transient flows are normally occurring phenomena in all reservoirs, but in the case of Wheeler and Chickamauga reservoirs where Browns Ferry and Sequoyah nuclear generating plants are under construction, these transients are of special concern. Here they are caused primarily by the intermittent hydropower operations of the turbines located at the upstream and downstream boundaries. Condenser cooling water for these plants will be withdrawn from, heated, and returned to these reservoirs in which the flow conditions are changing continuously. A thorough knowledge of the transient flow mechanics is one basic need for the design of the plants' cooling water facilities. They must be so designed as to maintain the established water quality standards for the local areas and to prevent recirculation of the heated effluent back through the condensers.

Field measurements were used to calibrate the mathematical models of these reservoirs. Thirty days of continuous stage and velocity measurements at the plant site were available for calibrating the Browns Ferry model. Because of the experience gained in this study, less extensive field testing was required for calibration of the Sequoyah model. Boundary conditions prescribed for these models were the actual turbine releases. Actual lateral inflows were also used.

Figure 3 shows a typical comparison of the computed and observed stage and velocity at the Browns Ferry site. Also shown are the turbine releases which produced these transients. The computed and observed stages agree perfectly. There is also good agreement between the computed mean velocity and the measured velocity. Figure 4 shows a comparison of the measured and observed stages and velocities at the Sequoyah site, and stage at several other locations along Chickamauga Reservoir for two days of tests and a subsequent period of transient flow. Again, the agreement is excellent.

Historical Flood Events (8) - Sequoyah and Watts Bar Nuclear Plant Safety Analysis Studies

Among the licensing requirements of the Atomic Energy Commission for the construction and operation permits for nuclear fueled generating plants is the determination of the maximum flood elevation which may occur at the plant site as a result of an extreme hydrologic flood event defined as the Probable Maximum Flood (PMF). Basic to this requirement is that it must be demonstrated that the mathematical model used to make this maximum flood determination faithfully reproduces a large historical flood event which has occurred on the reservoir. Figure 5 depicts the good agreement between the transient flow model and observed reservoir conditions for the March, 1963 flood in Chickamauga which is the site for two nuclear plants now under construction. The Sequoyah plant is located at mile 484.4 and the Watts Bar plant is located at mile 528.

Flood Events Larger Than Historical Occurrences (8) - Sequoyah and Watts Bar Nuclear Plant Safety Analysis Studies

Flows resulting from the occurrence of the extreme hydrologic event are considerably larger than historical events. Beyond the range of historical flows the model is calibrated against a standard-step backwater model which uses identical reservoir or river reach geometry and conveyance as does the transient flow model. Figure 6 illustrates the results of such a calibration in Chickamauga reservoir at the Watts Bar Dam location.

RIVERS

Cumberland River Navigation Study (6, 7, 17)

Navigation on the Cumberland River between the Ohio River and Barkley Dam, 30.6 miles upstream, sometimes experiences difficulty in negotiating the narrow winding channel. This is especially true when the Ohio is at low stage and the Barkley turbines are used for peaking. The river in this reach is about 500 ft wide, 10 ft to 40 ft deep, and follows an irregular and winding path. The Corps of Engineers, as a first step in finding a solution to this problem, decided to conduct a series of field tests at specific locations in a 28-mile reach below Barkley. The tests, made in August, 1967, were a cooperative effort among the Corps, USGS, and TVA. In these tests, a number of different turbine operating patterns were scheduled at Barkley, and during these scheduled releases measurements were made in the study reach to ascertain the flow conditions. Measurements of velocity and stage were taken at selected stations in the reach. Velocity measurements were taken at depths of 0.5 ft, 7.5 ft, and 11.0 ft at midstream to define the velocity in the navigation channel. Stage was automatically recorded at each selected station.

By prescribing the turbine operations at Barkley and the stage at Cumberland River mile 2.6 as boundary conditions, variations in stage, velocity, and discharge were computed using a mathematical model of the reach. The measured and computed stages are compared in Figure 7. The agreement is excellent. The sensitivity of the model is seen by noting the small blips on the stage some 11 miles downstream from Barkley Dam. These were caused by locking operations made during these turbine releases. Observed upper depth navigation channel velocities are compared with the mean channel velocity (Q/A) on Figure 8.

CANAL

Kentucky-Barkley Canal Study (6, 7, 17)

TVA's Kentucky and the Corps of Engineers' Barkley Lakes are linked together by an uncontrolled navigation canal. The magnitude and direction of the flow in this canal is determined by the head difference which exists between the canal ends. Because both these lakes are subject to intermittent power operations, this head difference, though small, is continuously varying. Consequently, there is a continuous flow interchange between these two water bodies. Because of the size of the canal, 20 ft deep by 400 ft wide, large interchange flows occur even for small head differences between the canal ends. The transient nature of these stage variations between the canal ends makes it difficult to determine the quantity and direction of these flows at a given time or on a daily average basis.

Even though continuous records of stage at the canal ends and periodic discharge measurements were available it was not possible to develop analytically a satisfactory canal rating. Using the best discharge measurements, i.e., when a nearly constant head differential existed between the canal ends the mathematical model was calibrated. Typical calculated results are shown on Figure 9. This figure also contrasts two field discharge measurements with the calculated results. One is good, the other poor.

MODEL APPLICATIONS

The foregoing examples, which in themselves are also specific model applications, have been presented to illustrate that the model does indeed reproduce known historical transient flow events. Because of this, the model can now be used with complete confidence to determine the transient flow behavior for a variety of anticipated complex transient flow operations or conditions. Used in this)de the model is an invaluable planning, operations and water management to.

NUCLEAR PLANT SAFETY ANALYSIS STUDIES

Extreme Hydrologic Events (8)

This example illustrates the computational procedure used to determine flood wave characteristics at two nuclear plant sites, Watts Bar and Sequoyah, located on Chickamauga Reservoir. The flood wave results from the occurrence of an extreme hydrologic event defined as the Probable Maximum Flood (PMF). Such studies are necessary as part of the licensing requirements of the Atomic Energy Commission for nuclear plant safety. Determination of the hydrologic events and earth embankment breaching analysis (9) caused by overtopping these embankments during passage of the flood event are beyond the scope of this paper. This example deals only with the unsteady flow aspects of these flood waves. The principal reservoirs of interest in this example, Watts Bar and Chickamauga, are shown on Figure 2.

In routing through the various reservoirs, assumptions must be made about how the individual reservoirs are operated. For all reservoir operations, guides were used which produced results comparable to those achieved in many years of actual system operation. Figure 10 shows the specific operating guides used to route the PMF through Chickamauga Reservoir. Similar flood operating guides were also used for the other reservoirs involved in this study.

Geometric descriptions of Watts Bar and Chickamauga Reservoirs, used with the mathematical models of these reservoirs, were prepared from cross-sections spaced from about 800 feet to 2.1 miles apart along the reservoir and surface areas from topographic maps with contours spaced 10 to 20 feet apart vertically. The cross-sections were segmented horizontally into channel and overbank subsections with different resistance coefficients. Areas, hydraulic radii, surface widths, and conveyance were computed for each subsection and for the total section. Storage widths were computed by dividing surface areas between sections by the appropriate distance between sections. The unsteady flow models were calibrated at low or medium levels, see Figure 5, using observed flow conditions along the reservoirs, and at extreme flows, see Figure 6, by comparison to standard steady-state backwater computations using identical reservoir geometry.

The general computational procedure for determining flow conditions at nuclear plant sites on a particular reservoir usually consists of two major steps: (1) routing of a pre-determined flood through the affected upstream reservoirs to establish times, flows, and elevations associated with any overtopping and subsequent failure of earth embankments or other dam sections or components, and (2) successive routing of the resulting outflows down through the reservoir containing the plant sites.

The necessary inputs for routing in a particular reservoir consist of an upstream boundary condition, usually discharge versus time, local inflows along the reservoir versus time, and a downstream boundary condition, usually a rating curve (discharge versus water surface elevation) or discharge or water surface elevation versus time. The local inflows along the reservoir often consist of an overall local flow distributed uniformly over the length of the reservoir, plus relatively large concentrated local flows at major tributaries along the reservoir.

When rating curves are used as the downstream boundary condition, and when overtopping and failure of earth embankments occur, several flow transitions such as gated discharge to free spillway flow, free spillway flow to orifice-type flow, and so forth will occur, as shown in Figure 11. Thus, the rating curve will have several discontinuities and several successive runs must be made to span the entire set of rating curves (one run for each continuous curve).

In this example, the upstream boundary condition for the Watts Bar Reservoir routing was the combined Fort Loudoun and Little Tennessee River outflows (the Little Tennessee enters Watts Bar Reservoir just downstream from Fort Loudoun Dam). The upstream boundary input included the outflow resulting from the erosion failure of the Fort Loudoun earth embankment. The local inflows to Watts Bar Reservoir consisted of a local flow distributed uniformly over the length of the reservoir plus the Clinch River outflow near the midlength of the reservoir. A discontinuous rating curve, Figure 11, reflecting the several flow transitions was used at the downstream boundary (Watts Bar Dam). Using these inputs, Watts Bar headwater elevation and discharge were computed as functions of time with the Watts Bar model. The Watts Bar Reservoir results obtained using a 2.1 mile Δx-spacing and a computational interval Δt of 2.5 minutes are shown in Figure 12. In this figure, the "spike" in the Fort Loudoun discharge input is caused by overtopping and consequent erosion failure of the Fort Loudoun earth embankment. The steep rise to peak discharge at Watts Bar Dam, and the corresponding drop in headwater elevation are caused by the erosion failure of the Watts Bar earth embankment. Other discontinuities in the Watts Bar discharge plot are caused by changes from one flow regime to another, for example, by shifting from a free spillway rating curve to an orifice flow rating curve as the upper nappe of the spillway flow rises above the lip of the spillway gates. The downstream boundary rating curves at Watts Bar Dam, with explanations of the various flow transitions that can occur are shown in Figure 11.

The upstream boundary condition for the Chickamauga Reservoir routing was the computed Watts Bar outflow described above and shown in Figures 12 and 15. The local inflows to Chickamauga consisted of a local flow distributed uniformly over the length of the reservoir plus the Hiwassee River outflow near the midlength of the reservoir. A discontinuous rating curve, Figure 13, reflecting several flow transitions, including provision for sequential erosion failure of two earth embankments was used at the downstream boundary (Chickamauga Dam). The Chickamauga routing was further complicated by the presence of the Dallas Bay saddle (reservoir rim depression) located ten miles up the reservoir above Chickamauga Dam. When the reservoir level at this location reaches 700 feet, water starts to flow out of the reservoir. Therefore, above elevation 700 feet, a mathematical model capable of handling the Dallas Bay outflow by means of side boundary rating curves was used. The Dallas Bay rating curves are shown in Figure 14. Several rating curves are required because the outflow from Chickamauga Reservoir by way of Dallas Bay flows into Chickamauga Dam tailwater. Any embankment failures at Chickamauga Dam suddenly raise the tailwater level which in turn affects the Dallas Bay rating relation.

Using the above inputs, water surface elevations and flows were computed every 2.5 minutes (Δt) at 2.1 mile intervals (Δx) all along Chickamauga Reservoir. Typical results for the two plant sites, Watts Bar and Sequoyah, are shown in Figure 15 along with other inputs and results. The steeply rising peak flows at Chickamauga Dam and the corresponding headwater elevation drops are caused by sequential failures of the two earth embankments, while the other discontinuities are caused by changes in flow regime. The Chickamauga Dam rating curves, with explanations of the various possible flow transitions are shown in Figure 13.

Similar maximum flood level determinations have been made for the Browns Ferry Nuclear Plant located on Wheeler Reservoir, the Bellefonte Nuclear Plant on Guntersville Reservoir and the Clinch River Breeder Reactor located on Watts Bar Reservoir.

Postulated Complete and Instantaneous Seismic Failure of an Upstream Dam Coupled With A Historical Flood Event (8)

Even though the model is, in its formulation, basically limited to the cases in which the flow is gradually varied, it is a useful tool for the determination of outflow hydrographs from failed structures. It is recognized that the initial flow from failed structures is clearly rapidly varying. However, with the passage of time and the propagation of the negative wave upstream and the positive wave downstream the flow very quickly, after failure, approaches the gradually varied state for which the model is valid. It should be recognized that at the instant of failure and for a short period of time thereafter, the use of the gradually varied flow model to compute values of stage, discharge and velocity at the failed structure are at best only approximations of the actual values which would occur.

The historical flood event used in this example is the 1963 flood. This flood event was routed through the separate Watts Bar and Chickamauga reservoir models. Watts Bar Dam was assumed to disappear instantaneously as the result of a large earthquake at the peak of the March, 1963 flood. Flow conditions just prior to the seismic failure were those accompanying the 1963 flood passage through Watts Bar and Chickamauga Reservoirs, with the postulated failure occurring at hour 13 on March 13, 1963. Following failure Watts Bar and Chickamauga Reservoirs become one unit, extending from the upstream boundary of Watts Bar reservoir (Fort Loudoun Dam) to the downstream boundary of Chickamauga Reservoir (Chickamauga Dam). The Watts Bar Dam location, formerly the downstream boundary of the separate Watts Bar model and the upstream boundary of the separate Chickamauga model, now becomes an internal net point in the new model extending over the length of both reservoirs. The discontinuity in water levels at the Watts Bar Dam net point at the instant of failure is eliminated by computing a starting elevation using the following basic fluid mechanics equations.

These equations for the fully breached dam are:

$$Q_{peak} = \frac{8}{27} B\sqrt{g}\, h^{3/2} \tag{5}$$

and

$$y = \frac{4}{9} h \tag{6}$$

in which:

Q_{peak} = peak discharge of the dam-break flood wave.

B = dam width.
h = initial water depth upstream from the failed dam.
g = acceleration due to gravity.
y = depth of flow at the failed structure.

These theoretical expressions developed by Saint-Venant (10) and checked experimentally by Schoklitsch (10), Dressler (11), the U.S. Army Waterways Experiment Station (12) and others (13, 14), are basically limited to wide frictionless rectangular channels with unlimited storage upstream from the failed structure and to a dry channel condition downstream from the failed dam. Rarely do real cases fit these idealized conditions. It, therefore, becomes necessary to adapt these equations to real cases were the length of the dam is relatively short, the volume of water stored in the upstream reservoir is limited, and the downstream channel into which the ruptured dam empties is not dry.

The valley cross-section at the failed dam site will govern the peak discharge which this section can pass at the instant of failure in accordance with the principal of minimum specific energy (15):

$$\frac{Q_c^2}{g} = \frac{A^3}{T} \tag{7}$$

in which:

Qc = critical discharge = Q_{peak}.

A = area of valley cross-section at the dam.
T = top width of the valley cross-section at the dam.
g = acceleration due to gravity.

A fair estimate of the peak discharge at the instant of failure can be obtained through the use of equation 5. Using this discharge in equation 7 will give the depth at which the flow will pass.

The reduced peak discharge due to the effect of the tailwater depth downstream from the failed structure can be approximated by applying the momentum principle to conditions upstream and downstream from the dam at the instant before failure:

$$\frac{Q\gamma}{g}\left(V_2 - V_1\right) = P_1 - P_2 \tag{8}$$

in which:

Q = discharge passing structure prior to failure.
γ = unit weight of water.
V_1 & V_2 = channel velocities upstream and downstream from structure, respectively.
P_1 & P_2 = hydrostatic pressure forces upstream and downstream, respectively.

Generally it is sufficient to ignore as negligible the kinetic energy components and determine the effect of tailwater by evaluating the hydrostatic pressure forces assuming a rectangular channel. For this case the equivalent dry-channel peak discharge can be determined from equation 5 using h' determined from:

$$\frac{y_1^2}{2} - \frac{y_2^2}{2} = \frac{(h')^2}{2} \tag{9}$$

in which:

y_1 = depth upstream from dam.
y_2 = depth downstream from dam.
h' = equivalent depth (comparable to y_1) for the condition of no tailwater.

The water surface elevations and discharges along the now connected reservoirs were from the unsteady flow profiles computed in the individual reservoirs. The discontinuity in water levels at the Watts Bar Dam net point was eliminated as described. The upstream boundary (Fort Loudoun Dam) condition was the observed flood discharge hydrograph. Distributed, Clinch River and Hiwassee River outflows were those observed during the 1963 flood. The downstream boundary (Chickamauga Dam) condition was the observed discharge hydrograph until gate top elevation 685.44 feet was reached. This elevation was then held constant, and it was found that the maximum flow could be passed without exceeding gate top elevation. The results are given in Figure 16.

Complete and Instantaneous Failure of A Downstream Dam (8)

In this case, Nickajack and Chickamauga Reservoirs function as one long, continuous reservoir following the failure of Chickamauga Dam, as were Chickamauga and Watts Bar in the previous example. However this time, interest was in how the failure of Chickamauga Dam affects flow conditions at the two plant sites located upstream from the failed dam. Chickamauga Dam was postulated to disappear instantaneously as the result of a large earthquake. Flow conditions just prior to the seismic failure were minimum pool levels of 632.0 and 675.0 feet, respectively, for Nickajack and Chickamauga with zero flow in both reservoirs. The water surface elevation just after failure at the Chickamauga site was computed from dam-break theory. This elevation was used as the starting elevation at the Chickamauga Dam net point in the coupled reservoir model. Other starting conditions in this model were the flat pool zero flow conditions mentioned above. The upstream boundary (Watts Bar Dam) condition was zero flow held constant. All local inflows were taken as zero. The downstream boundary (Nickajack Dam) condition was zero flow held constant until gate top elevation 635.0 was reached. Then, this elevation was held constant. Results are shown in Figure 17.

RACCOON MOUNTAIN PUMPED STORAGE STUDIES (6, 17)

Navigation Studies

TVA is constructing the Raccoon Mountain pumped storage generating station on Nickajack Reservoir. Water will be released into the reservoir during generation and withdrawn during pumping operations. Figure 18 illustrates schematically these releases and withdrawals to and from the reservoir. These effects needed to be evaluated in order to assess how these operations might affect navigation past the location of the intake-outlet structure. In order to adequately design the intake-outlet structure, hydraulic model studies were made to assure proper structure performance. The mathematical model was used to predict the overall reservoir transients which will result from the operation of the turbines at the upstream and downstream boundaries of Nickajack Reservoir coupled with the operation of the Raccoon Mountain station. Figure 19 shows these transients at selected locations. In order to properly operate the hydraulic model which extends approximately 1/2 mile above and below the intake-outlet structure, transient flow conditions must be known at the hydraulic model boundaries. To accomplish this, the reservoir mathematical model was ued to give transient boundary conditions for still another mathematical model extending some 4 miles on either side of the intake-outlet structures. This 8-mile long mathematical model used finely divided Δx spacing to yield the transients which will occur at the boundaries of the hydraulic model. Figure 20 illustrates the results obtained using this secondary model.

Water Quality Related Studies

The intermittent hydropower operations of Chickamauga, Nickajack and Raccoon Mountain will cause a continuously varying movement of water within Nickajack Reservoir, on which are located the water treatment and municipal waste plants for the City of Chattanooga. A knowledge of the movement of waters within this reservoir is basic to the maintenance of adequate water quality. Figure 21 illustrates the transient water behavior in this reservoir at a site near the municipal waste treatment plant for the anticipated hydropower operations of these plants during a typical wintertime operation.

FLOW FORECASTING FOR INDUSTRIAL WASTE RELEASES

Kentucky Reservoir Forecasting Model (16)

Maintaining or improving the quality of the waters in the TVA system is a major concern of the Authority and the pollution control boards of the states in which TVA is located. To achieve this goal, both TVA and the Tennessee Stream Pollution Control Board now require that certain waste treatment standards be met before releasing liquid wastes to the waters of the system within Tennessee. In addition, it may be required that waste discharges to the system be released in a certain proportion to the instantaneous flow passing the point of release. This is done to insure that the waste release does not in any way impair the water quality of the receiving reservoir. This was the case for a recently completed industrial plant located on Kentucky Reservoir near New Johnsonville, Tennessee.

Kentucky Reservoir, which is 184 miles long, is bounded upstream and downstream by Pickwick and Kentucky dams. Turbine operations at these two plants are intermittent and as a result of this the flow at any given time and location within the reservoir is quite variable.

Quantitative daily flow forecasting to achieve the multipurpose objectives of the reservoirs of the system has always been practiced by TVA. Among the data available for these forecasts are the anticipated hourly turbine releases which will be required to meet the generating demands for power. A mathematical model of Kentucky Reservoir which uses these anticipated hourly values of releases from the Pickwick and Kentucky turbines and the anticipated canal and other local inflows offers the most feasible solution for predicting instantaneous flows at Johnsonville, and thereby permit waste to be released in proportion to flow. However, to be useful as a predictive tool for daily forecasts the model had to be streamlined so that it could be used quickly and efficiently on a routine daily basis. For this a 9.2-mile (Δx) reach model was developed utilizing 21 average cross-sections.

Because the point of waste release is located in the central portion of the reservoir where the results from the simplified model are satisfactory, it was decided to use this model for these predictions. The anticipated hourly turbine releases are determined by the System Loading Branch of the Office of Power and the River Control Branch of the Division of Water Control Planning performs the actual routing and furnishes the forecast hourly flows to the industrial plant daily. The program requires initial conditions of stage and discharge at each of the 21 cross-sections. These are obtained from the previous day's forecast and checked against observed stages at the five permanent gages located in the reservoir, and hourly anticipated turbine flows. All this requires only 15 punched cards. Less than one minute of computer time on an IBM 360/50 system yields predicted flows and stages at one-hour intervals for a 42-hour forecast period at any of the 21 cross-sections along the reservoir. Figure 22 shows for the period August 6-9, 1969, for the simplified model a comparison between predicted and later observed conditions.

It must be pointed out that the reliability of these predictions depends upon how closely the actual operating schedules for Pickwick and Kentucky turbines follow the anticipated schedules upon which these predictions are based.

STATISTICAL STUDIES

Browns Ferry Transient Flow and Water Temperature Correlation Studies

With the continued and increased emphasis being placed on maintaining and improving the water resources through better quantity and quality management practices, the ability to trace transient water behavior becomes the key for attacking the more complex problems of water transport. In this example the entire year of 1969 historical flow releases at Guntersville and Wheeler were routed through Wheeler Reservoir, generating instantaneous flow data at the Browns Ferry Nuclear Plant site. These instantaneous flow data served as a base for more complex temperature-transient studies being conducted by TVA's Engineering Laboratory. Figure 3 illustrates the transient flow conditions at the Browns Ferry site which are typical of the conditions which occurred throughout the 1969 flow study.

MISCELLANEOUS STUDIES

Model Input Separation Technique (17)

Figure 23 shows, for the Sequoyah Nuclear Plant study, the transient flow conditions which occurred at the plant site in response to the actual turbine operations at the upstream and downstream boundaries of the reservoir. Figure 23 also shows the transients caused by assuming respectively, only downstream boundary turbines operating, only upstream boundary turbines operating, and local inflow alone. These "separately" caused transients are then added algebraically and compared to the real case in which these transients occur simultaneously. While not precisely correct, this technique does permit identifying these separated operations with the effect each produces at any point along the water course. Thus, the additive characteristics of these translatory waves may be exploited to arithmetically or graphically approximate a composite transient behavior. This suggests that by simple phase-shifting a wide variety of operations can be investigated coarsely from a few computer runs.

CONCLUSIONS

The unsteady flow mathematical model described in this paper can be applied with flexibility and efficiency to a wide range of engineering problems. In addition to the examples described herein, the model has great potential in a number of other areas. For example, it can be used to determine when flow measurements should be made, to aid in the collection and analyses of water quality data, to achieve any desired flow condition at a selected point along a stream, to compute water surface profiles, to analyze hydrographs, to aid in flow regulation and system operation, to select sites for thermal generating plants, and even to establish accurate resistance coefficients in open-channels. With mathematical models of the type described, it is no longer necessary for engineers to restrict their analyses to steady flow principles. More sophisticated versions of the model offer promise for handling stratified flows, and the more complex problems of water transport. In these transport problems it is the continuously moving waters which carry life-sustaining dissolved oxygen, the heated effluent from nuclear and conventional generating plants, and pollutants of all types from industrial and municipal sources. Such a mathematical model is the only method available which provides the detailed spatial and temporal data on water movement necessary to attack the more complex environmental problems.

APPENDIX I.-REFERENCES

1. Liggett, J. A., and Woolhiser, D. A., "Finite-Difference Solutions of the Shallow Water Equations," Cornell University Water Resources Center, Ithaca, N.Y., 1966.

2. McLaughlin, R. T., Kim, D., and Dailey, J. E. "Unsteady Flow in Reservoirs Operated for Peak Power," Hydrodynamics Laboratory, Massachusetts Institute of Technology, Report No. 101, November 1966.

3. Stoker, J. J., "Numerical Solution of Flood Prediction and River Regulation Problems," New York University, Institute of Mathematical Sciences, Reports I and II, New York, 1953-54.

4. Perkins, F. E., "The Role of Damping in the Stability of Finite Difference Techniques," ASCE National Meeting on Environmental Engineering, Meeting Preprint 689, Chattanooga, Tenn. May 13-17, 1968.

5. Buehler, B. J., Price, J. T., and Garrison, J. M., "Transient Flow Investigations for TVA's Browns Ferry Generating Station," Proceedings, 7th Annual Sanitary and Water Resources Engineering Conference, Vanderbilt University, Nashville, Tennessee, May 1968.

6. Garrison, J. M., Granju, J. P., and Price, J. T., "Unsteady Flow Simulation in Rivers and Reservoirs," Proceedings A.S.C.E., Journal of the Hydraulics Division, September 1969.

7. Buehler, B. J., Garrison, J. M., Granju, J. P., and Price, J. T., "Digital Computer Simulation of Transient Flows in the TVA System," Proceedings XIII Congress I.A.H.R., Kyoto, Japan, September 1969.

8. Price, J. T., and Garrison, J. M., "Floodwaves from Hydrologic and Seismic Dam Failures," Unpublished Paper Presented at ASCE National Water Resources Meeting, Washington, D.C., January, 1973.

9. Newton, D. W., and Cripe, M. W., "Flood Studies for Safety of TVA Nuclear Plants - Hydrologic and Embankment Breaching Analysis," paper presented at ASCE National Water Resources Engineering Conference, Washington, D.C., January 1973.

10. Keulegan, G. H., "Wave Motion," Chapter XI of Engineering Hydraulics, edited by H. Rouse, John Wiley & Sons, Inc., New York, 1961, pp. 754-756.

11. Dressler, R. F., "Mathematical Solution of the Problem of Roll-Waves in Inclined Open Channels," Communications on Pure and Applied Mathematics, New York University, Vol. II, No. 2/3, 1949, p. 149.

12. "Floods Resulting from Suddenly Breached Dams," U.S. Army Corps of Engineers, Vicksburg, Miss., 1961, Reports 1 and 2.

13. Thomas, W. A., "A Method for Analyzing Effects of Dam Failures in Design Studies," Paper Presented at the ASCE Hydraulics Division Specialty Conference, Cornell University, August, 1972.

14. Sakkas, J. G., and Strelkoff, "Computation of Floodwaves from a Ruptured Dam," Department of Water Science and Engineering, University of California at Davis, Davis, California, August, 1972.

15. Price, J. T., Lowe, G. W., Garrison, J. M., "Hydraulic Transients Generated by Parital and Total Failures of Large Dams," Paper presented at the ASCE Hydraulics Division Specialty Conference, University of Tennessee at Knoxville, August 1974.

16. Granju, J. P., Garrison, J. M., and Price, J. T., "Hydraulic Transients in Man-Made Lakes," Proceedings - International Symposium on Man-Made Lakes, Knoxville, Tennessee, May 1971.

17. Price, J. T., "Hydraulic Transients in the TVA System of Rivers and Reservoirs," Proceedings of a Seminar on Computer Applications in Hydrology, Corps of Engineers Hydrologic Engineering Center, Davis, California, February 23-25, 1971.

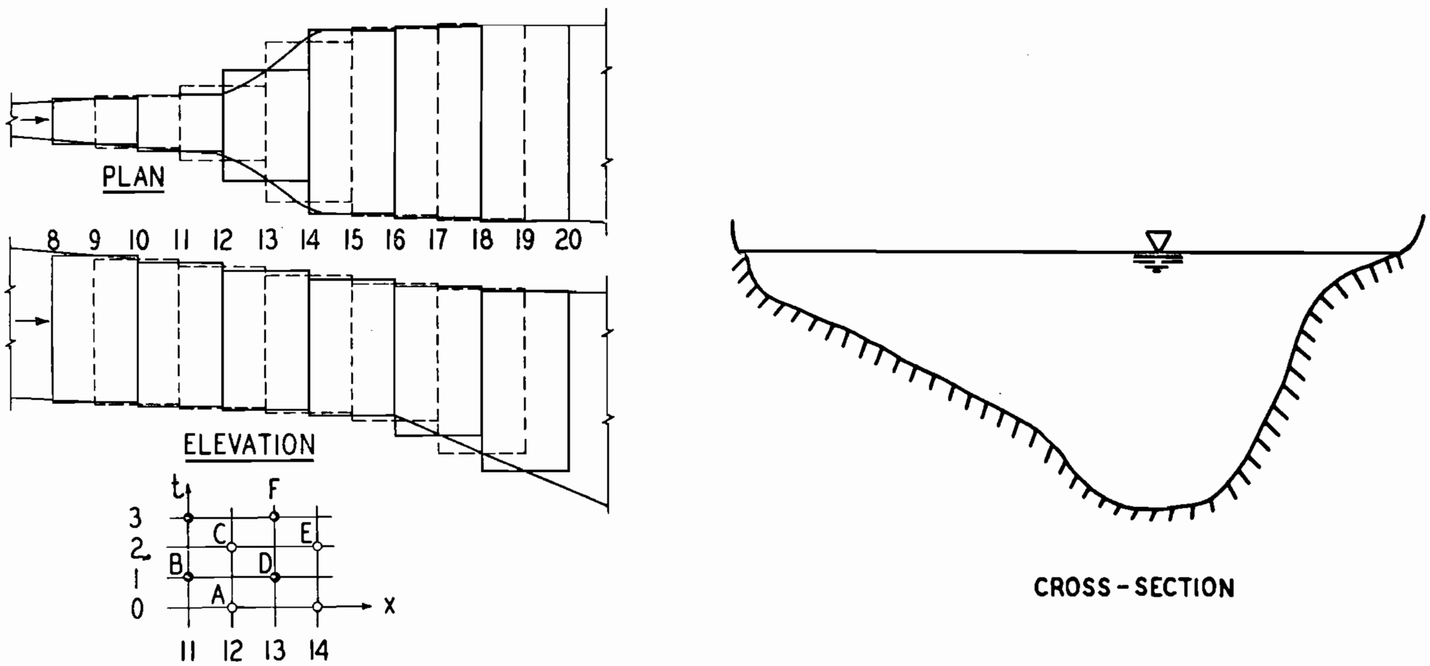
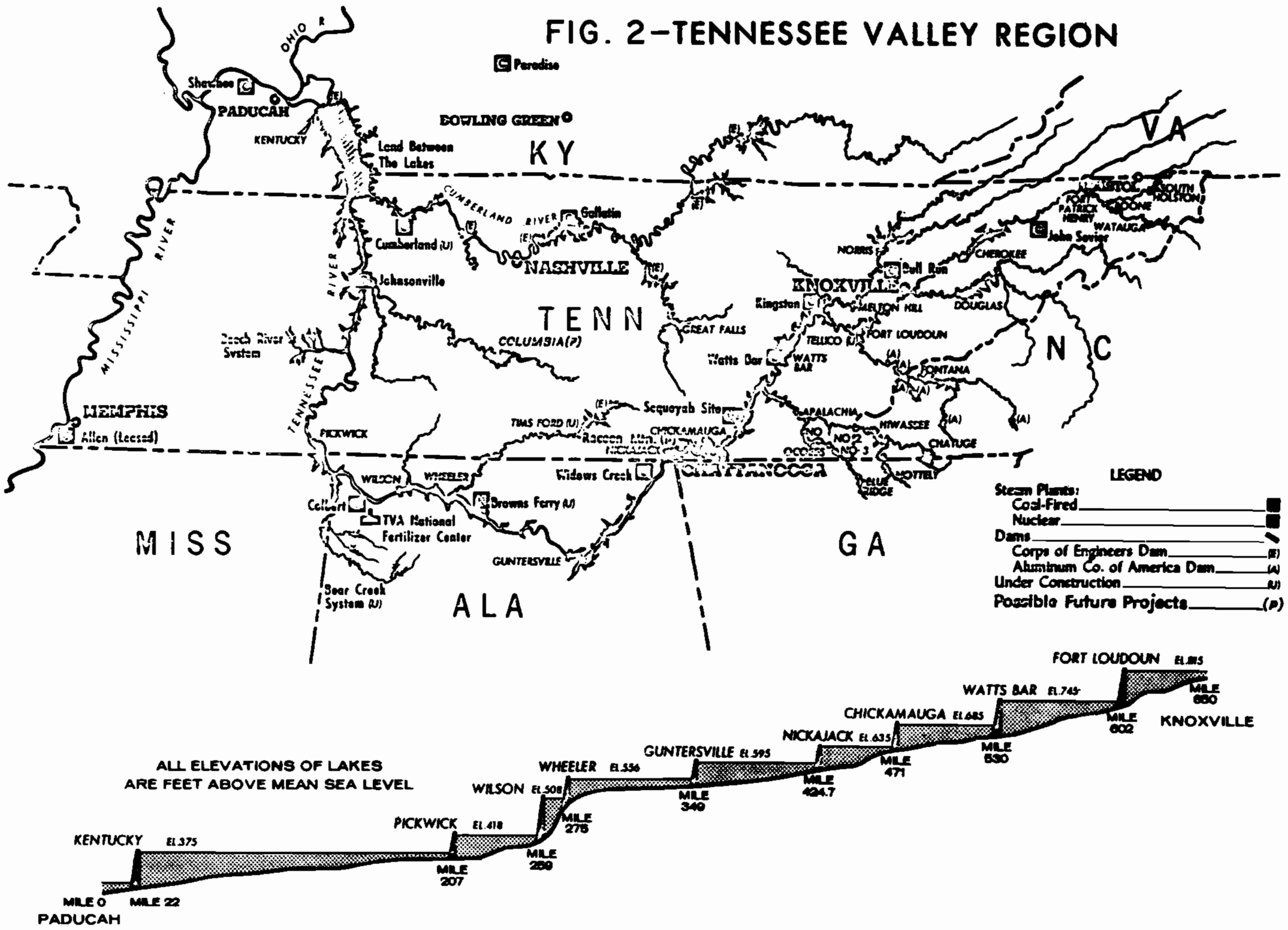


FIG. 1 – NET SCHEME AND CHANNEL GEOMETRY

FIG. 2–TENNESSEE VALLEY REGION



PROFILE OF THE TENNESSEE RIVER (ALL MAINSTREAM DAMS HAVE NAVIGATION LOCKS)

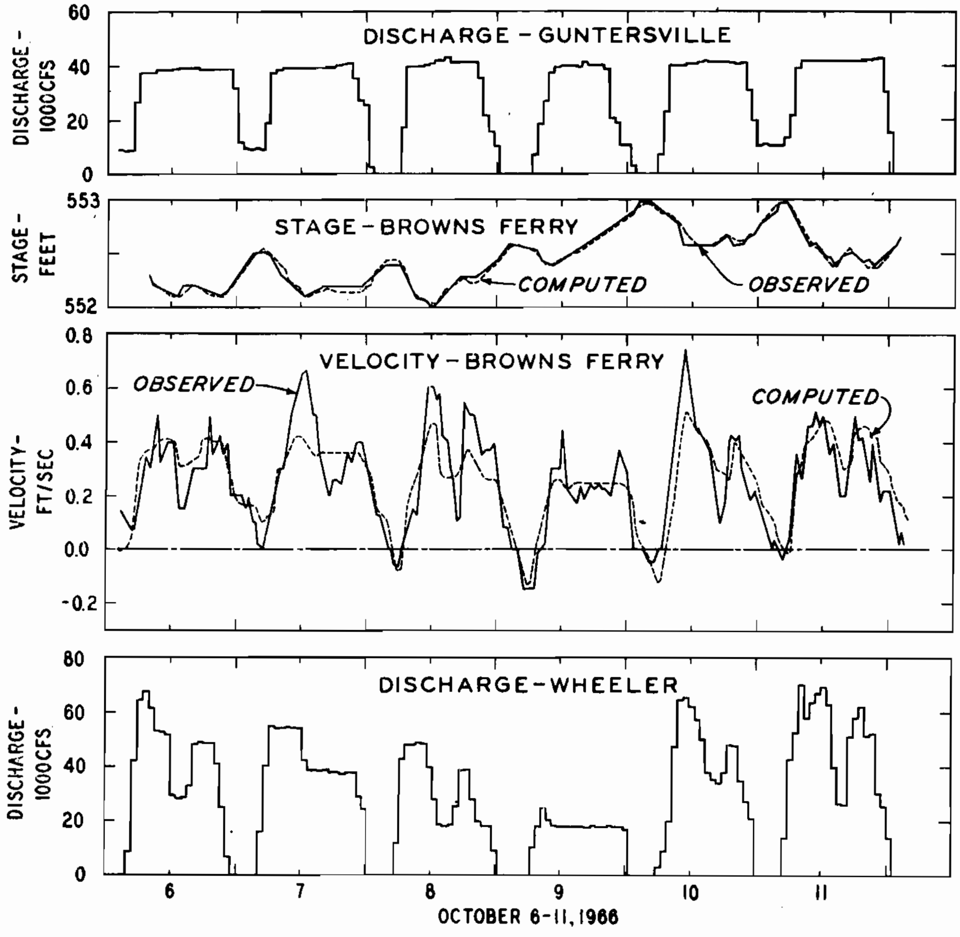


FIG. 3-RESERVOIR TRANSIENTS AT BROWNS FERRY SITE

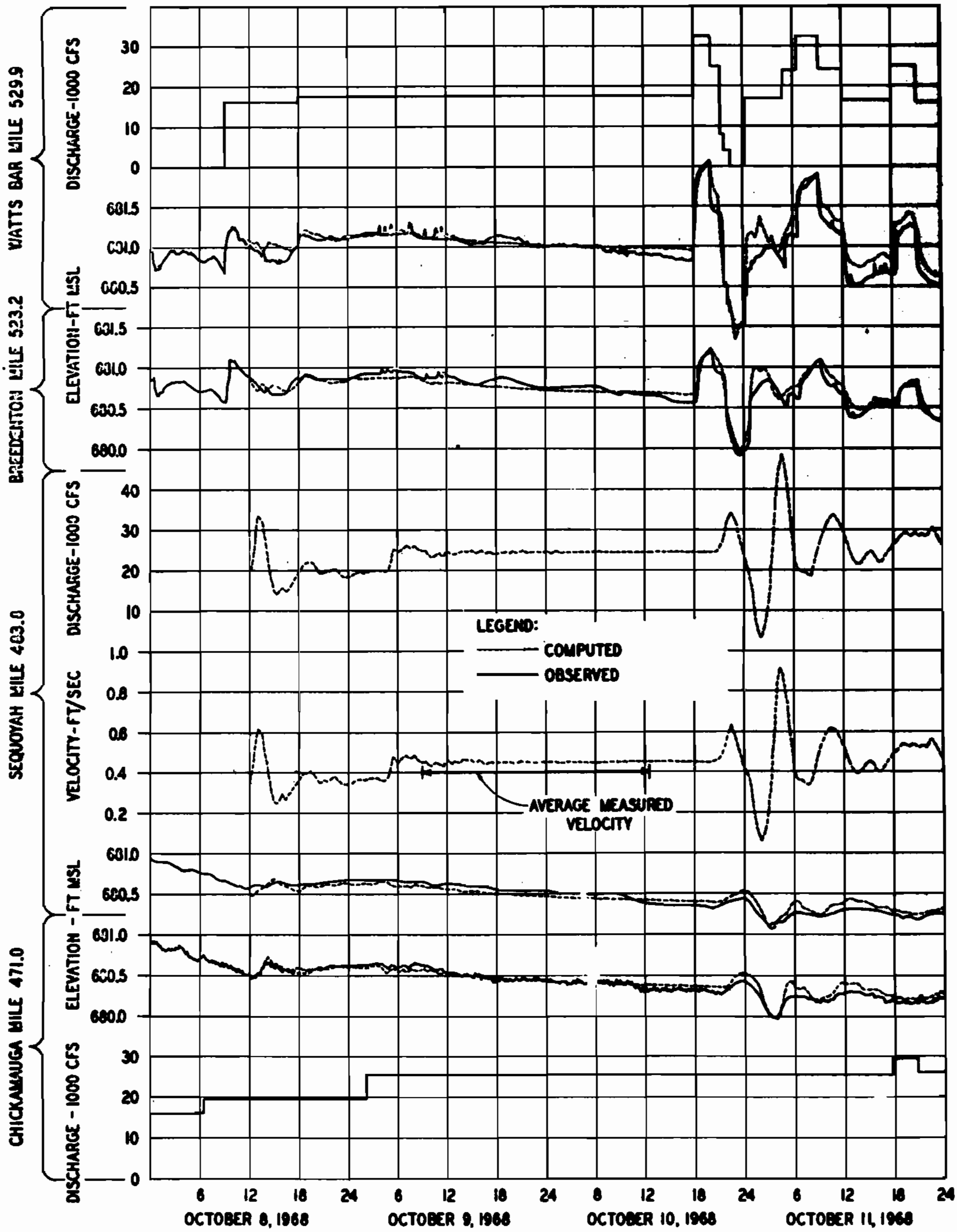


FIG. 4 -- COMPARISON OF COMPUTED AND OBSERVED QUANTITIES
SEQUOYAH NUCLEAR PLANT STUDIES

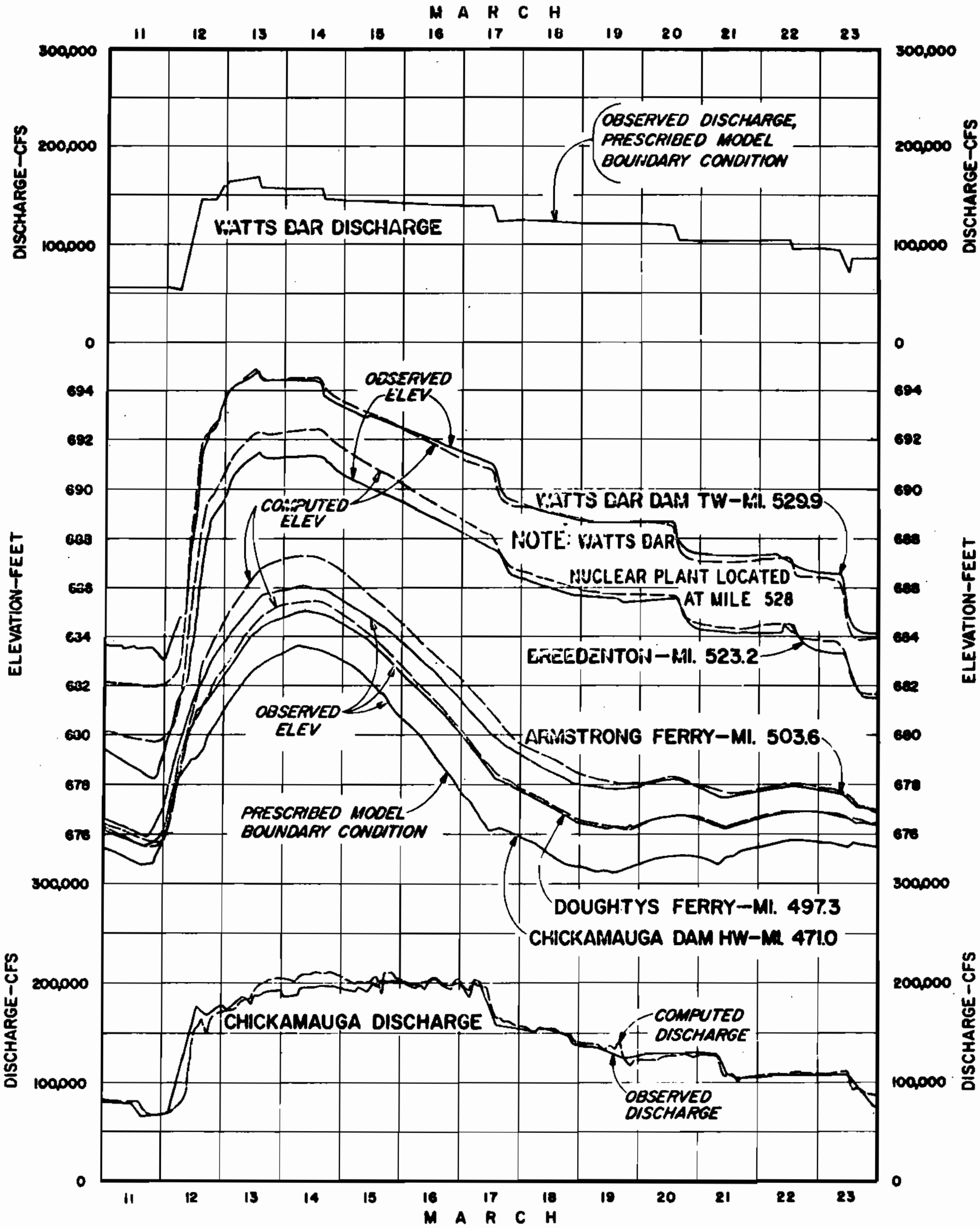


FIG. 5-1963 FLOOD-CHICKAMAUGA RESERVOIR
UNSTEADY FLOW MODEL VERIFICATION

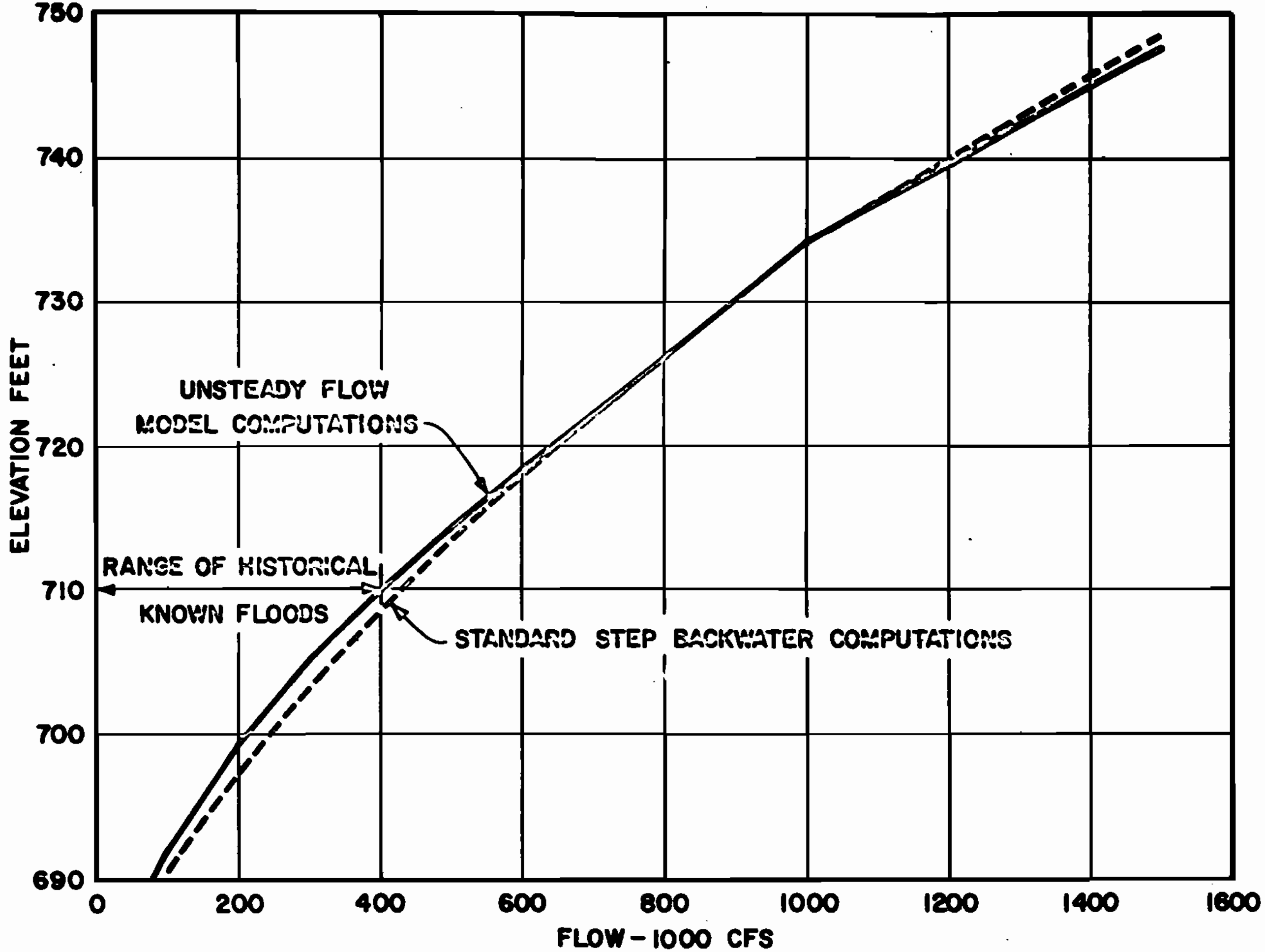


FIG. 6-STEADY-STATE MODEL VERIFICATION
WATTS BAR DAM TAILWATER RATING CURVE

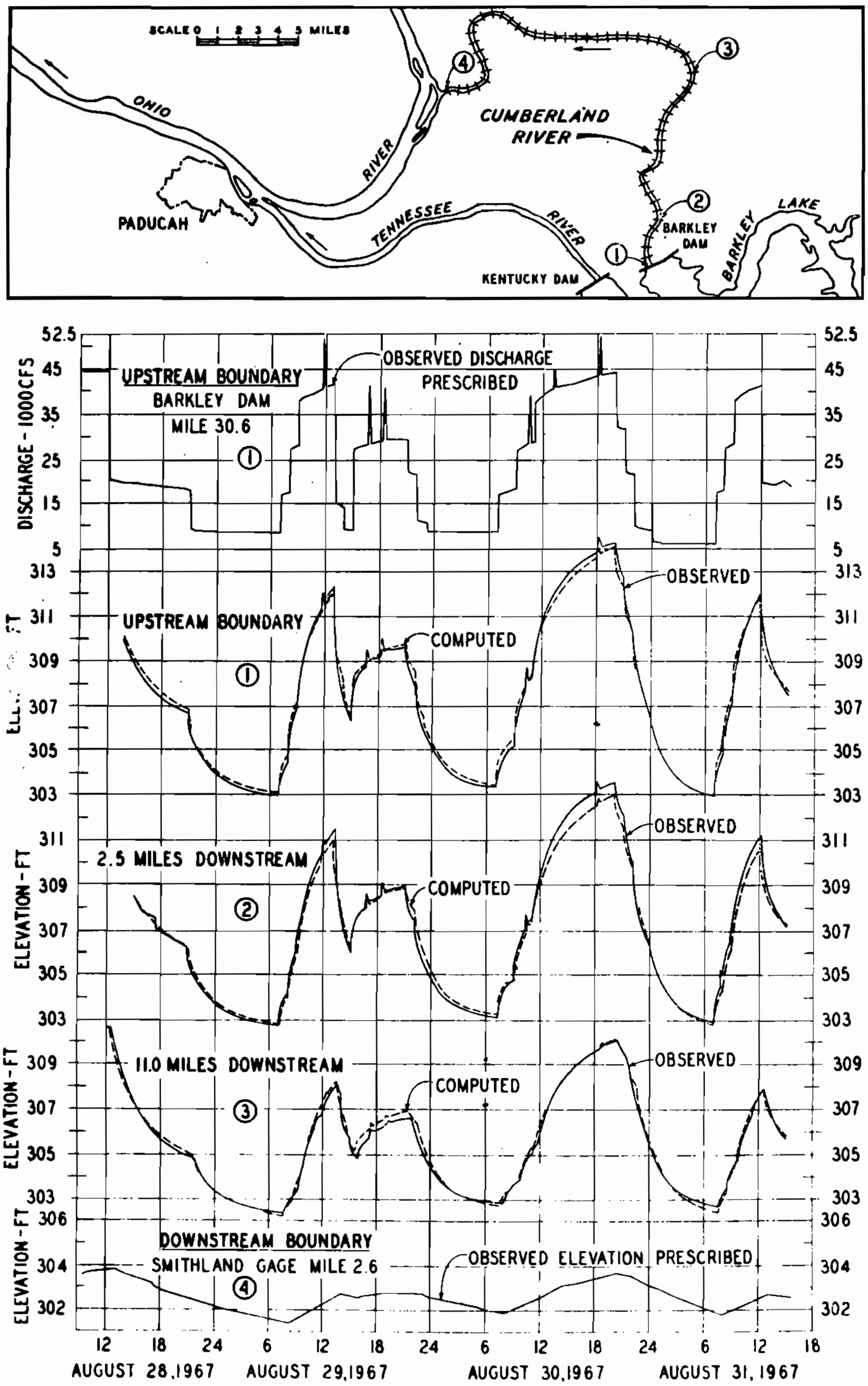

SCALE 0 1 2 3 4 5 MILES
OHIO
RIVER
PADUCAH
TENNESSEE
RIVER
KENTUCKY DAM
CUMBERLAND
RIVER
BARKLEY
DAM
BARKLEY
LAKE
UPSTREAM BOUNDARY
BARKLEY DAM
MILE 30.6
OBSERVED DISCHARGE
PRESCRIBED
DISCHARGE - 1000 CFS
UPSTREAM BOUNDARY
OBSERVED
COMPUTED
2.5 MILES DOWNSTREAM
ELEVATION - FT
11.0 MILES DOWNSTREAM
DOWNSTREAM BOUNDARY
SMITHLAND GAGE MILE 2.6
OBSERVED ELEVATION PRESCRIBED
AUGUST 28,1967
AUGUST 29,1967
AUGUST 30,1967
AUGUST 31, 1967

FIG. 7 - CUMBER[illegible]

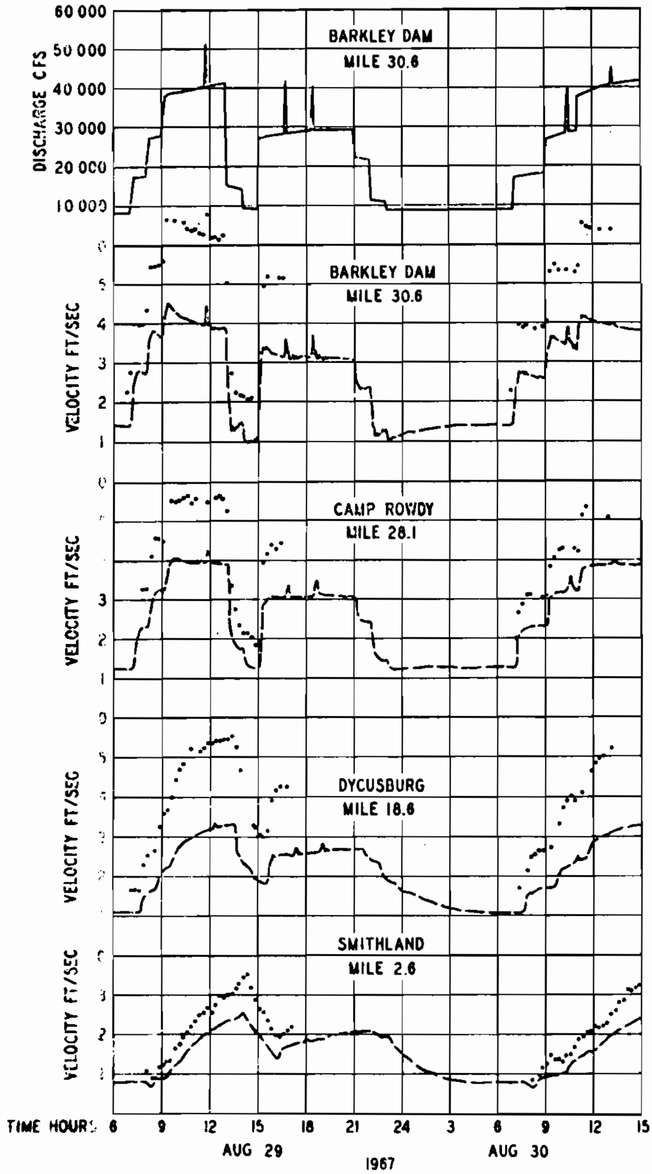


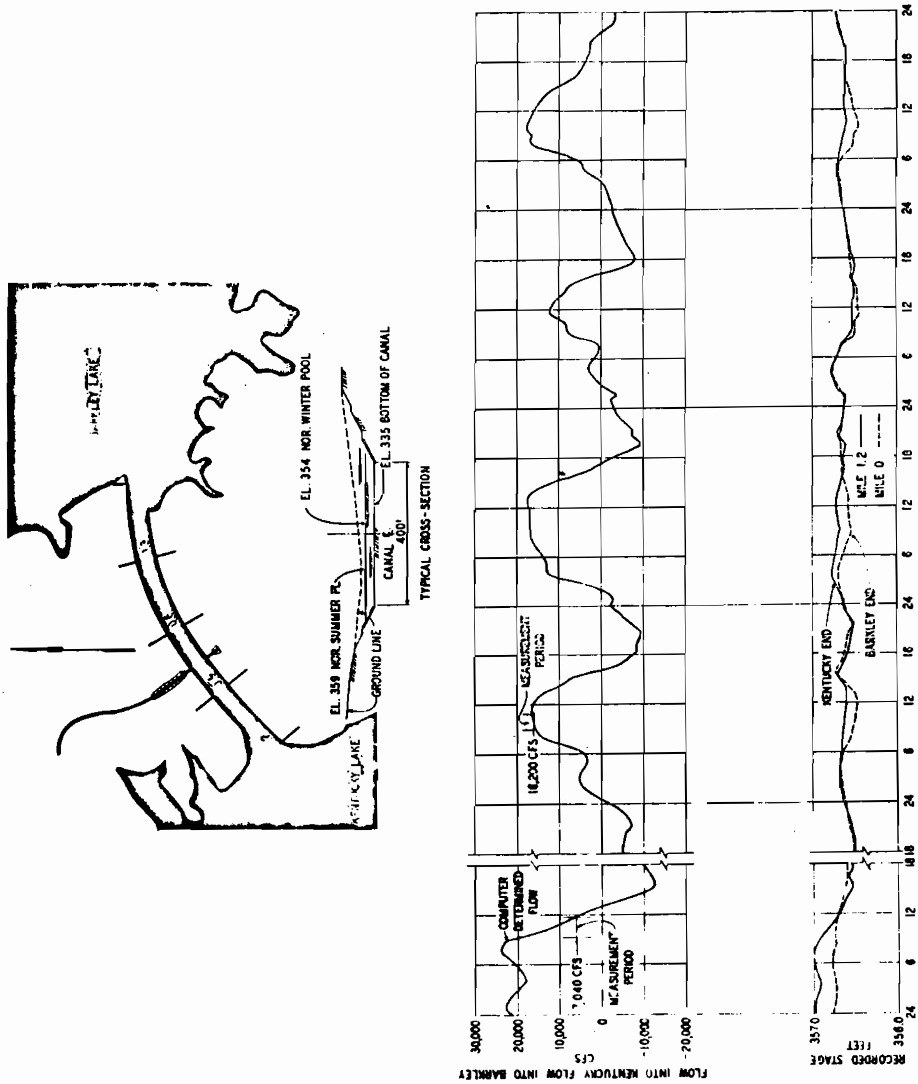
FIG. 8
OBSERVED AND COMPUTED HYDRAULIC CHARACTERISTICS CUMBERLAND RIVER BELOW BARKLEY DAM

AUG 28 - SEPT 1, 1967

LEGEND

---- COMPUTED MEAN VELOCITY

• • • NAVIGATION CHANNEL VELOCITY OBSERVATION


KENTUCKY LAKE
EL. 354 NOR. WINTER POOL
EL. 335 BOTTOM OF CANAL
EL. 359 NOR. SUMMER PL.
GROUND LINE
CANAL ℄
400'
TYPICAL CROSS-SECTION
COMPUTER DETERMINED FLOW
7,040 CFS
MEASUREMENT PERIOD
18,200 CFS
KENTUCKY END
BARKLEY END
MILE 1.2
MILE 0
FLOW INTO KENTUCKY FLOW INTO BARKLEY
CFS
30,000
20,000
10,000
0
-10,000
-20,000
RECORDED STAGE FEET
358.0
JUL 27
AUG 9
AUG 10
1966
AUG 11
AUG 12

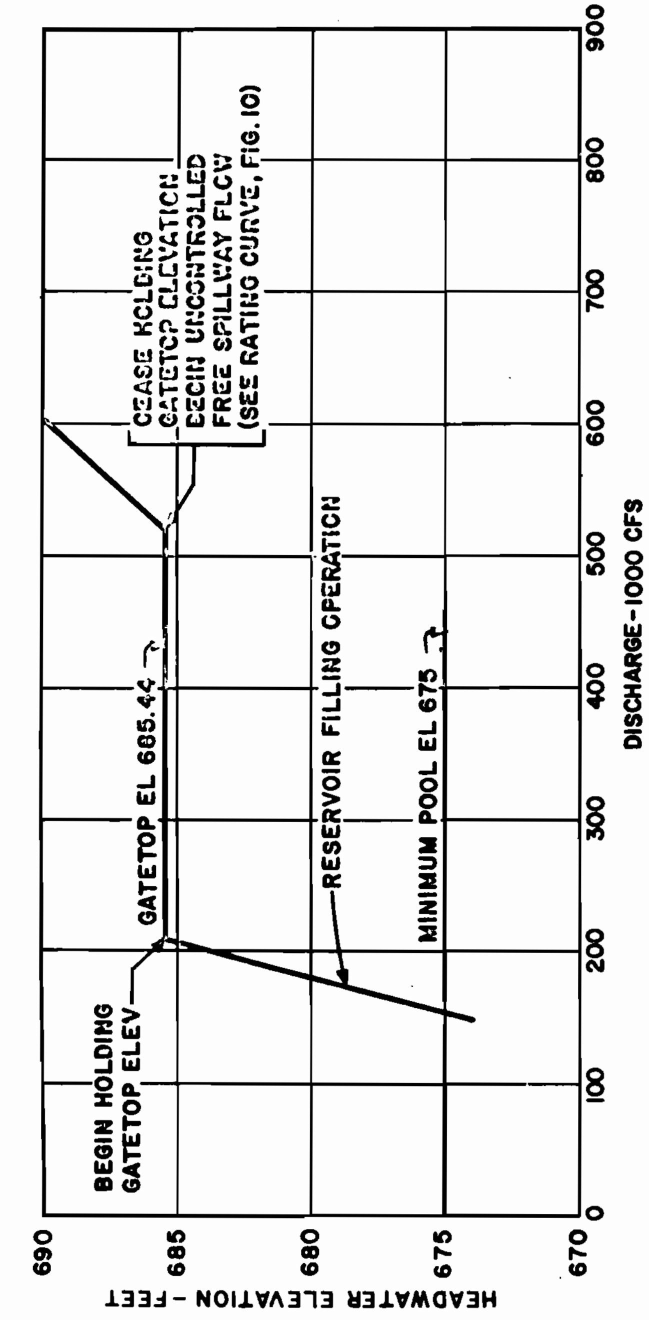


FIG.10 CHICKAMAUGA RESERVOIR FLOOD OPERATING GUIDE

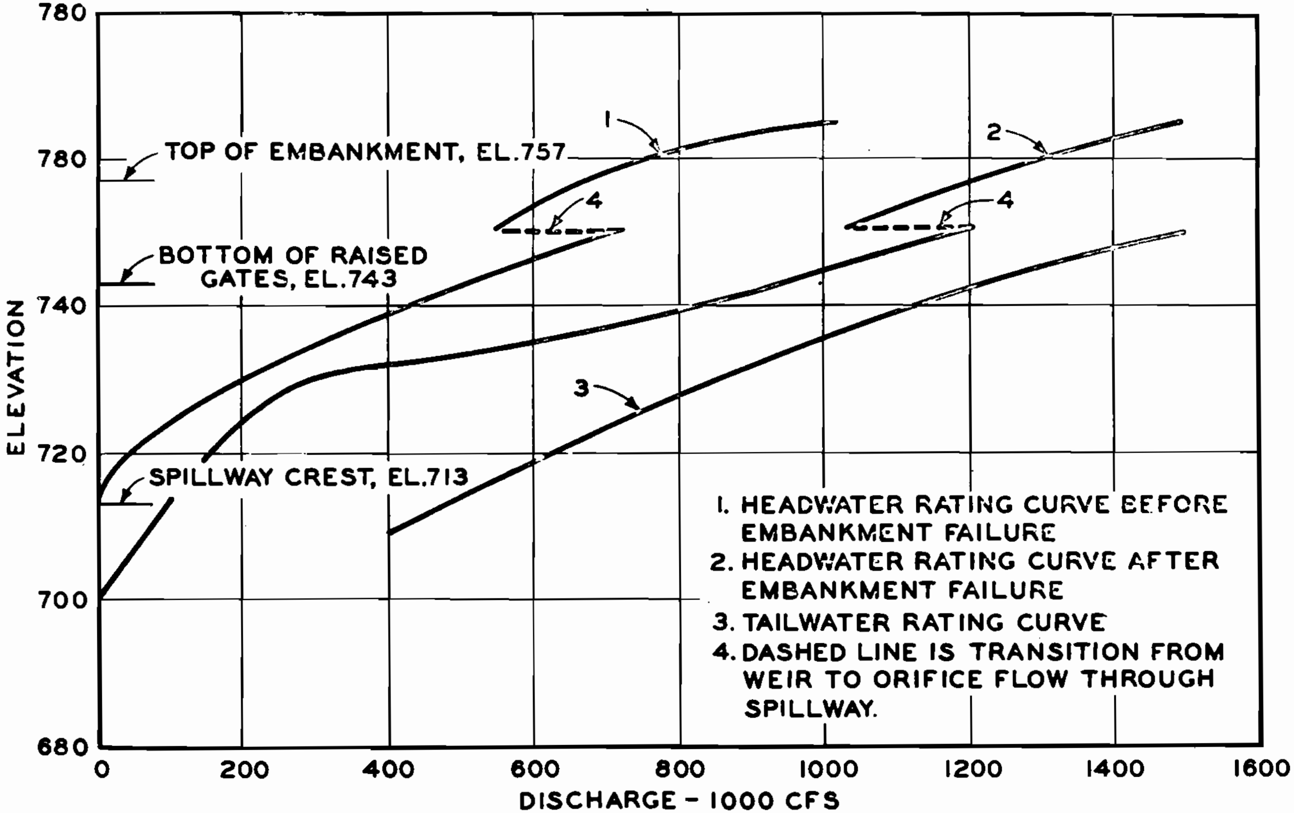


FIG. 11 - WATTS BAR DAM RATING CURVES

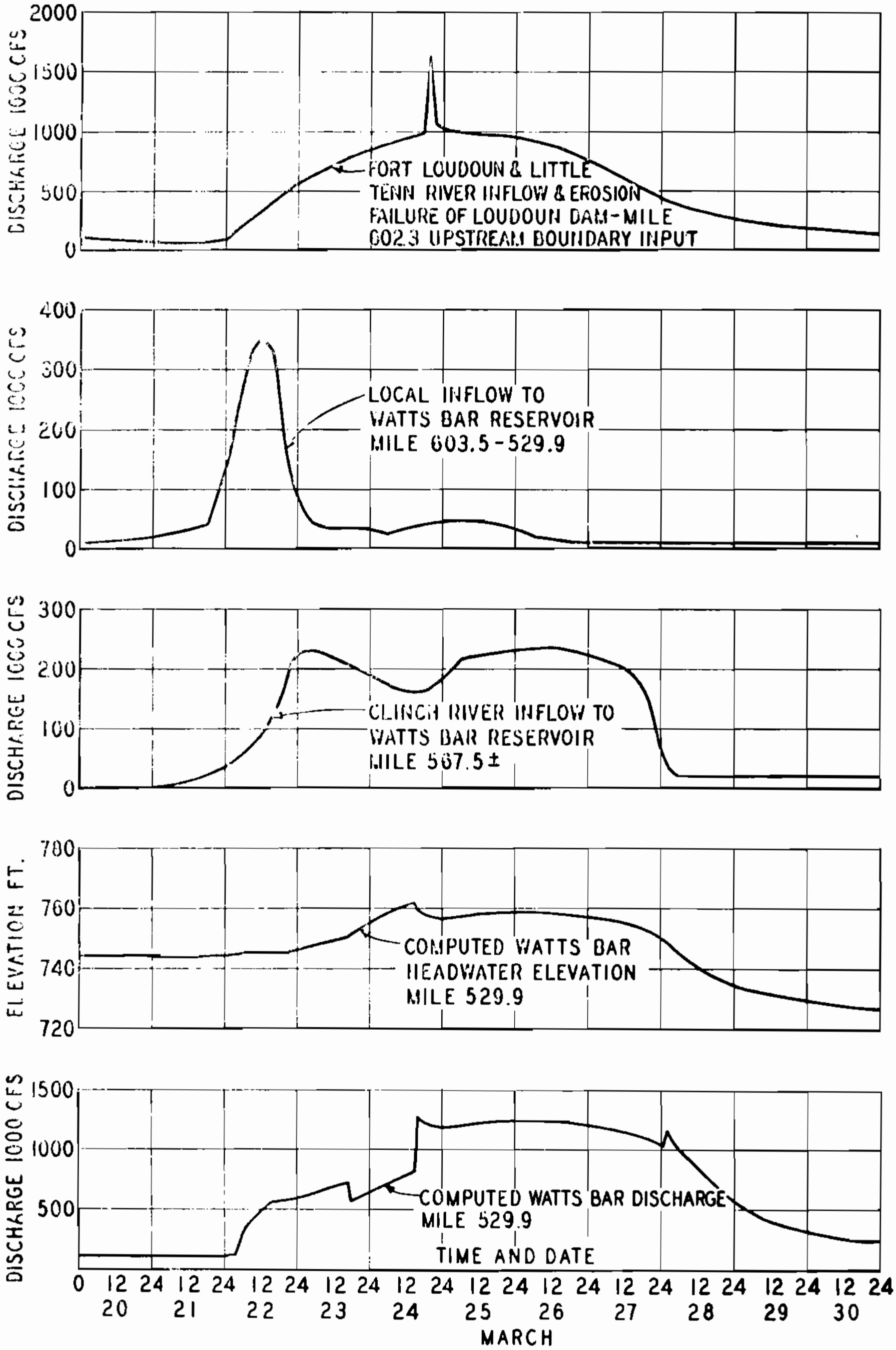


FIG.12-WATTS BAR RESERVOIR PROBABLE MAXIMUM FLOOD RESULTS

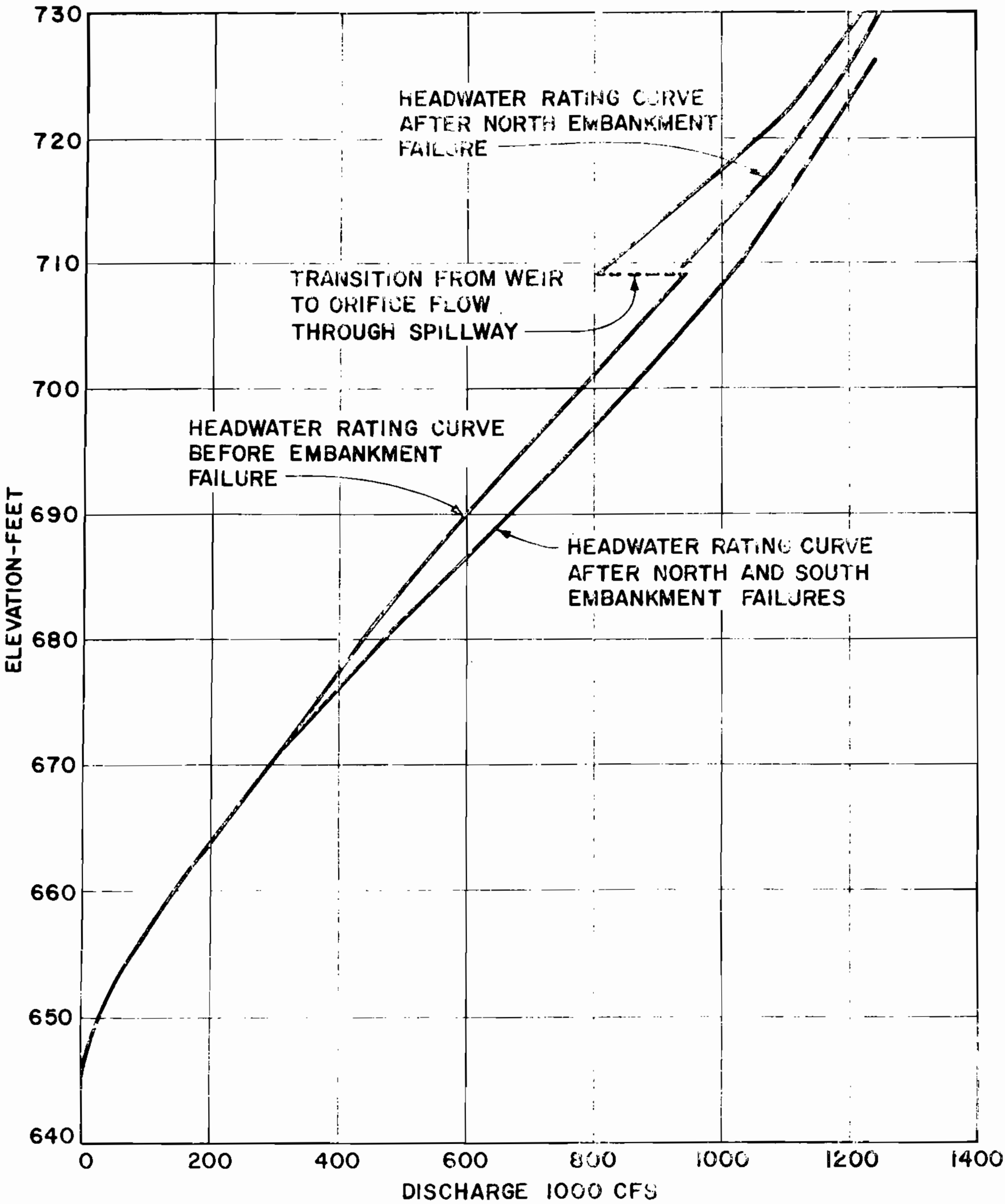


FIG. 13 - CHICKAMAUGA DAM RATING CURVES

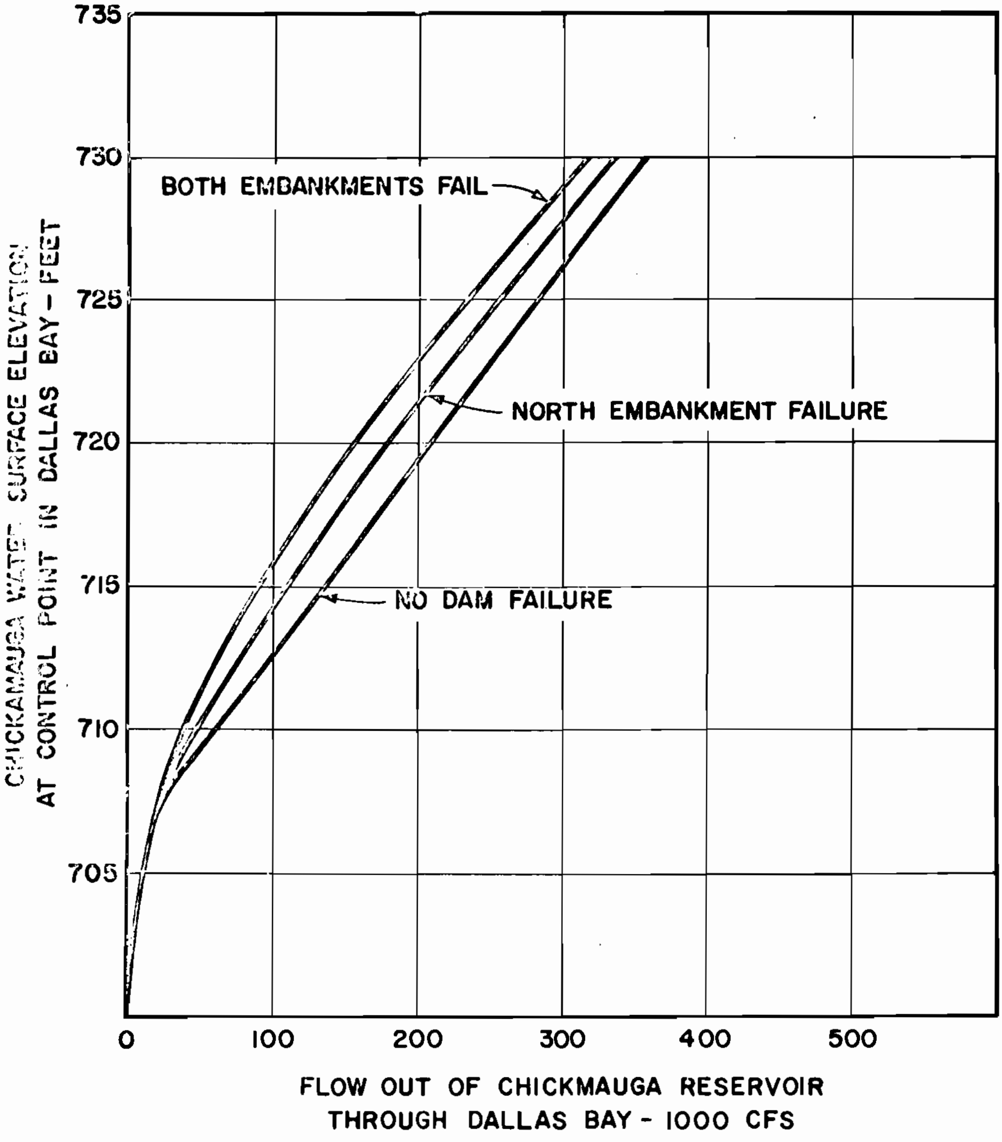


FIG. 14-DALLAS BAY RATING CURVES

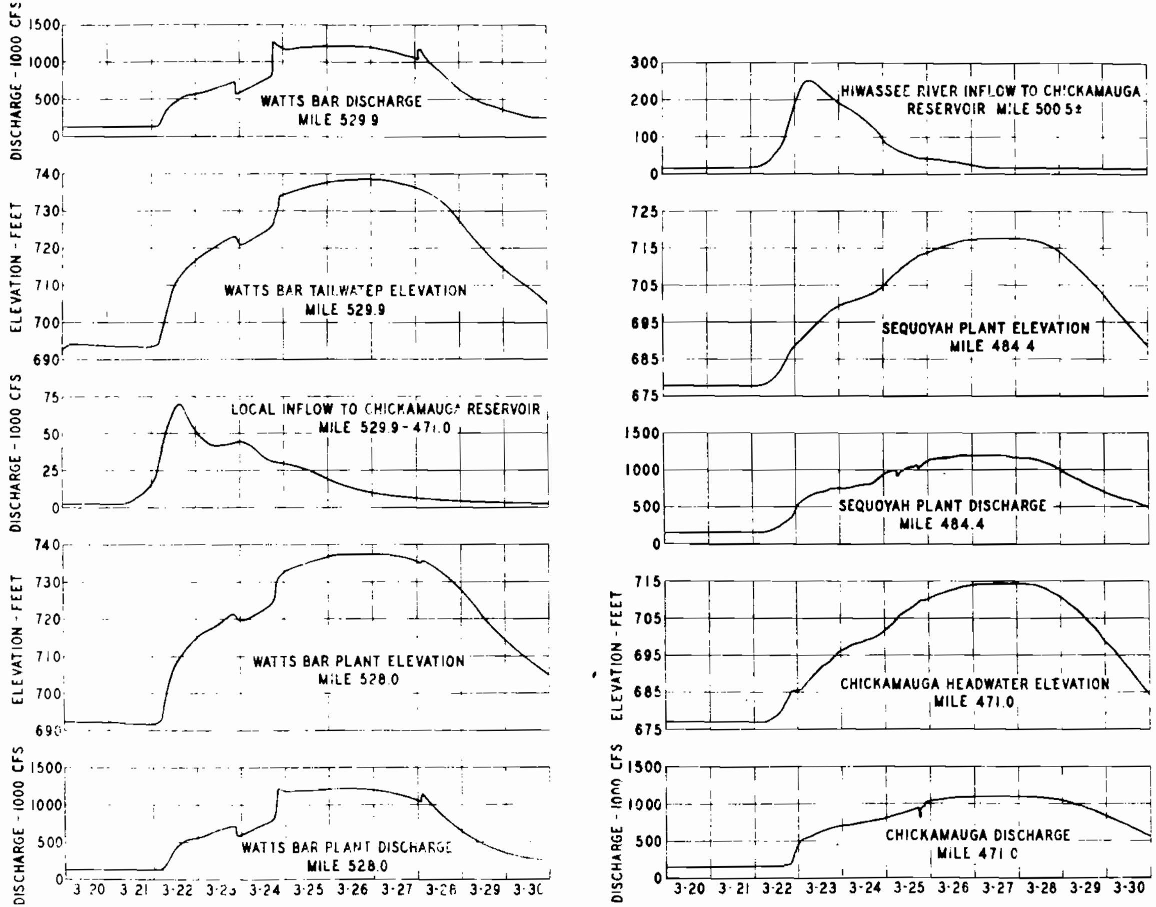


FIG. 15 - CHICKAMAUGA RESERVOIR RESULTS - PROBABLE MAXIMUM FLOOD

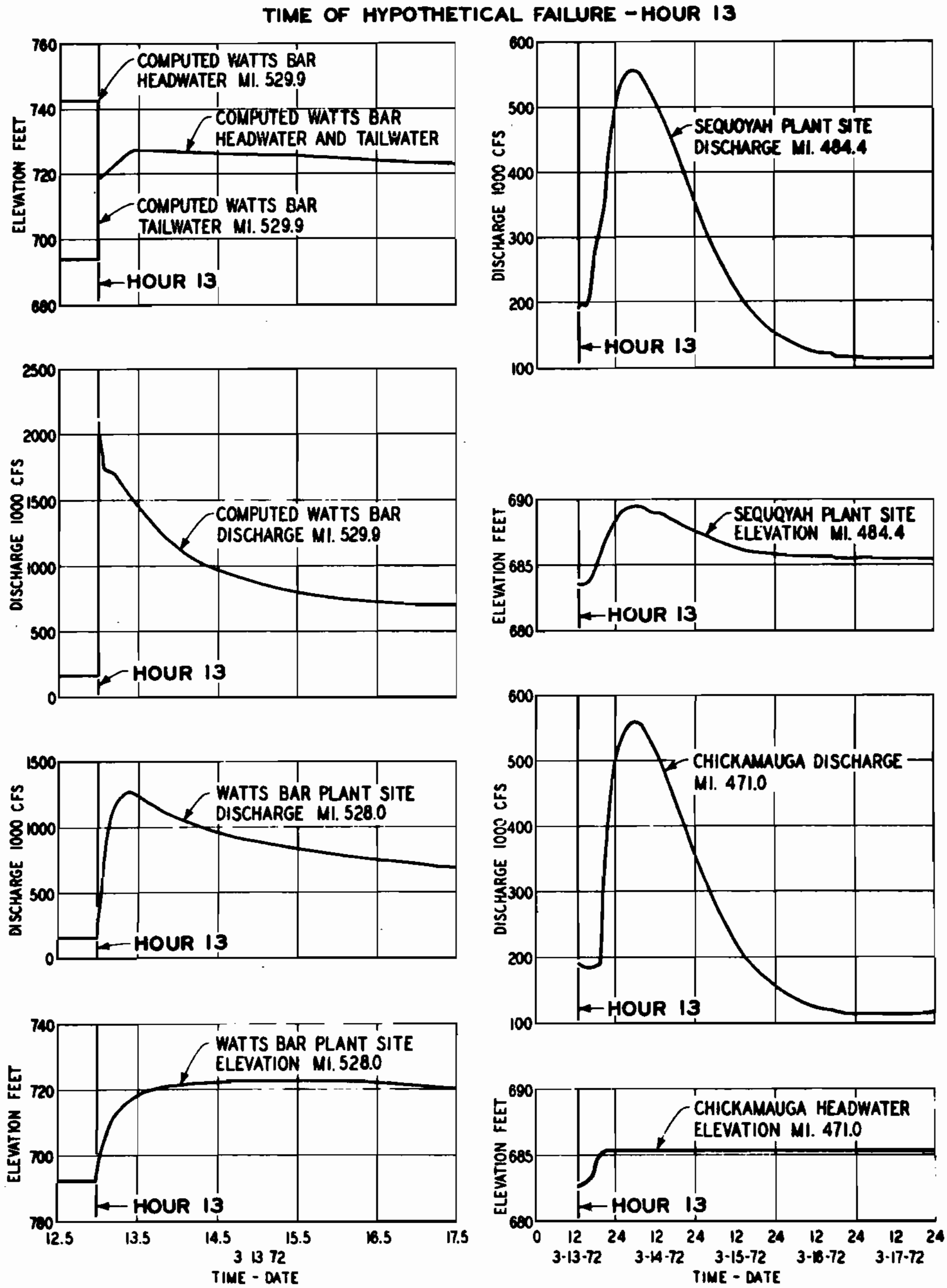


FIG. 16-WATTS BAR AND CHICKAMAUGA RESULTS - 1963 FLOOD WITH HYPOTHETICAL TOTAL FAILURE OF WATTS BAR DAM

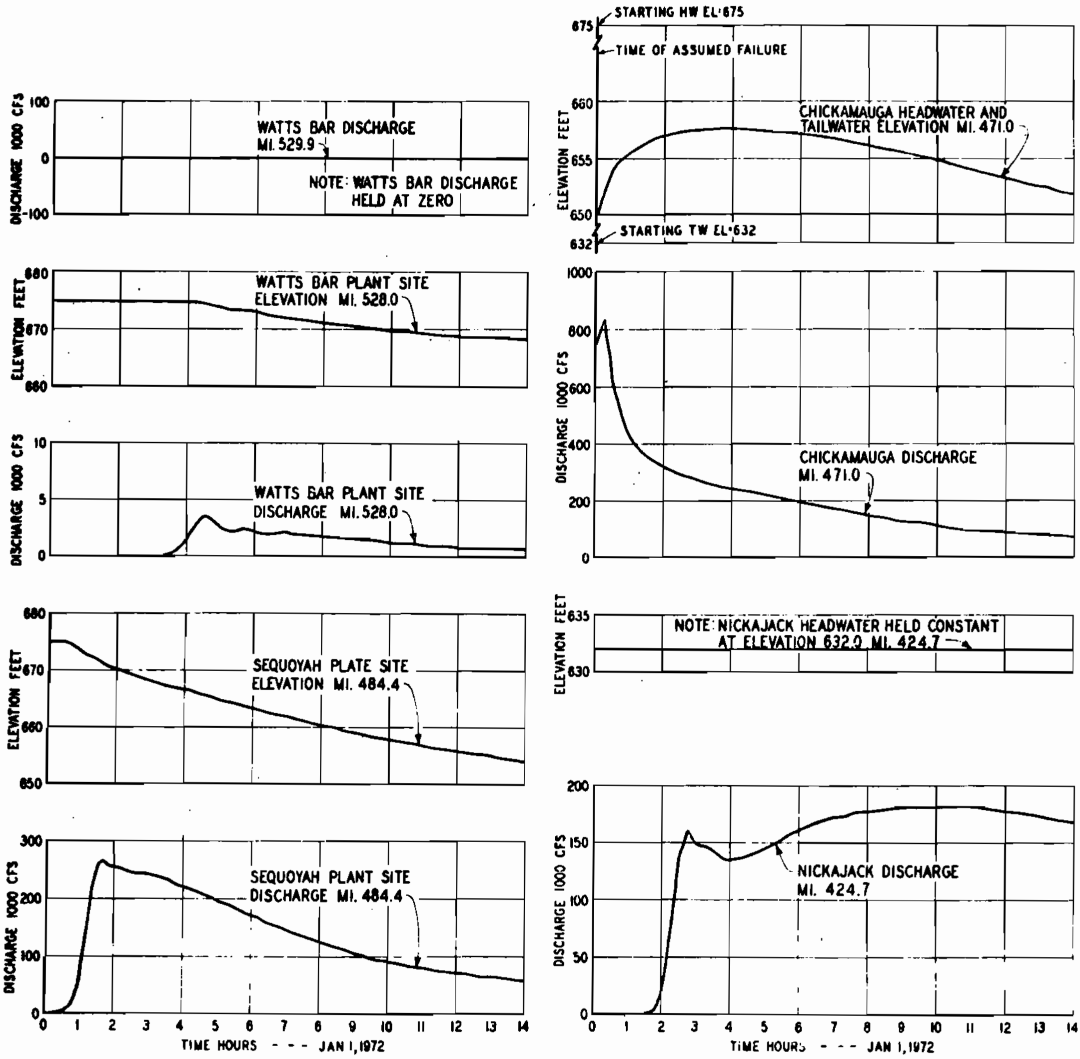


FIG. 17 CHICKAMAUGA AND NICKAJACK RESULTS – NORMAL WINTER DRAWDOWN CONDITIONS WITH TOTAL FAILURE OF CHICKAMAUGA DAM

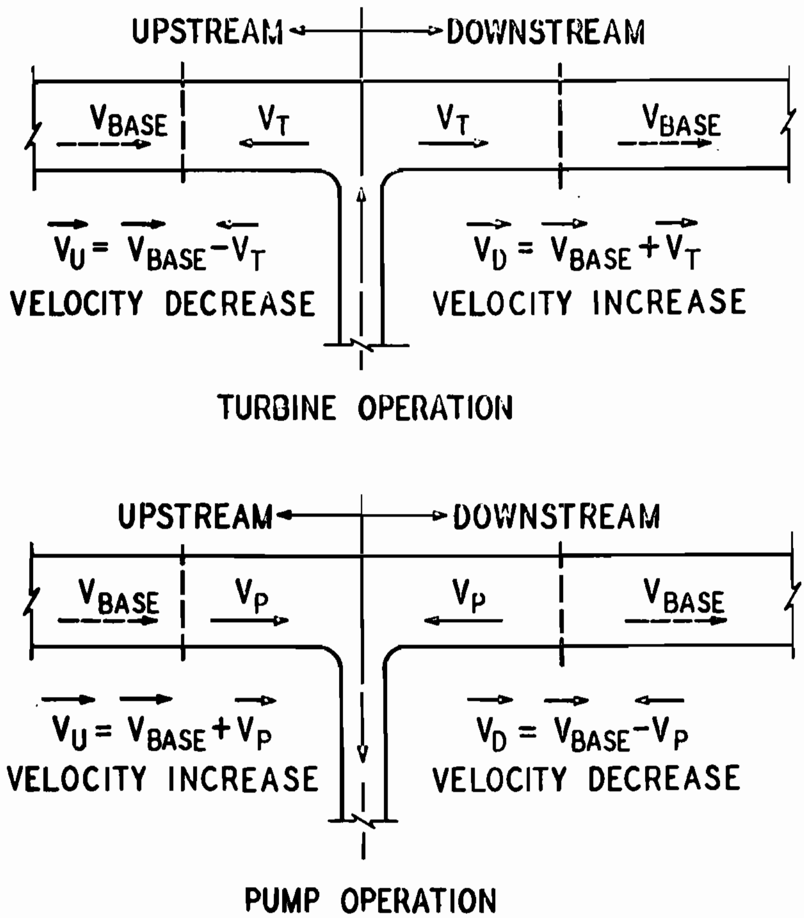


FIG. 18–EFFECT OF PUMPED-STORAGE PLANT ON RESERVOIR FLOW

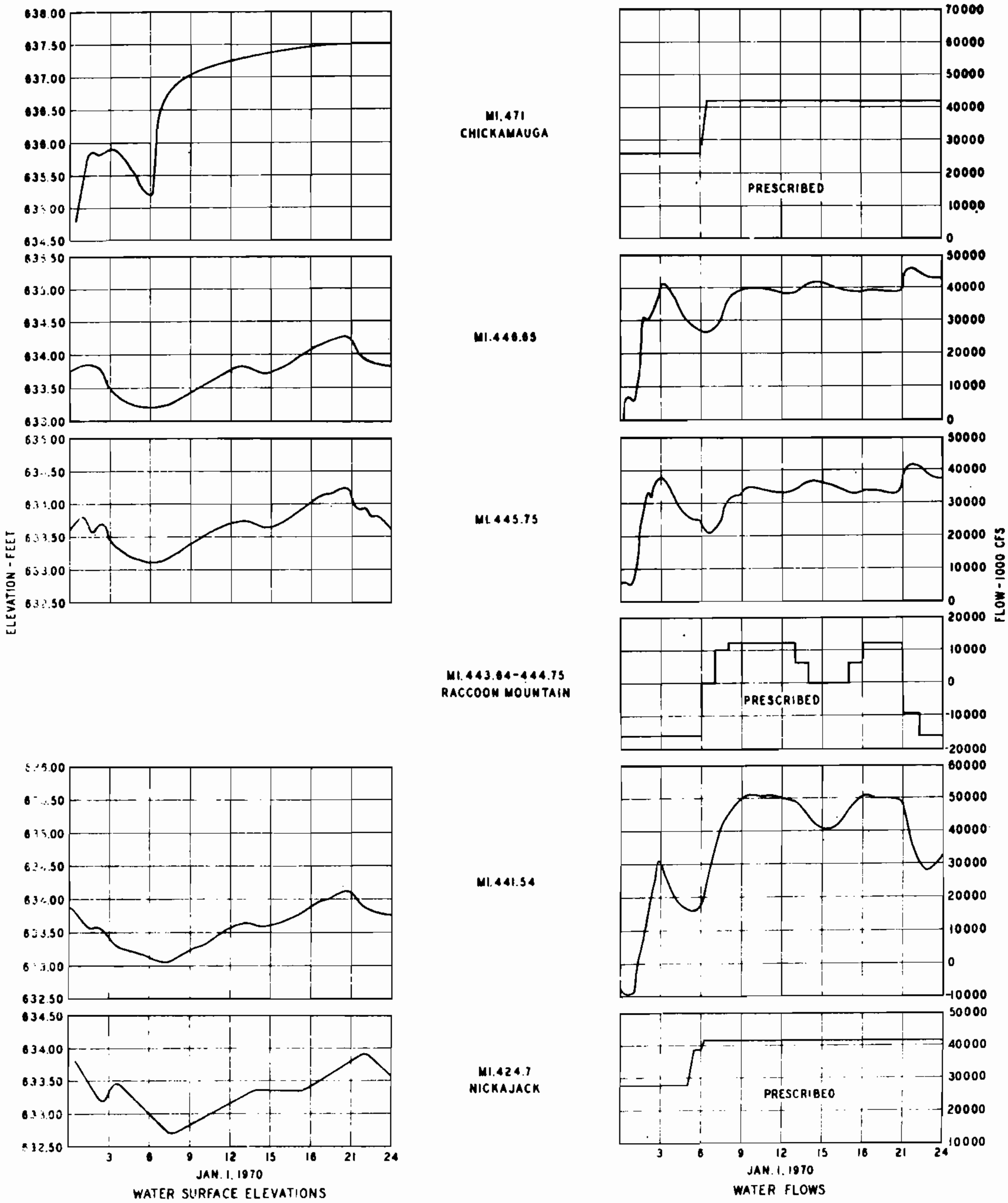


FIG. 19 TRANSIENT FLOW RESULTS – NICKAJACK RESERVOIR

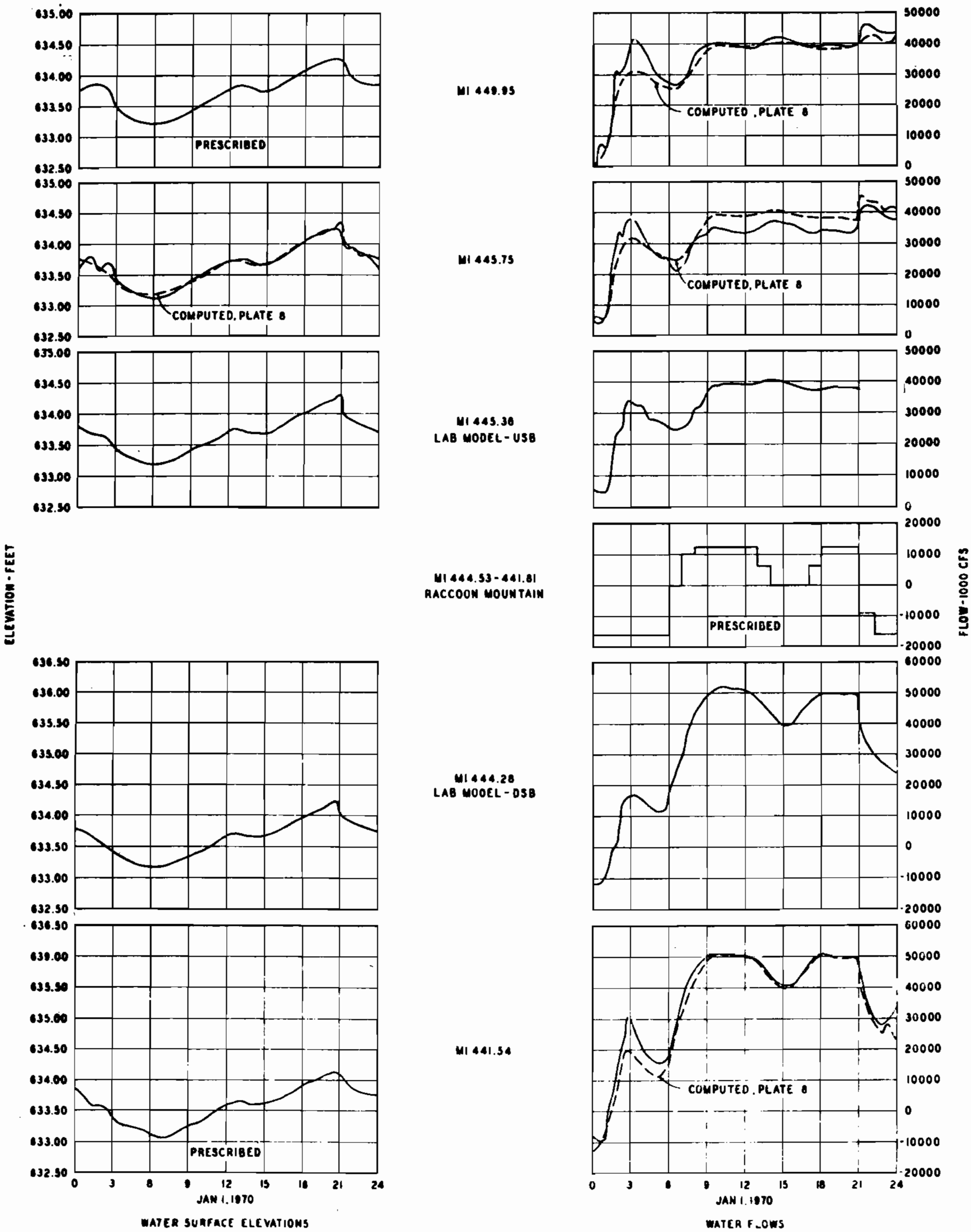


FIG. 20-TRANSIENT FLOW RESULTS - MI 441.54-449.95, NICKAJACK RESERVOIR

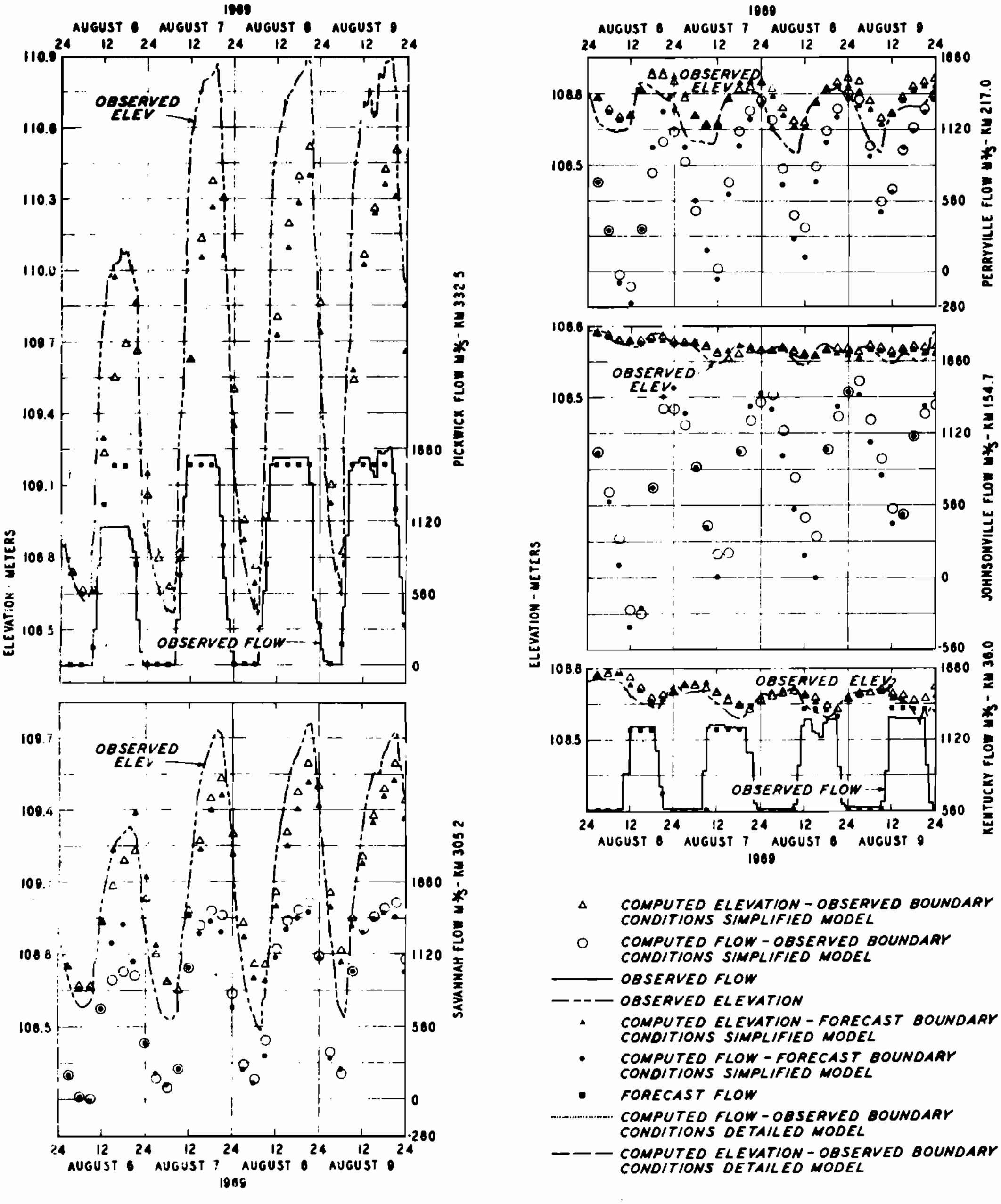


FIG. 22 - COMPARISON OF OBSERVED AND FORECAST FLOW CONDITIONS

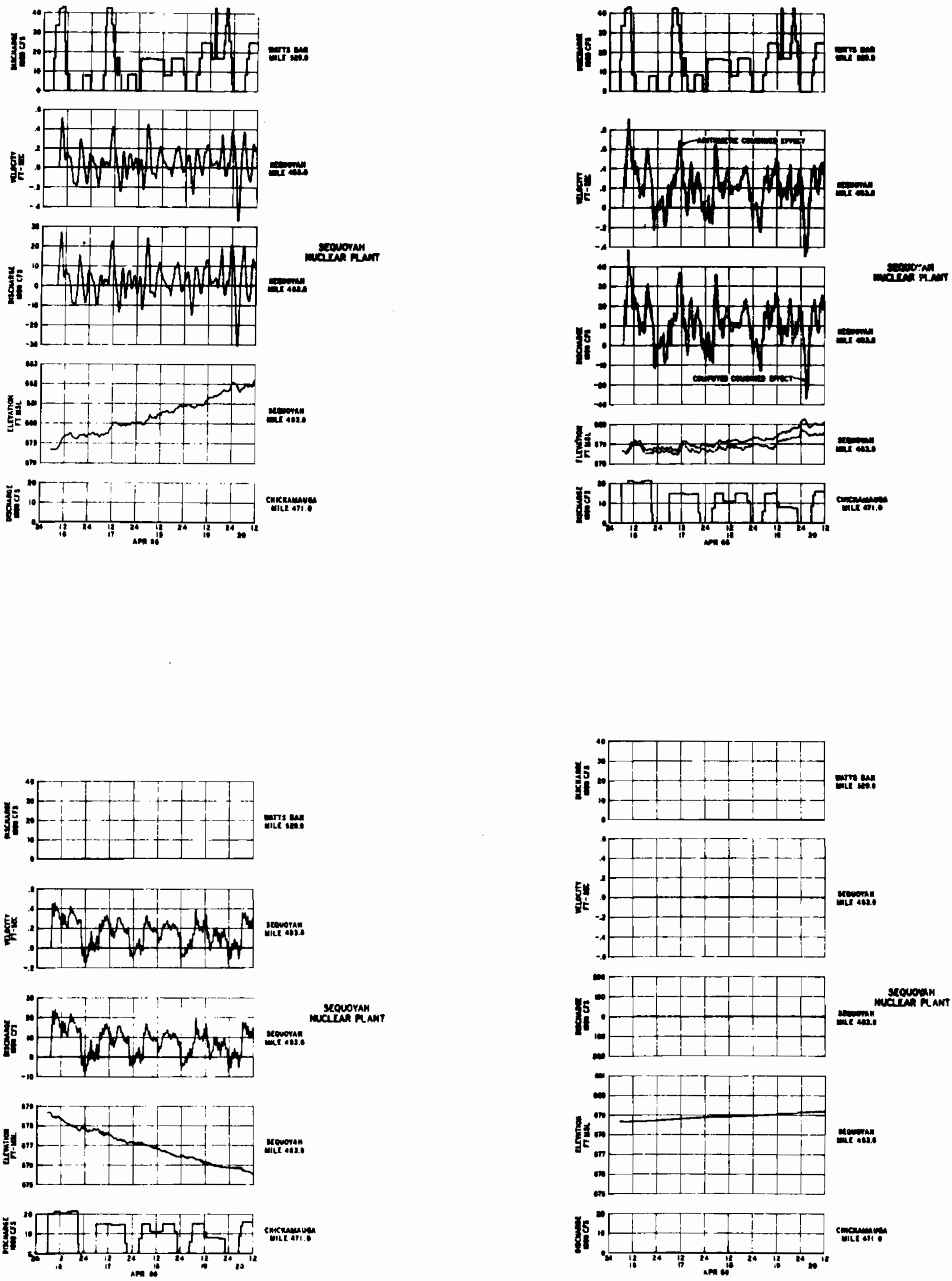


FIG. 23 - MODEL INPUT SEPARATION TECHNIQUE

HEAT TRANSPORT MODELS FOR RIVERS AND RESERVOIRS

1. INTRODUCTION

Water resource management systems with storage capacity can control and redistribute the natural runoff for a wide variety of purposes, such as flood protection, power production, water supply for industries and municipalities, low flow augmentation, irrigation and recreation. Generally, this control is accomplished by impounding water during periods of surplus for periods of need. As a consequence of such quantitative water regulation, considerable changes to the qualitative regime of the regulated water courses occur sometimes reaching over large distances. As an example the monthly temperature regime of the Tennessee River and its main tributaries for the month of July is shown in figure 1. While the natural temperature at this time of the year is about $86^{o}F$, considerably lower temperatures occur downstream from dams. A warming trend extending over more than 200 miles downstream from the major tributary storage reservoirs tends to bring the temperatures back to the natural regime.

Generally reservoirs have a beneficial effect on water quality but it is recognized that the program of impoundment and streamflow regulation for purposes of navigation, flood control, and power production may exert deleterious effects on water quality and on the waste assimilative capacity of the streams. It is TVA's goal to operate the reservoirs such as to minimize detrimental influences on water quality and to give due account to reasonable downstream uses. As an implementation of this policy, studies have been conducted for a number of years to observe, to analyze and to make amenable to prediction the effects of reservoir operations on the water quality in the river-reservoir system.

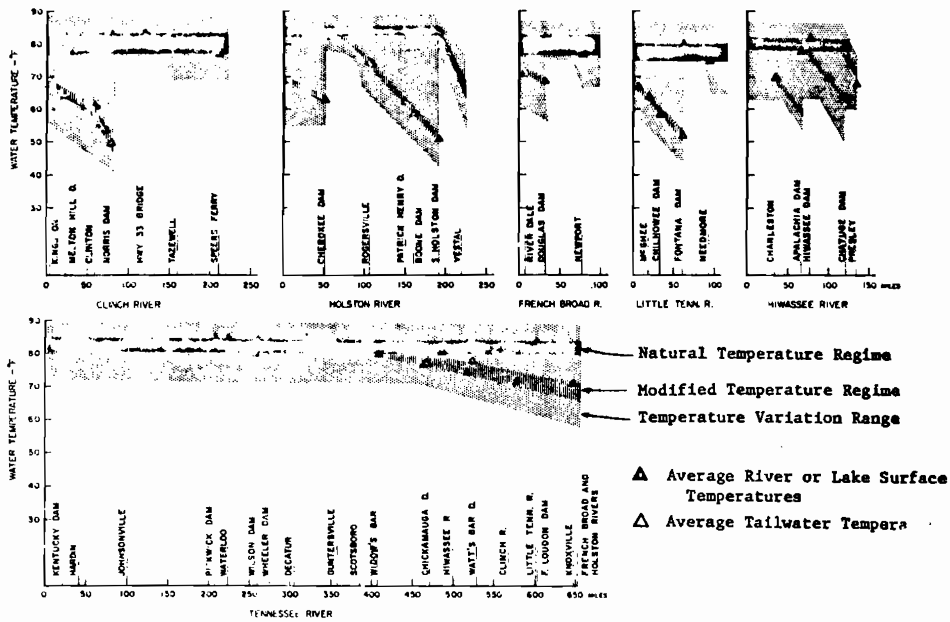


FIGURE 1 WATER TEMPERATURES IN THE TENNESSEE RIVER AND TRIBUTARIES - AVERAGE JULY TEMPERATURES

The study of water movements through density stratified reservoirs has received considerable attention in TVA. Also, the computation methods for heat transfer across the water surface were reviewed, tested and updated because of their important role in the modeling of reservoir thermo-hydrodynamics as well as in heat dissipation computations for steam plant sites. In the following chapters, a brief account will be given of the methods used and experiences gained.

In Chapter 2 the basic heat balance equation is introduced and simplified versions for practical use are discussed. In Chapter 3 the surface heat transfer computation method is described and illustrated by examples. In Chapter 4 river temperature prediction methods and application examples are presented. In Chapter 5 a one-dimensional deep reservoir temperature prediction model is described and examples are presented of computed and measured temperature distributions over the reservoir depth and of computed internal flow velocities. Also, experiences are described with attempts to expand the existing one-dimensional temperature prediction model into a segmented model and to include other water quality parameters besides temperature into reservoir water quality prediction.

2. BASIC HEAT TRANSPORT EQUATIONS

Water flow combined with heat transport can be described mathematically by the modified Navier-Stokes equations for turbulent three-dimensional flow, the continuity equation for water, the heat conservation equation and the state equation relating density and temperature. For all practical purposes, water is considered incompressible and all volume changes due to density changes are neglected. Only the density differentials associated with flow momentum must be considered which relate density, temperature and dissolved solid concentrations with flow patterns. In turbulent shallow rivers all density influences on the flow pattern can generally be negelected so that the water flow equations and the heat transport equation can be treated independently. For deep reservoirs this simplification generally does not apply (Chapter 5).

For brevity, only the heat balance equation will be discussed in the following. The temperature change in time for a volume element dx dy dz can be expressed by

$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z}$$

$$+ \frac{\partial}{\partial x}\left(D_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial T}{\partial z}\right) + \frac{1}{\rho c}\frac{\partial q_h}{\partial y} \quad (2.1)$$

in which T is water temperature; u, v and w are velocity components in the x, y and z directions; t is time; D_x, D_y and D_z are turbulent heat diffusivities; c is the specific heat of water; ρ is the density of water;

$\partial q_h / \partial y$ is the gradient of an internal heat source flux per unit horizontal area per unit vertical distance and time.

The density-temperature - and if applicable - dissolved solids relationship can be approximated by

$$\rho = \rho_o \ (1-k \ (T-4)^2) + C \tag{2.2}$$

where ρ_o is the density of pure water at 4^oC; k is a factor and C is the dissolved solid concentration in water.

In fully-mixed rivers with rather homogeneous cross sections heat transport in the flow direction (x) can be described by the one-dimensional equation

$$\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} - D_L \frac{\partial^2 T}{\partial x^2} = \frac{q_h}{\rho c d} \tag{2.3}$$

where D_L is a longitudinal dispersion term composed of turbulent diffusion in the x, y and z directions; q_h is the net heat flux through the water surface, and d is the total depth of the river. A numerical method suggested by King (1973) was used to numerically integrate equation (2.3) with q_h being a nonlinear function of water temperature and of time evaluated at every computation step. Discrepancies between results and observed data were found for unsteady flow conditions probably caused by inaccuracies in the description of the river reaches. It was also found that in many practical cases the dispersion term had little influence on the results.

Neglecting the dispersion term and the unsteady temperature term $\partial T / \partial t$ yields the simple but useful steady-state heat transport equation

$$u \ \partial T / \partial x = q_h / (\rho c d) \tag{2.4}$$

Reentering of the unsteady temperature term and introducing the total differential

$$\frac{dT}{dt} = \frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x}$$

where $u = dx/dt$

yields a simple equation for unsteady temperature regimes

$$dT/dt = q_h/(\rho c d) \tag{2.5}$$

In deep water bodies with small velocities, density gradient effects can become strong enough to stabilize water particles at their density level and thus suppressing turbulent vertical mixing and heat transfer. This effect leads to further strengthening of density gradients and to increased stability. This phenomenon can be observed during the summer season in many reservoirs and is known as thermal stratification. The same phenomenon does not inhibit horizontal water movements which become more persistent due to reduced internal mixing and are known as density currents. Based on this simplified model of a stratified reservoir and its dynamics, the reservoir can be cut into horizontal layers and a simplified heat balance equation can be applied to each of them

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} - D_v\frac{\partial^2 T}{\partial y^2} = \frac{1}{\rho c}\frac{\partial q_h}{\partial y} \tag{2.6}$$

with u being the advection velocity by density currents in the horizontal and v the vertical advection velocity due to different amounts of inflow and withdrawal at their respective density or withdrawal levels and water level variations. Much controversy exists about the overall vertical dispersion term D_v. Orlob and Selna (1970) suggest semi-empirical vertical distribution of D_v; Ryan and Harleman (1971) suggest the use of molecular heat diffusivity. Field data (Wunderlich and Fan, 1971) indicate that D_v is probably larger than molecular diffusion and a value of 30 times the molecular heat diffusivity is used in the temperature model described in Chapter 5. The heat source term $\partial q_h / \partial y$ is the gradient of solar radiation flux as function of depth. An explicit numerical integration of equation (2.6) is described in Chapter 5.

3. SURFACE HEAT TRANSFER COMPUTATION METHOD

In this chapter the surface heat transfer function is derived, the equilibrium temperature is defined and its use is illustrated by examples.

The heat transfer function and the equilibrium temperature as derived here are applicable without modification only to fully mixed water bodies with the heat exchange assumed to affect instantaneously the entire depth. The surface heat exchange in a stratified lake is explained in TVA (1973).

The net heat transfer across the water surface is computed as the summation of different types of heat fluxes.

$$q_h = (q_s - q_{rs} + q_a - q_{ra}) + (-q_w - q_e - q_m \pm q_{aw}) + (+q_{bw} \pm q_{ad}) \tag{3.1}$$

Where q_s is solar radiation, q_{rs} is reflected solar radiation, q_a is atmospheric radiation, q_{ra} is reflected atmospheric radiation, q_w is water surface radiation, q_e is evaporation heat transfer, q_m is advective heat transfer by evaporated water, q_{aw} is air-water interface convection and conduction, q_{bw} is boundary-water interface conduction, and q_{ad} is advection heat transfer. The first group of terms on the right side of equation (3.1) is independent of water surface temperature while the second group of terms is dependent on water surface temperature. The third group of terms on the right side as well as q_m are functions of the amount and temperature of advected water and are generally considered insignificant. For more details on heat transfer terms see TVA (1972).

Equation (3.1) can be more conveniently used in the heat transport equations by expressing q_h as a function of surface temperature. To avoid linearizations of individual terms it was found most practical to compute q_h for selected water temperatures from 0 to 40°C at 5°C intervals and then to use a quadratic least square fit

$$q_h = A\,T^2 + B\,T + C \tag{3.2}$$

to obtain the empirical coefficients A, B and C valid over the entire range of natural temperatures for the selected time period. Generally a temperature T_E exists for which the net heat exchange q_h is zero. Hence, for $q_h(T_E) = 0$, (the positive solution of) equation (3.2) yields the "meteorological" equilibrium temperature

$$T_E = -(B/2A) + \sqrt{(B/2A)^2 - C/A} \tag{3.3}$$

The net heat exchange can also be expressed in the sometimes useful form

$$q_h = -k(T-T_E) \tag{3.4}$$

with k being a heat transfer coefficient. Dividing (3.2) by $-(T-T_E)$ yields for the heat transfer coefficient

$$k = -A(T+T_E) - B \tag{3.5}$$

Equation (3.5) shows that k is generally not constant but depends on the surface temperature T. Characteristic heat flux terms and heat transfer coefficients as function of water surface temperature are given in table 1.

A graphical interpretation of the heat transfer function $q_h = q_h\,(T)$ and of the equilibrium temperature defined as $q_h(T_E) = 0$ is shown in figure 2.

TABLE 1 HEAT FLUX TERMS AND HEAT TRANSFER FUNCTIONS

Heat fluxes are in kcal/(m^2hr)

Heat transfer coefficients are in kcal/(m^2hr °C)

Month: 5 (May) Year: 1954

q_{sn} = 199 q_{an} = 284

Water Temp. T°C	q_w	q_e	q_{aw}	q_h	k
0	-263	46	74	340	14.5
5	-283	29	53	282	15.9
10	-304	6	31	216	17.3
15	-326	- 24	10	143	18.6
20	-350	- 64	-11	58	20.0
25	-374	-116	-33	- 40	21.4
30	-400	-183	-54	-154	22.8
35	-427	-267	-76	-287	24.1
40	-455	-375	-97	-444	25.5

Heat transfer function: $q_h = -0.2751\ T^2 - 8.22\ T + 332.9$

Heat transfer coefficient: $k = 0.2751\ (T + T_E) + 8.22$

Month: 7 (July) Year: 1954

q_{sn} = 213 q_{an} = 348

Water Temp. T °C	q_w	q_e	q_{aw}	q_h	k
0	-263	92	97	487	14.7
5	-283	78	80	436	15.8
10	-304	60	63	380	16.9
15	-326	36	46	317	18.0
20	-350	4	29	244	19.2
25	-374	- 37	12	162	20.3
30	-400	- 90	- 5	66	21.4
35	-427	-158	-22	- 46	22.5
40	-455	-243	-39	-176	23.6

Heat transfer function: $q_h = -0.2231\ T^2 - 7.35\ T + 481.1$

Heat transfer coefficient: $k = 0.2231\ (T + T_E) + 7.35$

---

*indices sn and an refer to "net" incoming radiation, with reflection the water surface deducted: $q_{sn} = q_s - q_{sr}$; $q_{an} = q_a - q_{ar}$.

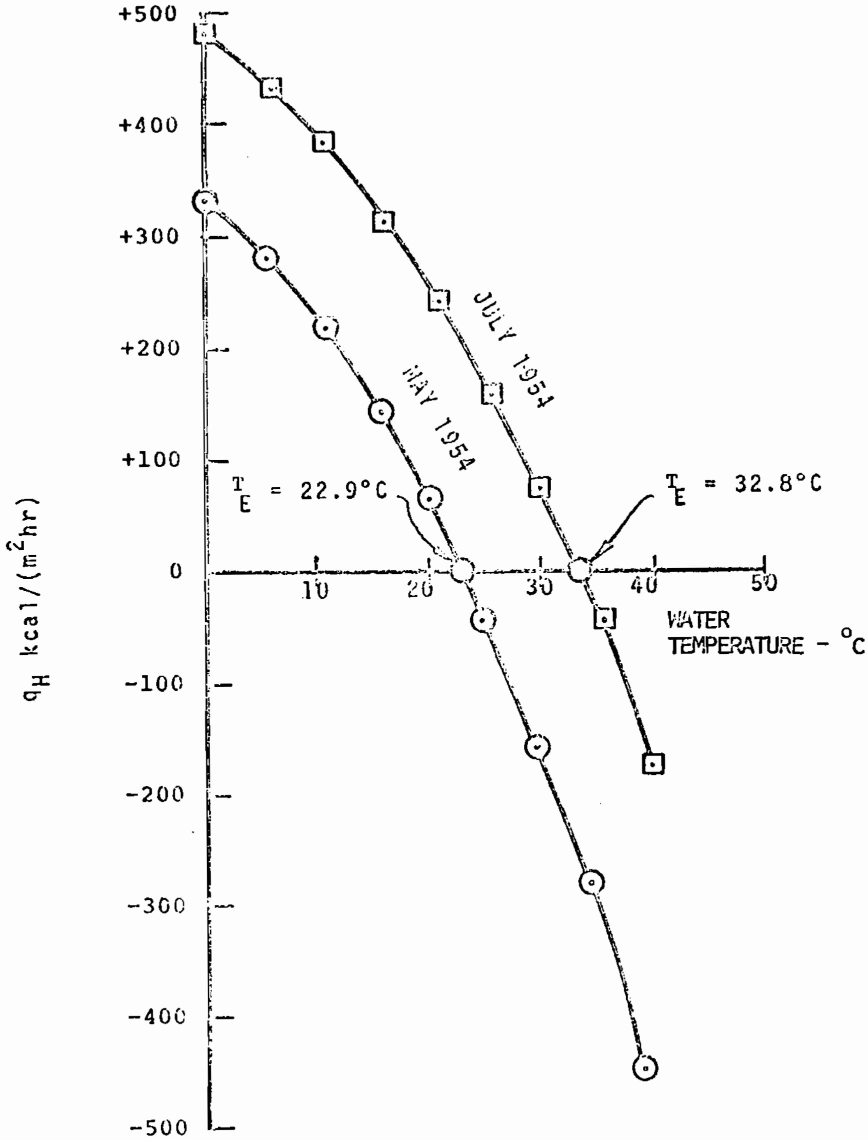


FIGURE 2 HEAT TRANSFER FUNCTION $q_h = q_h(T)$ AND EQUILIBRIUM TEMPERATURE T_E

The equilibrium temperature concept for a steady-state flow and temperature regime is illustrated in figure 3 in context with a thermal discharge source. Depending upon the resulting stream temperature rise ΔT and the local stream temperature's position with respect to equilibrium temperature, the warming trend may continue downstream(a), equilibrium temperature may just be reached with zero net heat exchange afterwards(b) or heat dissipation may result(c). Only in this last case, a frequent one, can streams be considered as having a heat dissipation capability. There are, however, many large rivers which only have dilution capability.

An unsteady diurnal temperature regime of a water body (or water slug travelling downstream) exposed to a sequence of meteorologically similar days is shown in figure 4. The diurnal regime of the meteorological equilibrium temperature can be computed by hourly application of equation (3.3). This temperature can be interpreted as the temperature of a water body of zero depth (Chapter 4). For a water body of finite depth the diurnal temperature amplitude is reduced to a few degrees.

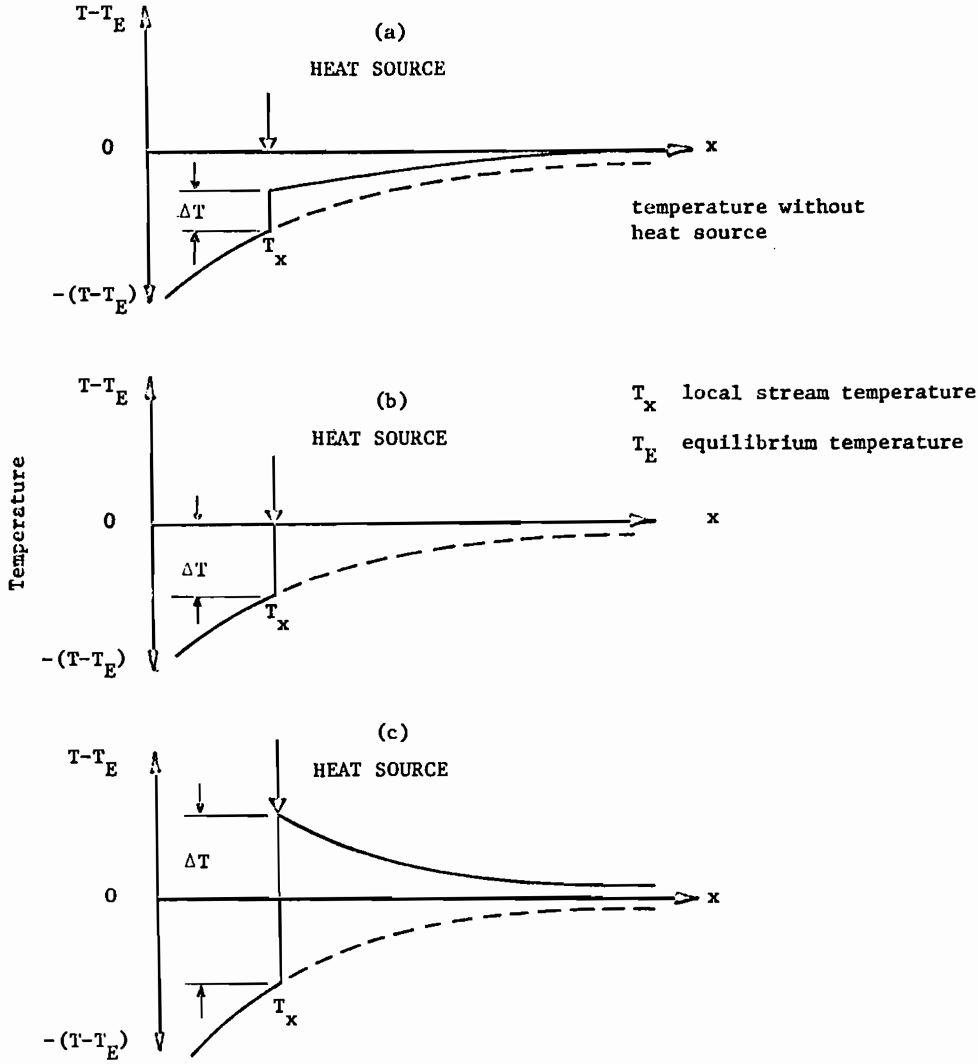


FIGURE 3 EFFECT OF HEAT SOURCE ON STREAM TEMPERATURE REGIME

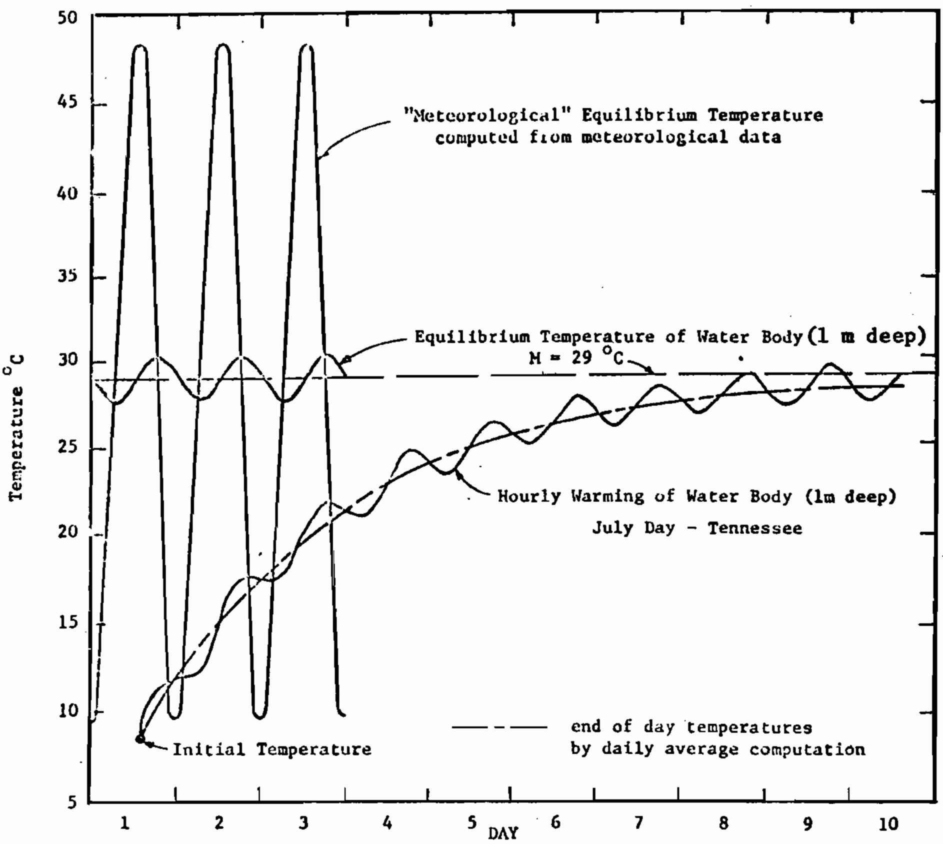


FIGURE 4 DIURNAL STREAM TEMPERATURE REGIME

4. RIVER TEMPERATURE PREDICTION MODELS

Computation methods for steady and unsteady temperature regimes will be described which have been used in planning studies.

Of considerable practical interest is the distance downstream from dams (cold releases) or steam plants (hot releases) over which the gradual approach to natural temperature occurs. In planning studies where steady-state temperature computations have been mostly used the nonlinear heat transfer equation (3.2) was combined with the steady-state heat transport equation (2.4) to yield after integration and rearrangement of terms (TVA, 1971)

$$(T_E-T)/(T_E-T_0) = zP \qquad (4.1)$$

with $P = \exp(-k_E W x/(\rho c Q))$; z a correction factor for the temperature dependence of k, varying from about 1.35 for water warming from very low temperatures ($T_E-T_0 = 20^oC$) to 0.80 for water cooling from very high temperatures ($T_E-T_0 = -20^oC$); exp is the exponential function with basis e; W is the width of the reach; x is the length of the reach, Q is the flow in the reach and T_o is the starting temperature. A nondimensional presentation of equation (4.1) is shown in figure 5. The solid line in the figure represents the temperature regime for small departures from equilibrium temperature for which the heat transfer coefficient at equilibrium temperature is representative.

Data collected on the Clinch River for the month of July are presented in figure 6 as suggested by the theory for discharges ranging from 500 to 5000 ft^3/s*. As can be seen from the figure the data indicate

*14 to 140 m^3/s; the data were not collected for this purpose and the equilibrium temperature had to be estimated.

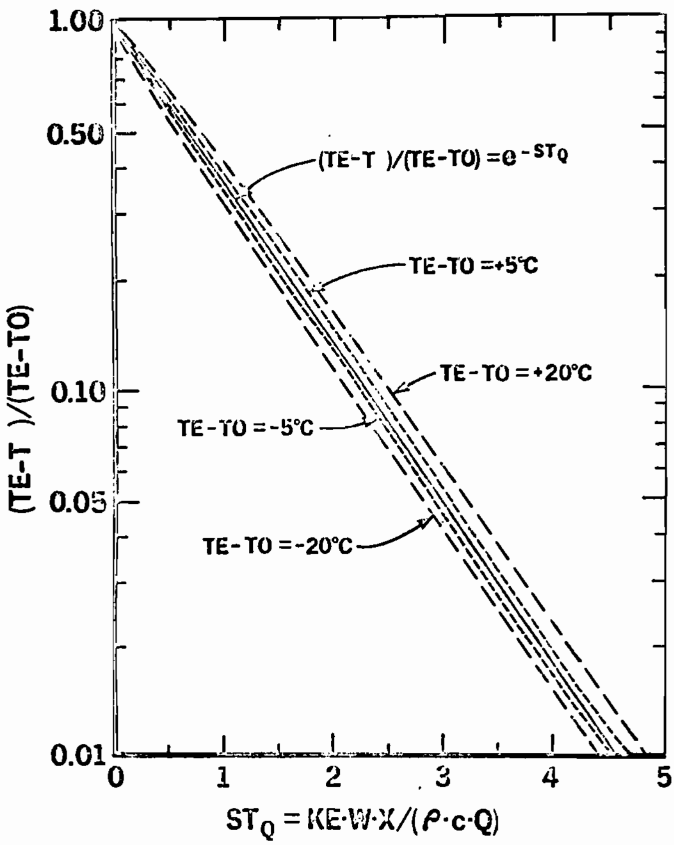


FIGURE 5 GRAPHICAL REPRESENTATION OF FULLY-MIXED STREAM TEMPERATURE REGIME

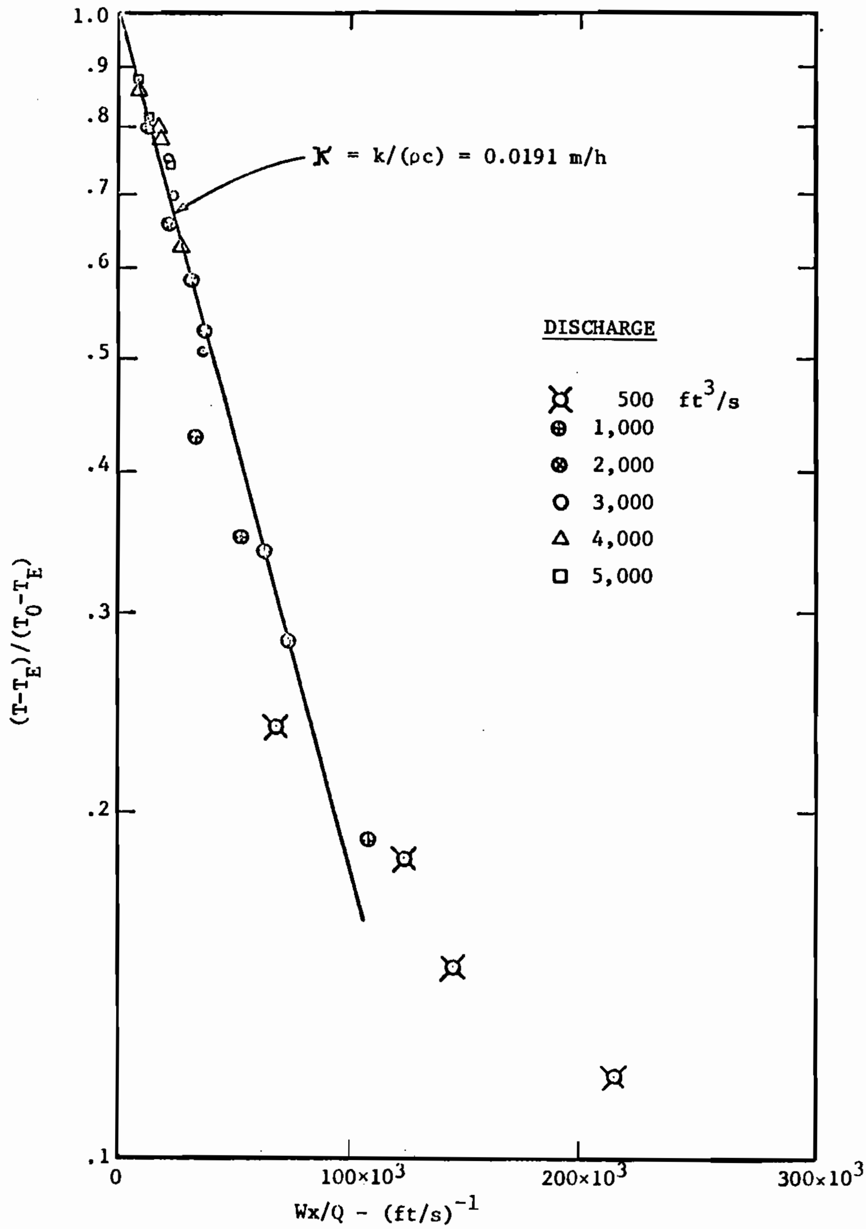


FIGURE 6 CLINCH RIVER - AVERAGE TEMPERATURE REGIME - JULY

exponential warming and produce an average heat transfer coefficient of $k = 19.1$ kcal/(m^2 ^oC h) which is very close to the heat transfer coefficient in table 1 computed from meteorological data.

As an example of unsteady temperature regime, the hourly meteorological equilibrium temperature was approximated by

$$T_E = M + N \cos w(t - \varphi) \qquad (4.2)$$

Integration of equation (2.5) after introducing $q_h = -k(T-T_E)$ with k a daily average yields (see TVA, 1968)

$$T_t - T_{E_t} = (T_o - T_{E_{t_o}})\, e^{-\mathcal{K}(t-t_o)/d} \qquad (4.3)$$

with $\mathcal{K} = k/(\rho c)$ in m/h, a heat transfer velocity; t_o the starting time; d the water depth; T_t the temperature at time t, T_o the starting temperature; $T_{E_{t_o}}$ the equilibrium temperature of the water body at time t_o and T_{E_t} the equilibrium temperature of the water body at time t:

$$T_{E_t} = M + a\,N\ (\cos w\,(t-\varphi) + b \sin w\,(t-\varphi)) \qquad (4.4)$$

The equilibrium temperature at the starting time t_o is obtained by substituting t_o into equation (4.4). The diurnal equilibrium temperature of the water body of depth d, described by equation (4.4), is shown in figure 4, oscillating around the daily mean equilibrium temperature M. Also shown in figure 3 is the "meteorological" equilibrium temperature T_E computed from hourly meteorological data and approximated by equation (4.2). It exhibits a considerably larger amplitude than T_{E_t}. Integration of equation (2.5) shows that "a" as well as "b" are functions of the dimensionless number $\mathcal{K}/(wd)$. For depth d = 0, a becomes 1 and b = 0, making equation (4.4) identical to equation (4.2). Thus the "meteorological" equilibrium temperature can be interpreted as temperature of a water body of zero depth (TVA, 1968). Also shown in the figure is the average daily warming of the water body, with merely the diurnal cyclic temperature fluctuations superimposed on it. It is also demonstrated that daily and longer term averages of water equilibrium and meteorological equilibrium temperatures may be identical despite of being very different on an hourly basis.

An actual event similar to the one described by equations (4.3) and (4.4) is shown in figure 7. It illustrates the warming of the Clinch River during a powerhouse shutdown period of about eight days. After five days, the water has reached equilibrium temperature. Such warming trends may be important for the survival of cold water fish species in rivers regulated by power operations.

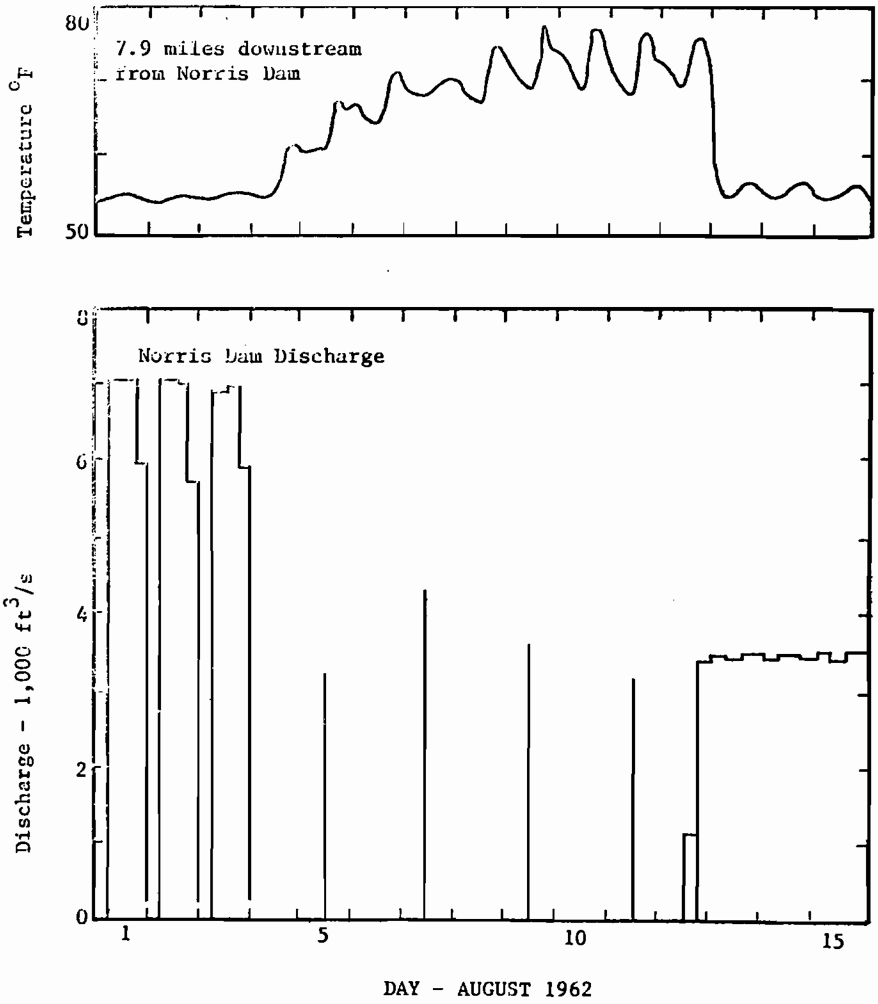


FIGURE 7 DIURNAL TEMPERATURE REGIME OF CLINCH RIVER DURING POWERHOUSE SHUTDOWN PERIODS

5. RESERVOIR TEMPERATURE PREDICTION MODELS

In the first section of this chapter, a deep reservoir temperature prediction model is described. Selected results obtained by the model on two large TVA tributary reservoirs are compared with field data. In the next two sections two extensions of this model are discussed, one with the purpose to accommodate longitudinal temperature variations and the other to include additional important water quality parameters into the prediction method besides temperature.

5.1 One-Dimensional Deep Reservoir Temperature Prediction Model

The model represents a solution by simulation techniques of the heat conservation equation (2.6) simultaneously with the water mass conservation equation and a simplified description of the flow field instead of a more rigorous but also much more expensive solution of the complete set of equations describing the time varying flow-temperature field represented by a stratified reservoir. A schematization of the problem is shown in figure 8. The model is described in detail in TVA (1973) and is based on a model by Ryan and Harleman (1971). The following is a brief summary of the salient features of the model.

The flow field is represented by inflow, outflow and vertical advection. Outflow can be caused by turbine, sluice or spillway discharge. The velocities are assumed horizontal and the thickness of the selective withdrawal layers caused by these outflows is computed by a trial and error method starting with a withdrawal layer equal to the height of the intake opening and successively expanding it to the required size

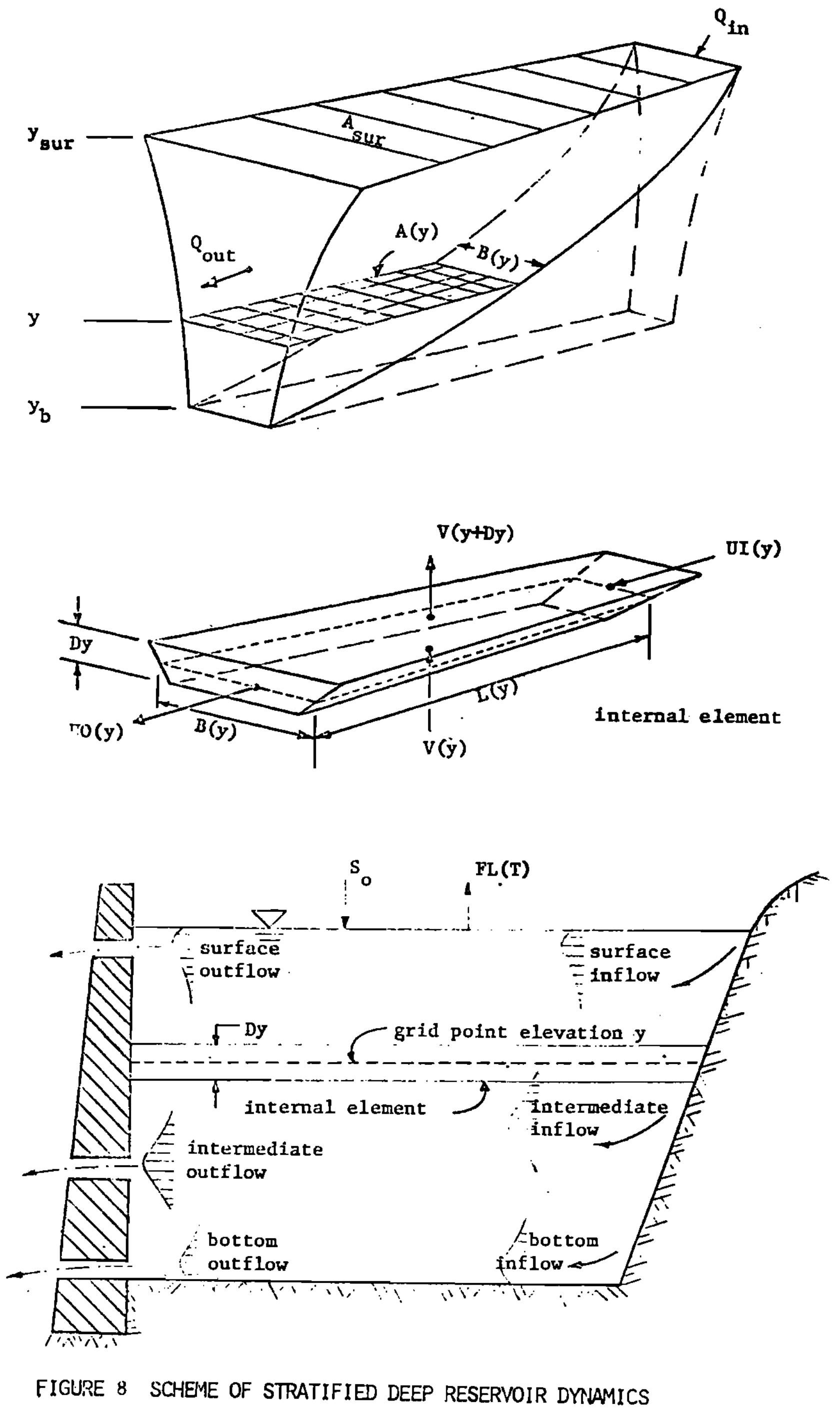


FIGURE 8 SCHEME OF STRATIFIED DEEP RESERVOIR DYNAMICS

depending on density gradient and discharge. A withdrawal layer formula based on average velocity and density gradient across the withdrawal zone is used (TVA, 1969) which was found well suited for irregular reservoir cross sections.

Generally, the hydro plants are operated intermittently to supply peaking power. The withdrawal is, therefore, computed for peak discharges which are most of the time considerably larger than the daily average discharges. It is assumed that these discharges correspond to best efficiency discharge which is computed as function of head. The number of operating turbines is computed from average plant-use data and the daily discharge. Best efficiency discharge multiplied by the estimated number of units yields the peak discharge used in the withdrawal layer computation.

Also inflow velocities are assumed horizontal. Both inflow and outflow velocities are assumed to be vertically distributed in form of Gaussian error functions, the spread depending upon the diurnal inflow density variation, density gradient in the reservoir and the computed withdrawal layer thickness, respectively.

After horizontal inflow and outflow velocities for each layer are determined the water balance for each layer yields the vertical advective velocities between the layers. This essentially completes the approximate determination of the internal reservoir flow pattern. With u and v known, the heat transport equation (2.6) is solved for each layer by explicitly computing the new temperature for each layer.

Bottom and surface layers are treated specially to account for specific flow and heat transfer conditions. The possibility of free convection in these layers (vertical water movements caused by density differences only) is accounted for by not allowing major inverse temperature gradients to develop in these layers. If the bottom layer becomes 0.1 °C warmer than the overlying water, vertical free convective mixing is assumed affecting successively as many layers as necessary to eliminate inverse gradients. In the surface layer, volume and heat content change is approximated by allowing change in depth between beginning and end of each time step due to water surface level changes. The new surface temperature is compared with the temperature of the underlying layer. If the surface layer is colder by more than 0.1 °C its temperature is recomputed after combining the surface layer and the underlying layer and the test is repeated. This procedure simulates free convective surface cooling which is essentially responsible for the existence of homogeneous epilimnions in reservoirs. In late summer when the temperature gradient becomes weak, free convective cooling may reach the bottom of the reservoir (if it is not too deep) whereupon the water body becomes homogeneous in temperature and generally also in other water quality.

The surface dependent heat flux is included in the surface temperature computation by a gradient formulation which accounts for variation of the flux due to temperature change of the layer during the time step. An option is provided to either compute solar radiation fluxes or to use data. The computation method (TVA, 1972) is used in the model due to scarcity of radiation observation stations.

Figures 9 through 16 illustrate output from the model for two large TVA reservoirs, Fontana and Douglas. For interpretation of the results some pertinent facts of the projects are summarized in table 2. Fontana is deep and has turbine outlets at an intermediate elevation. It receives warm and cold inflows. Fontana lake surface temperatures and turbine discharge temperatures are shown in figures 9 and 10. A typical temperature profile in late summer (mid-September), about 200 days after computation starts, is shown in figure 11. All three figures also show comparison with observed data. In figure 12 computed inflow and outflow velocities are presented. The two inflow types, warm (high) and cold (low) can be well distinguished. The results are qualitatively very similar to data obtained by field measurements.

Douglas is more shallow than Fontana. It has a larger useful volume than Fontana but also a much larger inflow, table 2. These factors and its low intake cause the cold water to be flushed from the reservoir early in the year as indicated by the rapidly rising outflow temperature in the first half of the year, figure 14. Due to the low intake and potentially large turbine peak discharges (table 2) the outflow velocity distribution is often limited by the reservoir bottom, figure 16. Sometimes it also reaches to the water surface.

The described model has been tested on seven TVA reservoirs including one main stream reservoir with satisfactory results. It is considered a rather reliable basis for further expansions in the field of water quality modeling and a tool for water quality management planning and operation studies.

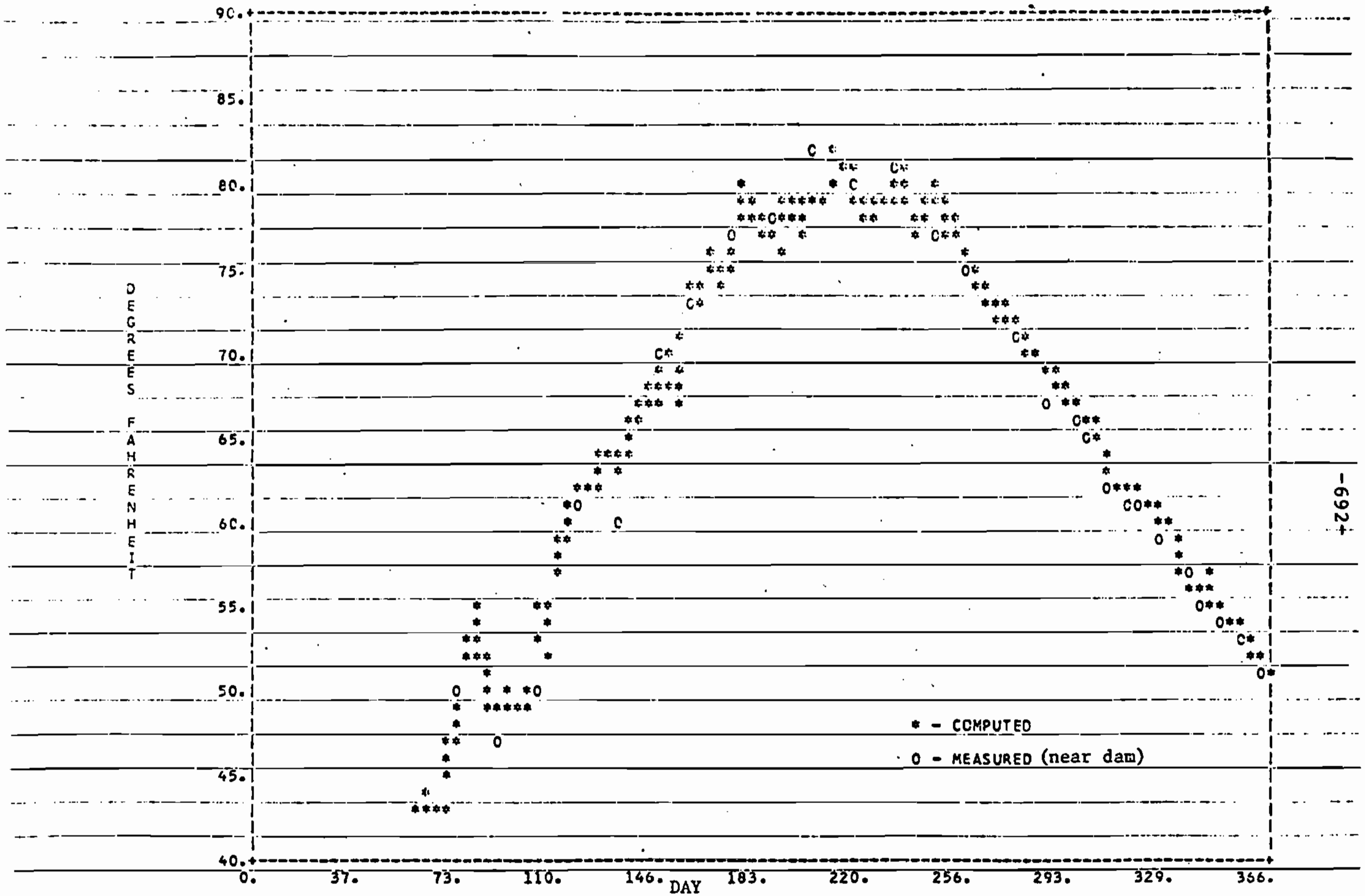


FIGURE 9 FONTANA RESERVOIR - PREDICTED AND OBSERVED SURFACE TEMPERATURES

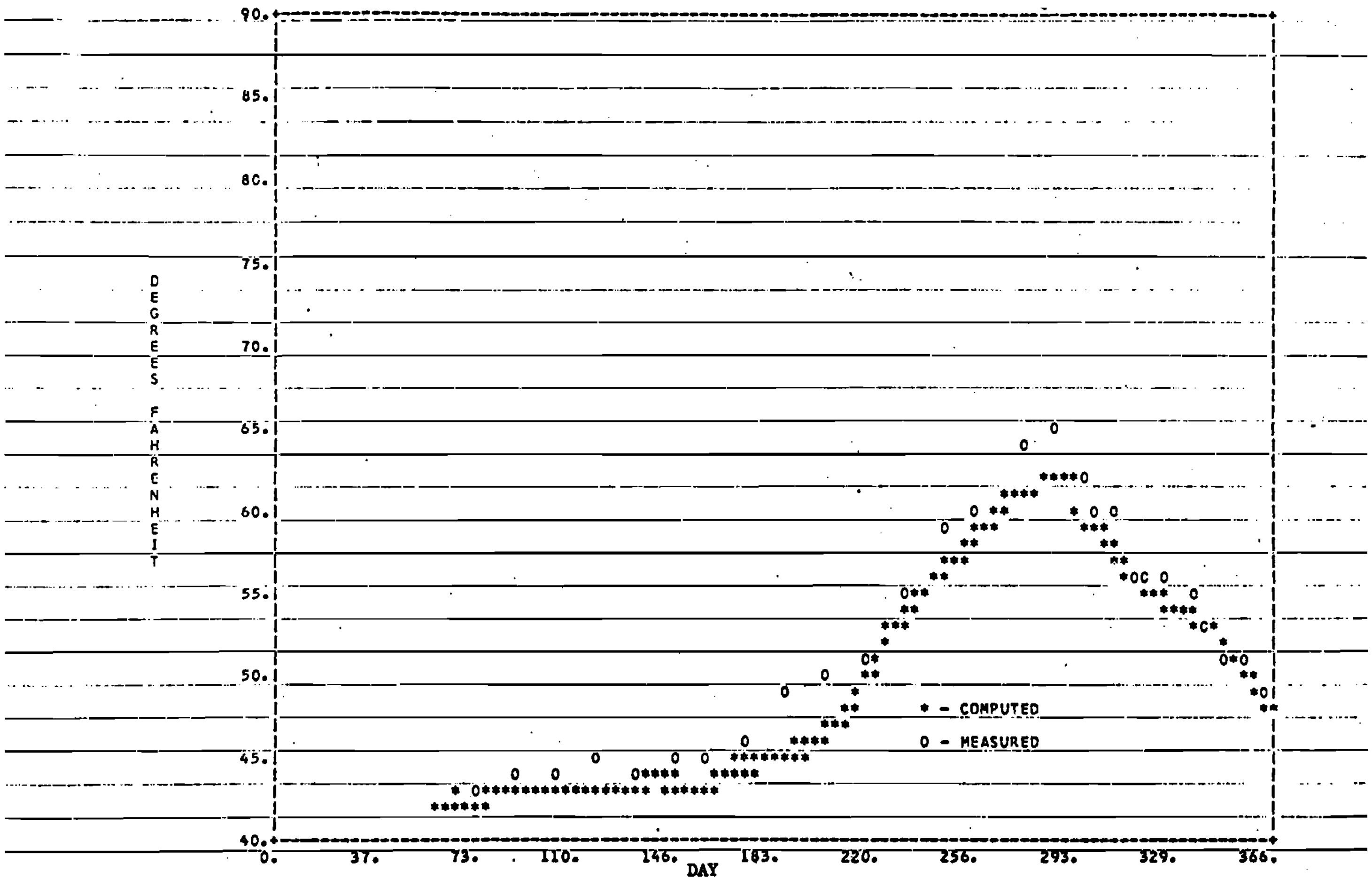


FIGURE 10 FONTANA RESERVOIR - PREDICTED AND OBSERVED OUTFLOW TEMPERATURES

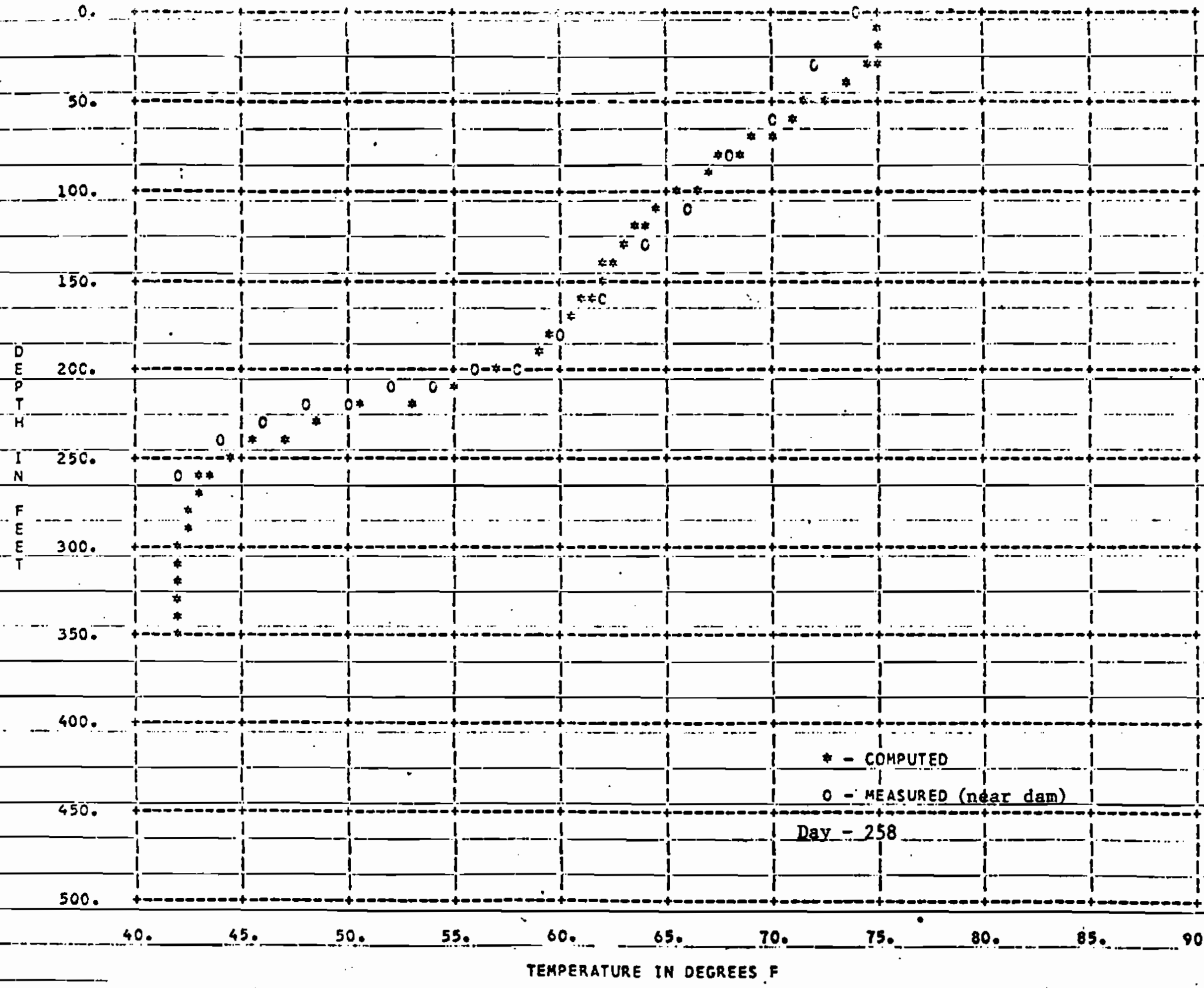


FIGURE 11 FONTANA RESERVOIR - PREDICTED AND OBSERVED TEMPERATURE PROFILE FOR A DAY IN SEPTEMBER

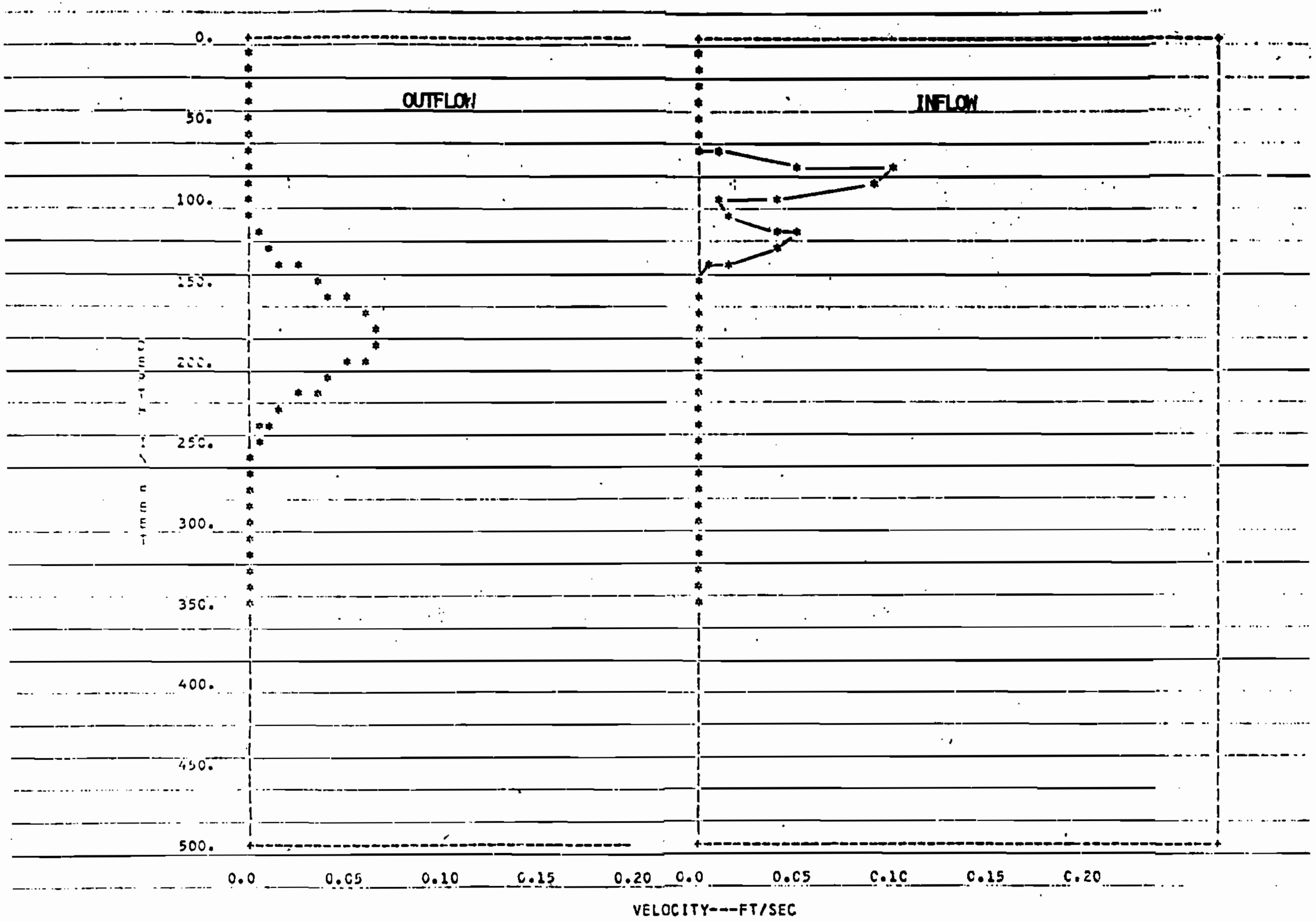


FIGURE 12 FONTANA RESERVOIR - COMPUTED INFLOW AND OUTFLOW VELOCITIES FOR A DAY IN SEPTEMBER

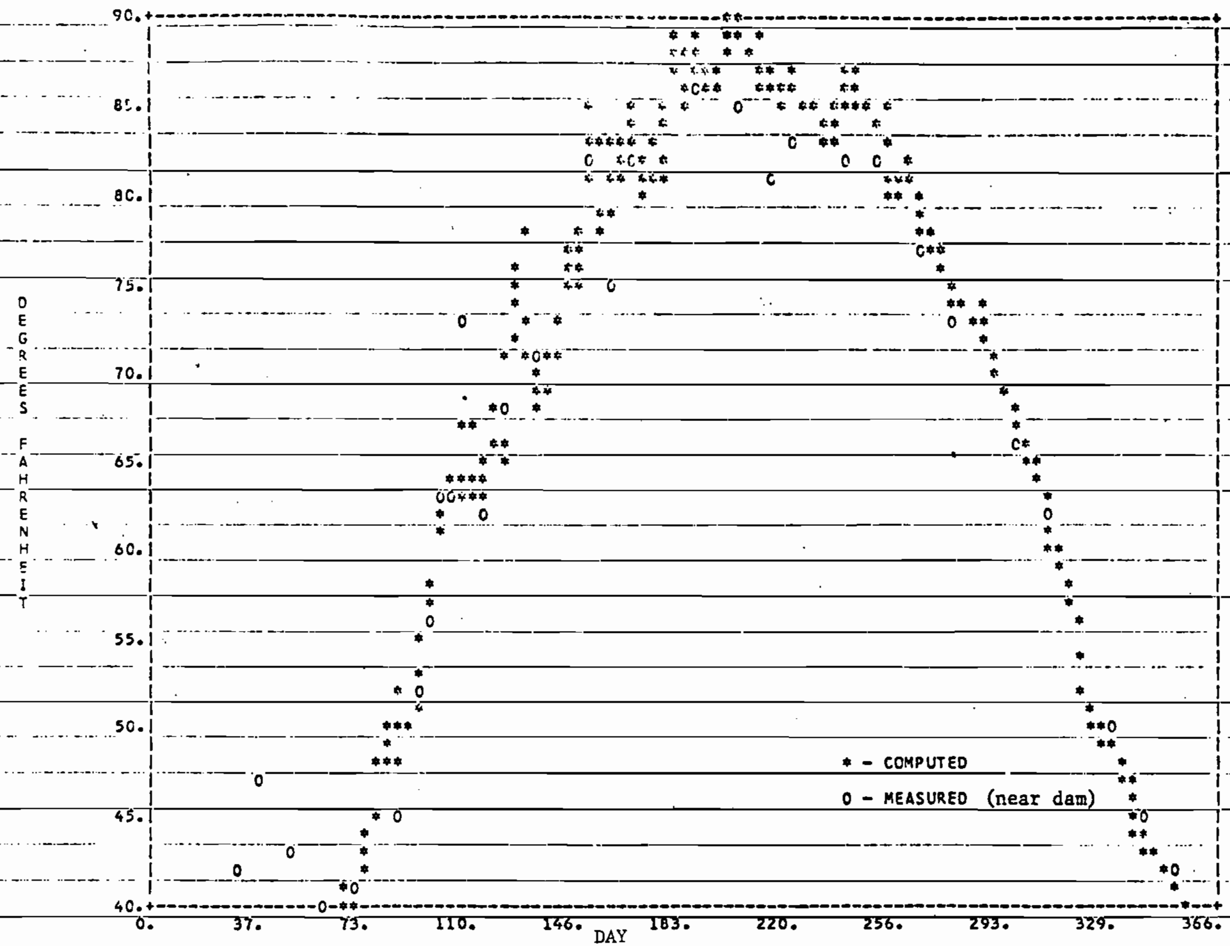


FIGURE 13 DOUGLAS RESERVOIR - PREDICTED AND OBSERVED SURFACE TEMPERATURES

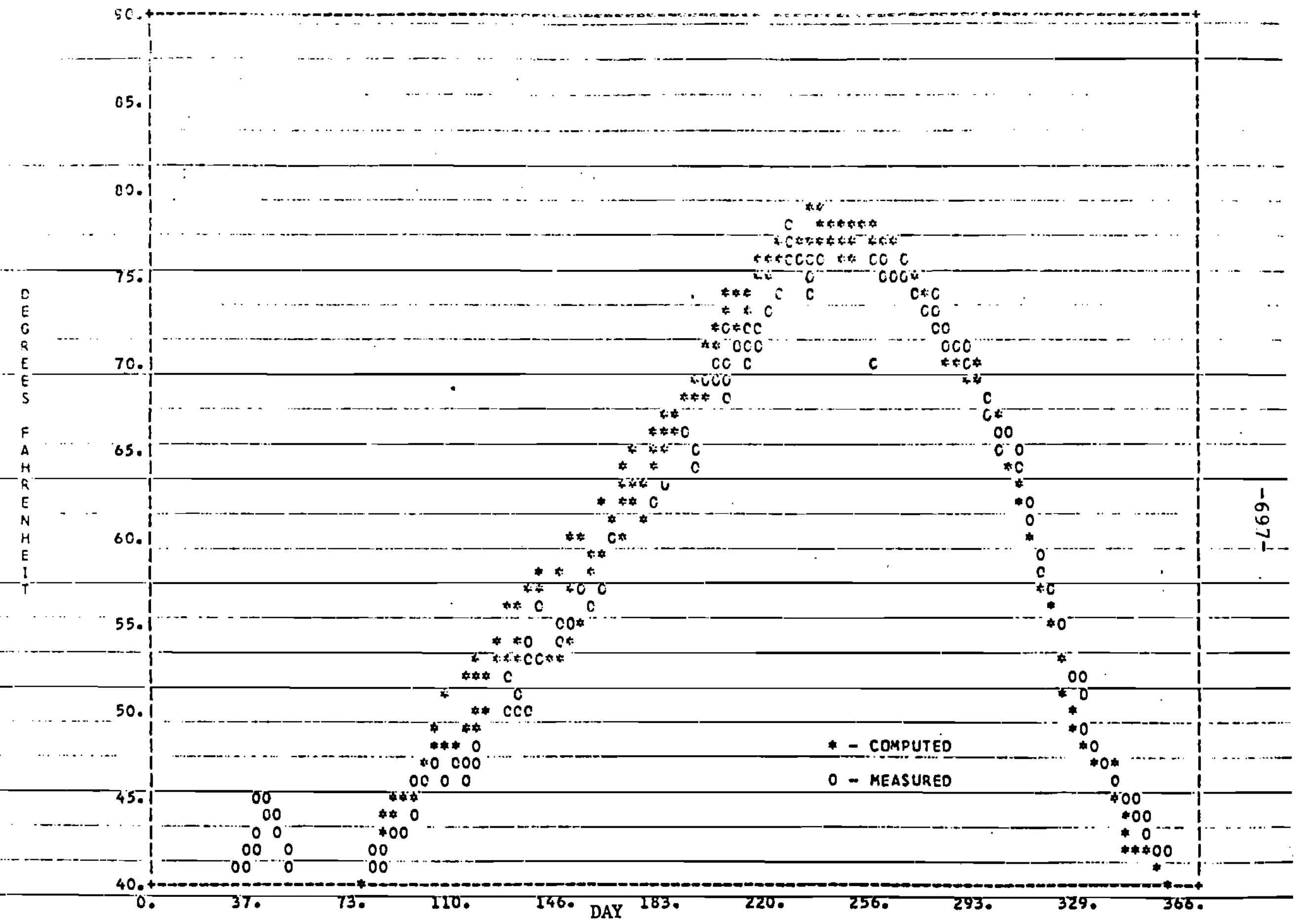


FIGURE 14 DOUGLAS RESERVOIR - PREDICTED AND OBSERVED OUTFLOW TEMPERATURES

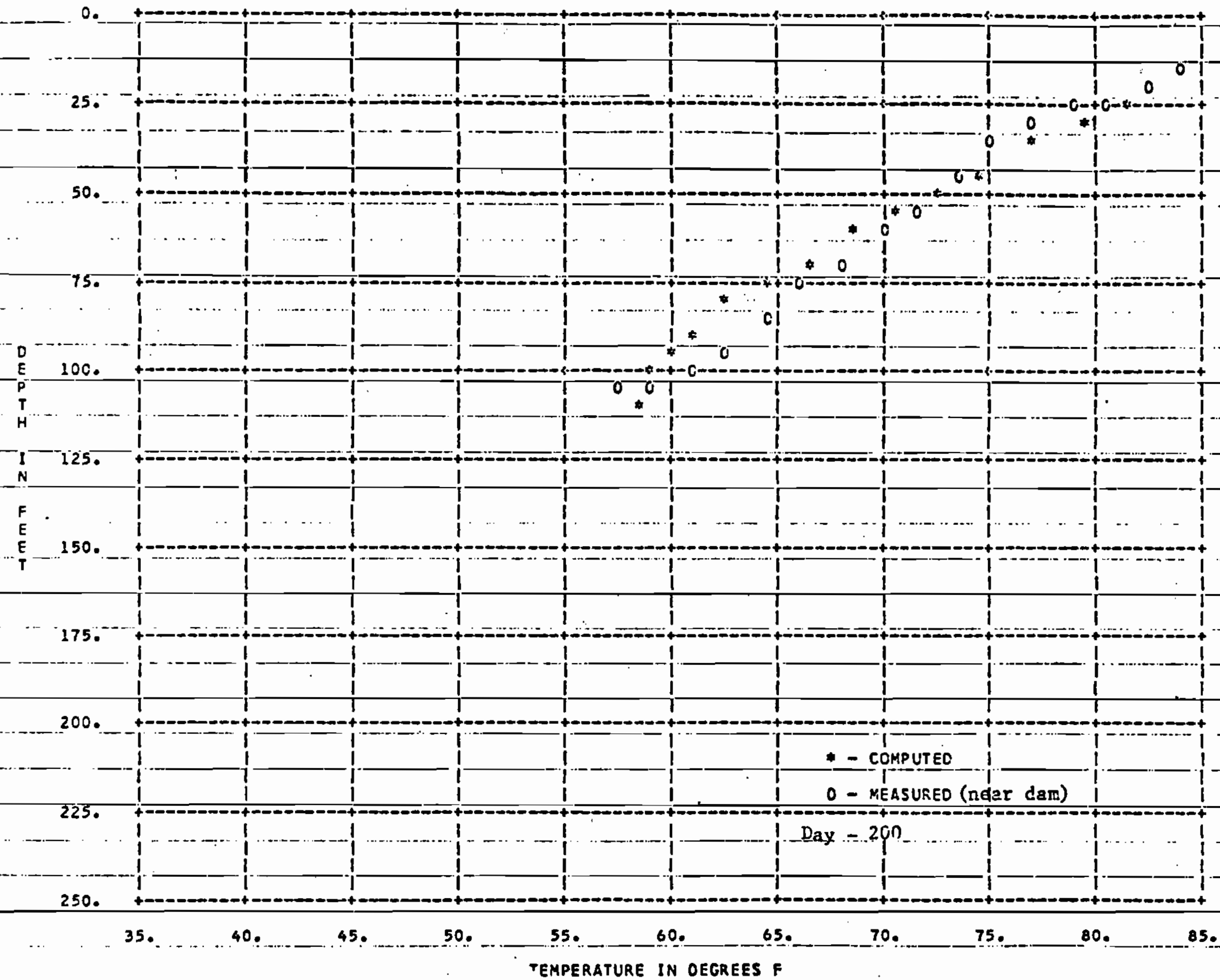


FIGURE 15 DOUGLAS RESERVOIR - PREDICTED AND OBSERVED TEMPERATURE PROFILE FOR A DAY IN JULY

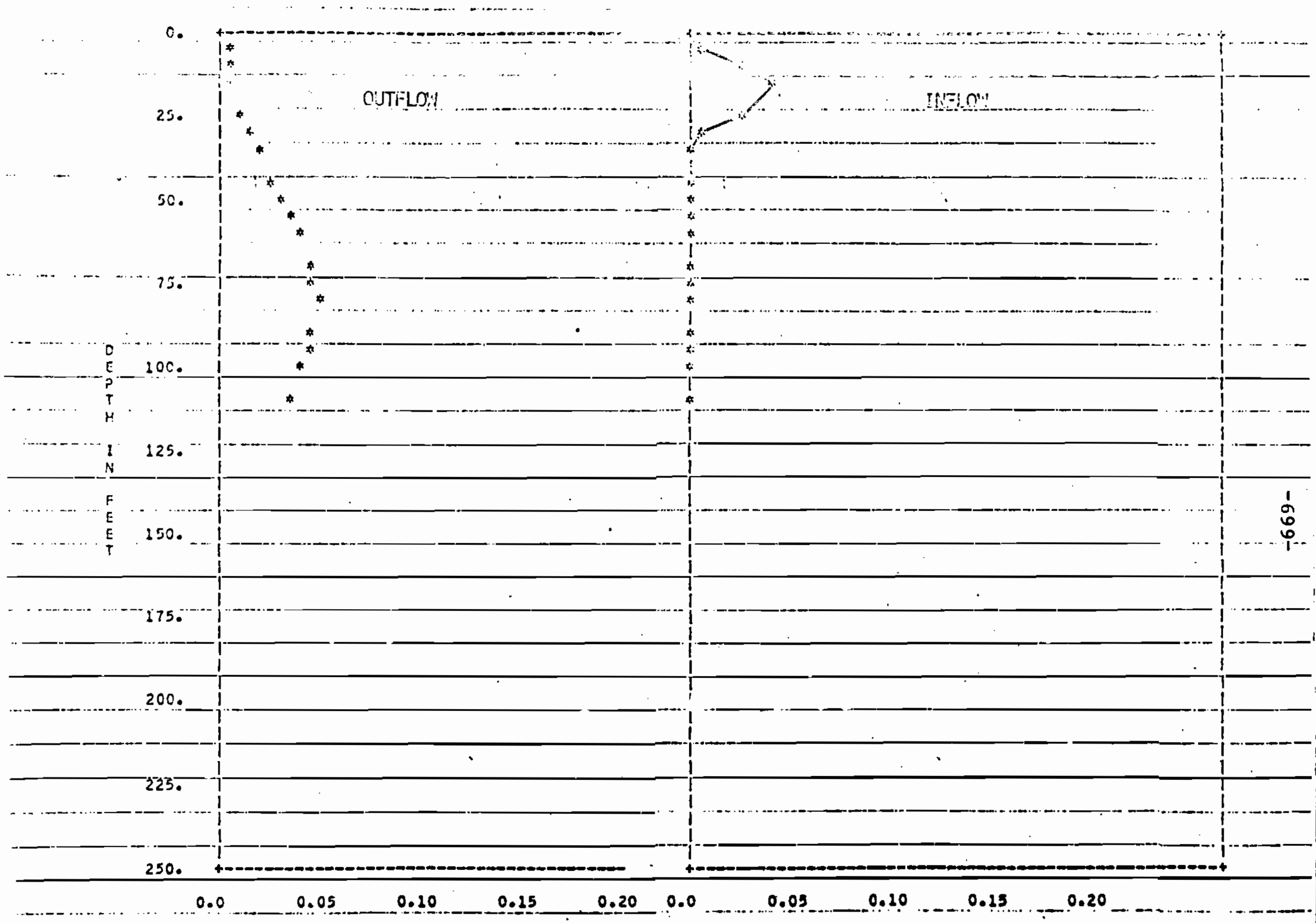


FIGURE 16 DOUGLAS RESERVOIR - COMPUTED INFLOW AND OUTFLOW VELOCITIES FOR A DAY IN JULY

TABLE 2 CHARACTERISTICS OF FONTANA AND DOUGLAS RESERVOIRS

Item	Units	Fontana	Douglas
Annual average flow at dam site	ft^3/s	3700	6700
	m^3/s	105	190
Total volume	10^3 acft	1444	1514
	$10^6 m^3$	1780	1866
Useful volume	10^3 acft	1157	1420
	$10^6 m^3$	1426	1750
Storage/runoff ratio	years	0.43	0.29
Maximum depth	ft	450	150
	m	137	46
Lake surface area at normal maximum pool	acres	10640	30400
	$10^6 m^2$	43	123
Intake centerline above bottom	ft	184	28
	m	56	8.5
Number of turbines	-	3	4
Best efficiency discharge at normal maximum pool per unit	ft^3/s	3200	4100
	m^3/s	91	116

5.2 Segmented Deep Reservoir Temperature Prediction Model

The expansion of the one-dimensional model into a segmented model is supposed to serve two purposes. First, it should produce a spatially and temporally more accurate simulation of large irregularly shaped reservoirs. It is known that significant temperature differences exists between upper and lower reaches especially during spring and fall periods. The one-dimensional model can only produce an average temperature of a layer over its entire length. Second, the segmented reservoir temperature simulation model is needed to more realistically simulate the development of water quality along the longitudinal extension of the reservoir as function of water travel path and travel time through the reservoir.

The concept of the segmented reservoir temperature model is to divide the reservoir longitudinally into several segments and to simulate energy and mass transfer phenomena within each segment by a deep reservoir temperature prediction model. However, such a model is only meaningful if the weaknesses of the one-dimensional model can be overcome by introducing travel time and travel path simulation for the water constituents as they advance from one segment to the next. This problem is not so critical for the temperature model as it is for a multiparameters water quality model. The computation sequence for each segment of the model is similar to that of the one-dimensional model. To economize on computing time, total reservoir water computations and surface heat flux computations are no more part of the program. These computations are made externally and the results are read in as data.

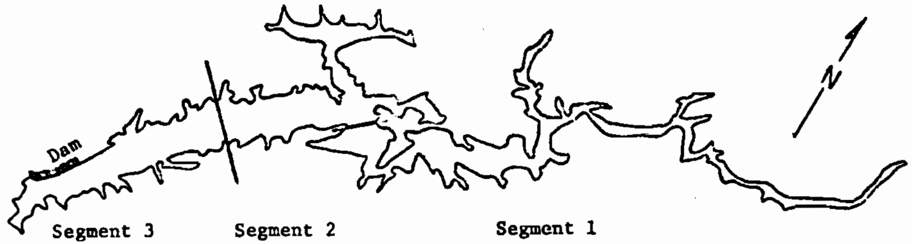
In the segmented model it is assumed that the water surface is horizontal throughout the reservoir. Given the water surface elevation for each time step and segment, a mass balance can be made for each segment beginning with the segment farthest upstream and continuing downstream toward the dam. With the inflow to the farthest upstream segment given as the river flow, the continuity equation yields the outflow from that segment. This outflow becomes the inflow to the next segment and so on. The local inflows for each segment are included as part of the total inflow. The outflow for the last segment ending at the dam is identical to the reservoir outflow.

Inflow is assumed to enter the water column of a segment at the level of inflow density. Gaussian velocity distributions are used for the external inflows and for the interflows between segments. The method used is similar to that in the one-dimensional model (TVA, 1973). A major problem is the computation of the velocity distribution at interfaces between adjacent segments which yet remains to be solved in a satisfactory way. Gaussian error functions are also used for the outflow velocity distributions. The maximum outflow velocity is assumed to occur at the outlet centerline. The outflow distribution is computed similar to the one-dimensional model. Imaginary outlets are assumed at the interface between adjacent segments. The vertical location of an imaginary outlet is determined jointly by the momentum of the flow and by buoyancy forces. The momentum and buoyancy forces are approximately accounted for in the model by assuming that the flow within a reservoir segment is horizontal and at constant velocity. At the interface between segments, an abrupt change in elevation of the flow is allowed to occur as required to simulate changes in flow direction. The density differences between segments are used to compute the outflow from the upper segment. Three different types of outflow are considered: surface outflow, with the centerline of the imaginary outlet at the surface; intermediate outflow with centerline at mid-depth of the interface and bottom outflow with centerline at the bottom. The heat balance for all layers of each segment for each time step produces the new water temperatures at the end of the time step for all layers of each segment. The computations are similar to those of the one-dimensional model.

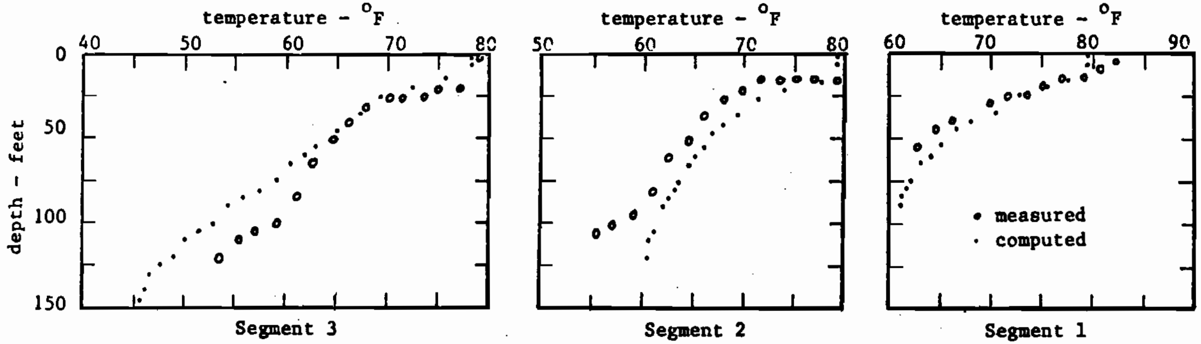
Cherokee Reservoir was chosen for model testing. The reservoir was divided into three segments with segment 3 starting at the dam, Holston River mile 52.3, and the two interfaces at mile 60.9 and mile 71.9, respectively, see figure 17. A time step of one day was used as in the one-dimensional model. Preliminary results of the simulation are shown in figure 17. Reasonable agreement with the field data was obtained. The running time of the three-segmented model was not more than two to three times that of the one-dimensional model. Various improvements are still necessary before the program can be considered operational.

5.3 Multiple Quality Parameter Prediction Model

The prediction of dissolved oxygen concentrations, biological oxygen demand, alkalinity and other water quality parameters of interest in reservoirs and in their discharges requires comprehensive multiple parameter models which can simulate the biological, chemical and biochemical processes interrelating these parameters. A state-of-the-art investigation was made of models including those developed by Chen and Orlob (1972),



a) Cherokee Reservoir Subdivided into 3 Segments



b) Comparison of Computed and Observed Temperature - for day 178, 1967

FIGURE 17 APPLICATION OF SEGMENTED RESERVOIR TEMPERATURE PREDICTION MODEL TO CHEROKEE RESERVOIR

O'Connor et al. (1973), Lombardo and Franz (1972) and Bloomfield et al. (1973). As a result of this survey, a computer program was compiled including 18 water quality parameters which are considered essential in an aquatic ecosystem, see table 3. The program is based on the one-dimensional temperature prediction model described in section 5.1. A verified reservoir thermo- hydrodynamics model is the basis of any rational approach to the simulation of reservoir water quality development due to the strong interrelationships between temperature, flow dynamics and water quality development.

In the model the reservoir is considered a rectangular box subdivided into horizontal slices, as shown in figure 8. Mass and energy advection by input and output can take place in the horizontal direction but quality parameter development can take place only in the vertical direction of this system. The resulting vertical parameter distribution as function of time is obtained by solving for each time step the appropriate set of mass and energy balance equations similar to the one-dimensional temperature prediction model. In this first approach, a one-dimensional ecologic model is considered which can be expanded, if need arises, into a multisegmented or two-dimensional model, depending upon the progress in methodology development.

In principle, an aquatic ecosystem consists of five components, see figure 18:

1. Abiotic substances including basic elements and compounds such as H_2O, CO_2, NO_3, PO_4, etc.
2. Producers which include autotrophic organisms (organisms that can fix energy from inorganic sources into organic molecules) such as phytoplankton.

TABLE 3 ESSENTIAL QUALITY PARAMETERS IN AN AQUATIC ECOSYSTEM

No.	Quality Parameter	Units
1	temperature	^oC
2	alkalinity	mg/m^3
3	TDS*	mg/m^3
4	BOD†	mg/m^3
5	phosphate	mg/m^3
6	total carbon	mg/m^3
7	NH_3-N	mg/m^3
8	NO_2-N	mg/m^3
9	NO_3-N	mg/m^3
10	DO#	mg/m^3
11	coliform bacteria	$count/m^3$
12	detritus	mg/m^3
13	phytoplankton	mg/m^3-dry weight
14	zooplankton	mg/m^3-dry weight
15	pH	
16	CO_2	mg/m^3
17	benthos	mg/m^2-dry weight
18	sediment (organic)	mg/m^2
	fish type 1	kg
	fish type 2	kg

*total dissolved solids
†biochemical oxygen demand
#dissolved oxygen concentration

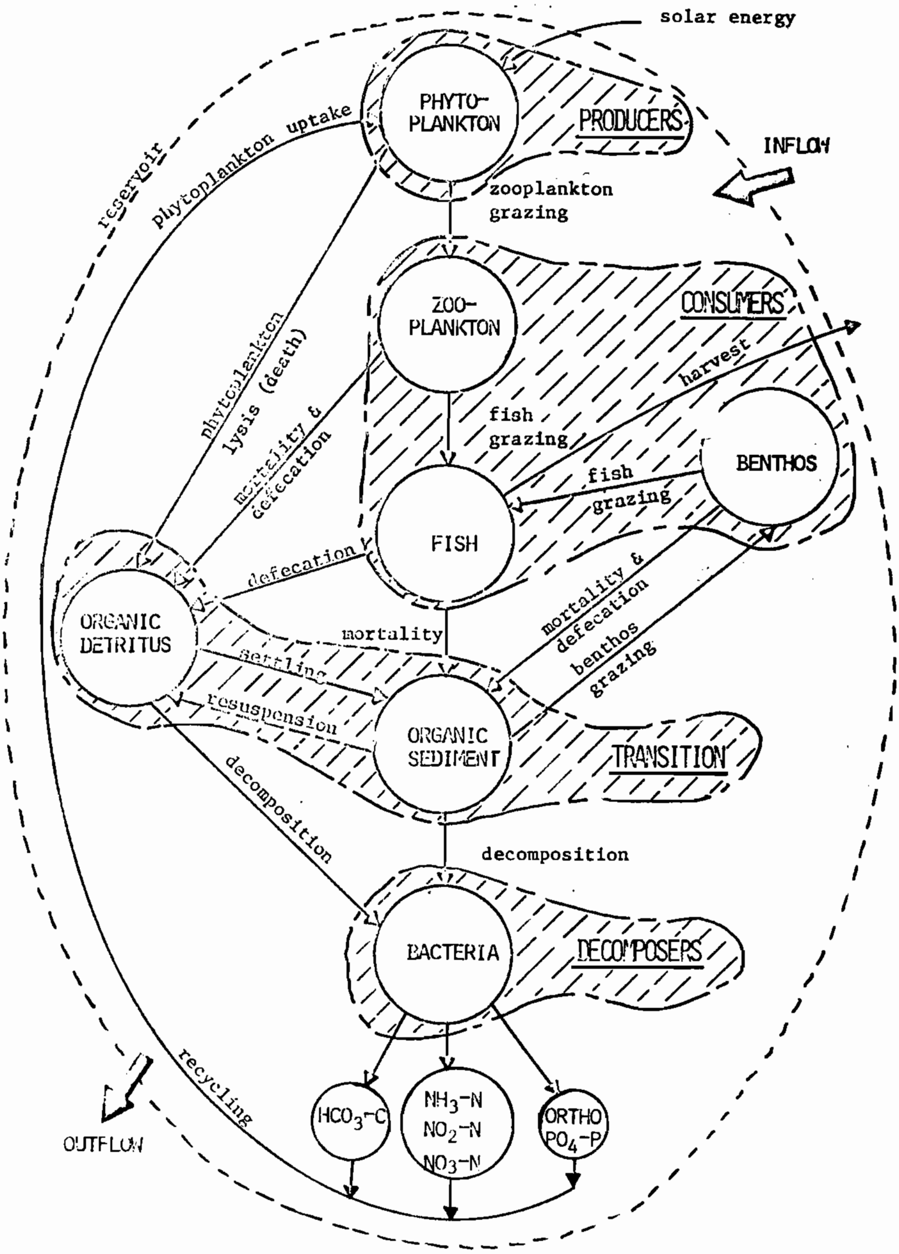


FIGURE 18 SCHEME OF AN

3. Consumers which include heterotrophic organisms (organisms that cannot obtain energy from abiotic sources, but depend on energy-rich organic molecules for their energy supply) such as zooplankton and animals (benthos and fish).

4. Decomposers which include bacteria and fungi.

5. Transition stage which includes detritus and organic sediment.

The environmental setting is the water body of the reservoir with its abiotic substances and its supply of energy. The producers, with the aid of solar energy, produce complex organic materials from the abiotic substances through photosynthetic reaction. These organic materials serve as primary food sources for consumers such as herbivorous animals which in turn are consumed by carnivorous animals, such as fish. All these biological activities generate organic detritus which consists of dead cell material and excreta. The decomposers, bacteria and fungi, operate on the detritus whereupon the original abiotic substances are released for use by the producers, thus completing the cycle.

Masses of abiotic substances can be transported where applicable by the processes of advection, diffusion, input, output, sedimentation, resuspension and gasification. They can also be increased or decreased in concentration by chemical reactions and biodegradation. The latter processes include nitrification (NH_3 - NO_2 - NO_3), BOD decay (BOD - CO_2), and detritus decay (organic - NH_3, CO_2, PO_4). Oxygen may be consumed (BOD) or produced (photosynthesis) in conjunction with biological transformations. It is also transferred by physical-chemical processes. Other abiotic substances, such as the organic carbon, nitrogen, and phosphorous are biologically consumed or released. Mass balances of these substances will, therefore, be affected by biological processes. It is assumed that the above processes act independently and simultaneously. The total mass transfer will then be equal to the sum of the individual transfers:

Rate of Mass Transfer	=	Advection + Diffusion + Input - Output
	-	Sedimentation + Resuspension $\pm$ Gasification - Decay
	$\pm$	Chemical Transformation $\pm$ Biological Transformation

Organic biomass is also subjected to advection, diffusion, input, output and sedimentation. In addition, there are metabolic processes of growth, respiration and mortality. Depending on the trophic levels involved, there may also be a grazing effect. Again, a general mass transfer equation can be written as sum of individual transfers:

Rate of Mass Transfer	=	Advection + Diffusion + Input - Output
	+	Growth - Respiration - Sedimentation
	-	Mortality - Grazing by higher trophic animals

Feedback between temperature distribution, flow dynamics and biological activities is accounted for by correcting the water temperature development for algal self-shading.

The development and verification of water quality ecological models requires a considerable amount of input data. To obtain consistent and complete data sets for model verification, special reservoir water quality data collection programs were proposed including sampling locations, frequency of sampling and water quality parameters to be measured in three major TVA reservoirs. At present, due to lack of data, verification of the ecological model is incomplete.

6. CONCLUSIONS AND OUTLOOK

Water quality prediction methods for streams and reservoirs are used with increasing frequency in TVA planning and design studies. The methodology developed and used to date has led to better understanding of the basic principles of water quality development in streams and reservoirs and has provided a basis on which more sophisticated and more comprehensive models can be built. The extreme complexity of the interrelations between the various parameters and the involvement of various disciplines, such as hydro- and thermodynamics, aquatic chemistry and biology, represent a great challenge to those trying to advance water quality modeling technology.

In the TVA region considerable efforts will have to be expended to deal with the multidimensional and unsteady character of flow-quality dynamics. A major effort will be required to forge the various mathematical models for system components such as rivers and reservoirs in a system-encompassing flow-quality routing scheme. In addition and parallel to model development, there is an urgent need for extensive field investigations to provide data sets on system components and entire subbasins over defined survey periods to verify and improve water quality simulation models of increasing complexity. This increased data need requires a continued effort to improve data acquisition and data handling techniques.

The question arises as to the benefits derived from all these modeling efforts. Increasing population density, man's continued strive for progress and development of some sort and the recognition in recent years that a high quality environment must be preserved if this endeavor is not to be self-defeating are spawning the need for tools to resolve conflicts of interest involving water resource use. Increasing industrial and especially nuclear power developments will require more and more sophisticated environmental impact models to trace pollutant pathways from point and non-point sources (runoff, atmospheric washout and ground water) through rivers and reservoirs and ultimately to man. Also additions to existing systems and operational changes in response to changing priorities, etc. will require impact evaluation tools if socially costly mismanagement of a basic resource is to be avoided. These requirements impose a continued and growing responsibility on organizations charged with water resource management to develop in time the proper planning, design and decision-making tools.

REFERENCES

Bloomfield, J. A.; R. A. Park; D. Scavia and C.S. Zahorcak, "Aquatic Modeling in the Eastern Deciduous Forest Biome, U.S. - International Biological Program," Modeling the Eutrophication Process Proceedings of a Workshop held at Utah State University, Logan, Utah, September 5-7, 1973.

Chen, C. W. and G. T. Orlob, "Ecologic Simulation for Aquatic Environments, Final Report," OWRR Project No. C-2044, Office of Water Resources Research, Department of Interior, December 1972.

King, I. P., "A River Basin Ecologic Model," Water Resources Engineers, Inc., Walnut Creek, California, August 1973. Private Communication.

Lombardo, P. S., "Critical Review of Currently Available Water Quality Models," OWRR Project No. 14-31-0001-3751, Office of Water Resources Research, Department of Interior, July 1973.

Lombardo, P. S. and D. D. Franz, "Mathematical Model of Water Quality in Rivers and Impoundments," Hydrocomp, Inc., Palo Alto, California, December 1972.

O'Conner, D. J.; Thomann, R. V. and DiToro, D.M., "Dynamic Water Quality Forecasting and Management," EPA-660/3-73-009, August 1973.

Orlob, G. T. and L. Selna, "Temperature Variations in Deep Reservoirs," Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY2, Proceedings Paper 7063, February 1970.

Ryan, P. J. and D.R.F. Harleman, "A Predictive Model for Thermal Stratification and Water Quality in Reservoirs," R. M. Parsons Laboratory for Water Resources and Hydrodynamics, MIT, Report 134, January 1971.

TVA - 1968, "The Water Temperature Regime of Fully Mixed Streams," Water Resources Research, Laboratory Report No. 15, Norris, Tennessee, March 1968.

TVA - 1969, "Cherokee Reservoir Selective Withdrawal," Water Resources Research, Laboratory Report No. 13, Norris, Tennessee, 1969.

TVA - 1971, "The Computation of Daily Mean Stream Temperatures," Water Resources Research, Laboratory Report No. 25, Norris, Tennessee, 1971.

TVA - 1972, "Heat and Mass Transfer Between a Water Surface and the Atmosphere," Water Resources Research, Laboratory Report No. 14, Norris, Tennessee, April 1972.

REFERENCES - Continued

TVA - 1973, "Water Temperature Prediction Model for Deep Reservoirs," Water Resource Management Methods Staff, Report A-2, Knoxville, Tennessee, October 1973.

Wunderlich, W. O. and L. N. Fan, "Turbulent Transfer in Stratified Reservoirs," TVA Engineering Laboratory, Norris, Tennessee, August 1971.

IIASA DISCUSSION PAPER

Dr. Pavel Koryavov

The experience of the TVA has proved that mathematical models could be used very efficiently for management, control, prediction, and planning of a large, complicated, and multipurpose water resource system in a large river basin. For years the TVA has used mathematical modelling for flood control, navigation and power generation. Now they are beginning to use models also for recreation and environmental considerations such as dissolved oxygen content, thermal effects, water supply, liquid waste disposal, and many others.

The hydrodynamic model of the river flow is the core of the water resource mathematical model. The TVA uses the classical approximation of the river flow by the one-dimensional unsteady flow in open channel for the two main characteristics of the flow: depth and velocity (average for each stream cross section) depending only on the longitudinal direction and time. The TVA has two nonlinear partial differential equations which are called usually as Saint-Venant equations. Then they use a finite-difference approximation of those equations by explicit centered difference scheme which had been applied to the river flow calculations for the first time by J.J. Stoker in the beginning of the fifties.

An actual river-bed geometry is approximated in the mathematical model by a series of adjacent prisms. Channel geometry data are determined by interpolation from tubular values of area, hydraulic radius, and storage width, all versus water surface elevation for each station. With respect to the statement of the hydrodynamic river flow problem and the good agreement between computed and measured characteristics of the flow, I have the following comments:

1) In spite of using a rough classical one-dimensional model with some additional simplified assumptions such as zero bottom slope of the channel and others, this model has shown after verification, the accurate reflection of the water behavior in response to the operations involved. This is illustrated in a number of examples.

2) It is not completely clear enough in the explanation of the hydrodynamic model formulation given in this paper and some questions come to mind:

   a) What introduces off-channel storages in reaches into mathematical models?

TVA COMMENTS ON DISCUSSION BY P. KORYAVOV

In the one-dimensional transient flow model, the off-channel storages are introduced by plantimetered surface areas divided by reach length which produce an average reach width. The bottom slope is eliminated and all quantities are related to the surface slope. The bottom slope can have any value and is implicit in the water surface term. Lateral flows can be inflows and outflows, point or distributed values. Tributary inflows depend only on depth in the main river. No momentum exchange between lateral flow and main river flow is considered. The model reproduces flow upstream in tributaries as they occur. A special version of the one-dimensional flow model is used to handle confluence problems. At the junction, continuity is satisfied by an iterative process.

The deep resevoir temperature model is called one-dimensional because it can only predict temperature variations in the vertical direction. The vertical dimension is subdivided into layers and horizontal inflows into each layer are determined by comparing layer density and inflow density. If both are the same, the centerline of the inflow distribution is considered to be at that layer grid point. The centerline of the outflow distribution is at the grid point of the outlet centerline. The velocity distributions are determined by empirical distribution formulas as function of the prevailing density gradient. Vertical water movements are then computed by a layer water balance.

For unsteady temperature regime the formula has the form

$$\frac{T_{E_t} - T_t}{T_{E_t} - T_o} \quad e^{-\frac{K(t - t_o)}{\rho CQ}}$$

where

d = the water depth, and

t_o = the starting time.

It seems that after calibration, these very simple formulae agree closely with real water temperature measurements.

I should say that I have a few questions about Section 5 of this paper. First of all, the authors declare that they are considering a one-dimensional deep reservoir temperature prediction model, but twice mention that they are solving equation (2.6) which is two dimensional. It is also not clear how they determined the horizontal velocity in the layer.

The development of the water quality prediction mathematical model is considered very important by the TVA. It seems very reasonable that they use thermo and hydrodynamic models as a basis for simulation of water quality since there are strong interrelationships between flow dynamics, temperature and water quality characteristics.

The first step is in fact a definition of the upstream boundary condition and the second step is the selection of a more suitable downstream condition for the problem of water flow calculation in the reservoir containing the plant sites such as the special restriction on the values of the dependent variables: depth and velocity of the flow in the resevoir is fulfilled.

In the second paper, the TVA describes heat transport models for rivers and reservoirs. The temperature of the water is a very important characteristic of water quality. Studies have been conducted at the TVA for a number of years to observe, to analyze, and to make amenable the prediction of the effects of resevoir operations on the water quality and in particular on the water temperature in the river-reservoir system.

Of considerable practical interest is the distance downstream from dams (cold releases) or steam plants (hot releases) over which the gradual approach to the natural temperature occurs. In planning studies the steady-state temperature computations have been mostly used.

After neglecting the dispersion term in one-dimensional heat transport equations and integrating it under the assumption that the net heat flux through the water surface is a quadratic function of the temperature, the following formula could be found

$$\frac{T_E - T}{T_E - T_o} = Ze^{-\frac{K_E WX}{\rho CQ}}$$

where

z = a correction factor for the temperature dependence of K,

W = the width of the reach,

X = the length of the reach,

Q = the flow in the reach,

T_o = the starting temperature,

T_E = the equilibrium temperature,

ρ = the density of the water, and

C = the specific heat of the water.

b) How does the whole model and the off-channel storage function in flood situations with an overflow?

c) Is the value q considered only as lateral local inflow from tributaries, but not as outflow from the river during the flood?

d) Were tributary inflows distributed over a reach length or entered as point sources prescribed as given functions of time and location but independent from depth and velocity in the main river flow for all possible regimes of flow?

e) Is it possible to have a so-called backward effect of the main river flow on tributary flows in the TVA river basin flow model?

f) In the model have they used some conditions for matching discharge and depth of the main river and tributary waters at the point of tributary inflow; what form was used?

All of these questions seem very important to me from the methodological point of view, and they have arisen in every hydrodynamic modelling of the regular and flood regimes of the river basin flows.

3) It seems important for good agreement between computed and measured flow characteristics to calibrate the mathematical models by using a great number of field stage and velocity measurements for about one month.

Could the problem of safety for a nuclear plant during the flood considered in the first paper be formulated in the same way for any plant or city located on the bank of the reservoir.

The authors did not touch the determinations of the hydrologic events and each embankment breaching analysis caused by overtopping these embankments during a flood but only dealt with the unsteady flow aspects of the flood waves.

The computational procedure for determining flow conditions at nuclear plant sites on a reservoir consists of two steps:

1) routing of a pre-determined flood through the affected reservoirs to establish times, flows, and elevations associated with any overtopping and subsequent failure of earth embankments or other dam sections or components;

2) successive routing of the resulting outflow down through the reservoir containing the plant sites.

SUMMARY OF DISCUSSION TOPICS

PART 5

In the discussions which followed the presentations the following people took part:

W. Wunderlich	TVA
E. Wood	IIASA
I. Lefkowitz	IIASA
I. Gouevsky	IIASA
B. Uzunov	Bulgaria
K. Takeuchi	JPN
M. Benedini	Italy
V. Karelin	USSR
G. Preissler	GDR

The main problem topics discussed were:

- Preliminary evaluation of initial investment and allocation between different parts of multi-purpose projects in the Tennessee Valley.
- Strategic models for developing water control systems and increasing future needs.
- Environmental problems (arrangements for preventing water and soil pollution - systems created to prevent disturbances in ecological equilibrium - methodology for control of water quality in the Tennessee River basin - influences of industrial waste water and fertilizers upon water quality.
- Network of hydrological and water quality stations, records, and tools for management and operation available in TVA.
- Underground water system in TVA - stage it is in and relationships between underground and surface water systems.
- Evaluation of efficiency of flood protection.
- Decision maker for future electrical priorities.
- Need for special agreements between neighboring countries for many European watersheds (during planning process).
- Mosquito control fluctuations.

- Combinations of manual and computerized methods to predict untrolled inflows into each reservoir.
- Establishment of operational priorities.
- Estimation of flood control benefits.
- Time scale for flood forecasting and flood routing operations.
- Rainfall-runoff modelling.