DECISION SUPPORT SYSTEMS FOR MANAGING LARGE INTERNATIONAL RIVERS

Report

Project Number: 850–1034

to

The Ford Foundation
320 East 43rd Street
New York, NY 10017

Co–Principal Investigators: *Dr. K.A. Salewicz* and *Professor D.P. Loucks*

Authors: *K.A. Salewicz, D.P. Loucks* and *A. McDonald*

Kazimierz A. Salewicz
Project Leader
Large International Rivers Project
International Institute for
Applied Systems Analysis

Alan McDonald
Staff Director
United States Committee for IIASA
American Academy of Arts
and Sciences

January 1989
International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

CONTENTS

1. INTRODUCTION

As of 1987 only 61 of the world's 215 international river basins were affected by any of the 286 transboundary water treaties then on record (UN, 1987). And in only 25 cases were there institutional arrangements in place for joint management or development. Because joint development is often far more productive than unilateral alternatives, and because one country's diversion or pollution of a shared river usually affects others, we can expect in many international river basins either new initiatives or continued diplomatic efforts to work out mutually beneficial development and management agreements among riparian neighbors.

In 1985 it was proposed that IIASA should undertake research to help those involved in such negotiations.

- IIASA has an extensive research network and long history in analyzing and modeling the management of water resources.
- IIASA has experience and active programs researching Decision Support Systems (DSS).
- Computer hardware and software are becoming increasingly cheap and easy to use, therefore making them more accessible to people at all levels of international negotiations, and in all regions of the world.
- Six of the eight countries in the Danube Basin have member organizations in IIASA.

With support from the Ford Foundation, work at IIASA therefore got underway in 1986 to improve the exploitation of increasingly cheap and powerful computer analyses in international river basin negotiations and management. For hardware, the focus is on personal computers, as they may be the only technology reliably available in some parts of the world. For software the emphasis is on graphics and menu-driven routines that are easy to use and interpret.

The computer work is being done in connection with two case studies of international negotiations and joint management. One has been initiated in the context of the Zambezi Action Plan (ZACPLAN), signed by five of the eight Zambezi River Basin states in May 1987. The other concerns water resources management for the Danube River. One purpose is to assure that IIASA's software development is directly relevant and useful to specific issues and institutions in these two river basins. However there is a second purpose. The development of interactive computerized decision support systems (DSSs) is a field characterized by diversity, rapid progress in many areas, and a relatively small, though growing, base of systematic experience with specific applications. It is a young field. Therefore the lessons learned through the case studies on the use and acceptance of these decision support systems (DSSs), and generalizations that we at IIASA can draw from the experience and pass on to others, will also be important results of the Project.

The Project has been funded by the Ford Foundation, the United Nations Environment Programme (UNEP), the National Centre for Scientific Research (CNRS) of France, and IIASA. The provisions of the Ford Foundation's support call for periodic reports on the Project's progress. This is such a report.

2. PROJECT OBJECTIVES AND EXPECTED RESULTS

The Project's objective is to provide methodological and technical assistance to collaborative efforts of countries, river basin commissions, and international agencies engaged in the use of international rivers. Our specific contribution to these efforts will include a highly user friendly decision aid prototype computer system that can be used for developing coordinated, environmentally-balanced, long-term river basin policies. It is both politically and scientifically important that the major product of our research not be solely a report suggesting "final" solutions to particular problems, but rather a set of efficient analytical tools that can be used by river basin commissions as well as by individual riparian countries for assessing consequences of various planning and management policy options. The intention of the Project is to provide results useful to a wider audience than only specialists in water management. We believe that our results should be of value to a wide range of individuals involved in planning, management, and negotiation.

Specific examples of how we aspire to assist the processes of planning, management, and negotiation include the following.

1. The impact of pictures, and the ability of personal computers to rapidly modify pictures and graphics of all sorts, can help those who are not expert in the fields of water resources engineering and mathematical modeling to better understand the physical phenomena taking place in their particular system, and to identify relations between management and development actions on the one hand, and possible outcomes or impacts on the other.

2. The ability of the DSS to display consequences of various management and development policy options can be used directly for initial exploration and screening based on simple models, to narrow down a broad range of options to those deserving detailed analysis using more accurate models, more extensive data, more people, or larger machines.

3. A feature common to almost all disputes over rivers is differences in data, models and approaches used by the parties involved. In this case, software developed for decision support systems can be used by various parties to test their own and other's data, models and assumptions. Consequently, *information sharing and analysis* aided through the use of an interactive decision support system could not only help each party better understand the interests and reasoning of other parties, but also focus the debate on the important differences and their resulting implications, rather than on those that turn out to have no major consequences. Focussing discussion on differences that matter, rather than on those that don't, should facilitate the process of coming to an acceptable negotiated agreement (see Loucks and Salewicz, 1986).

The core product of the Project will be a software package, manual(s) and methodological guide describing the logical steps to be followed when adapting the package for a particular case study. Though it is impossible to develop a package that can be all things to all people, the Project's software will be easily transferable and flexible, and able to serve as a versatile interface between users, models and data.

Additional results of the Project will include:

1. A carefully assembled collection of data and models relevant to each case study to be used with the software package in evaluating policy options.
2. A training program for professionals and decision-makers from the countries in the Zambezi river basin involved in river basin management.
3. Prototype DSSs implemented on microcomputers.
4. A network of scholars and practitioners involved in the Project's studies and software development.
5. Working Papers and publications in refereed journals.

3. RESEARCH APPROACH AND ACTIVITIES

There are three lines of work within the Project, all of which proceed in parallel. One line tracks theoretical developments and applications in the fields of decision support systems and negotiation analysis. A second line applies the Project's research to two specific case studies in the Danube and Zambezi river basins. In furtherance of this activity, the Project is also active to a less detailed extent in other instances of joint river basin management where our research has either something to contribute, or something to learn. The third line of work is software development, carried out at IIASA and collaborating institutions, that is guided by both generalizations derived from the first line of work and specific demands imposed by the applications of the second.

We feel this mixture of theoretical scouting, specific applications, and responsive software development is the best approach to providing analyses and software that exploit insights from current theoretical research, but do so in ways that make the resulting software understandable, useful, and applicable. On the theoretical side the Project depends significantly on other IIASA projects, as the LIR* Project itself does not have the resources to be on the cutting edge of DSS theory and negotiation analysis. The Methodology of Decision Analysis Project within IIASA's System and Decision Sciences Program is particularly expert in the field of DSSs and has just published a 353-page opus on "Theory, Software and Testing Examples in Decision Support Systems" (Lewandowski and Wierzbicki, 1988). The Processes of International Negotiations Project (PIN) addresses negotiation analysis, and its work has contributed significantly to two LIR papers by Linnerooth (1988) and McDonald (1988).

By definition, the two case studies and other applications also depend greatly on collaboration with others directly involved in the management and development of the rivers in question. Sections 4, 5, and, to a lesser extent, 7 describe the Project's coordination with other researchers on specific applications. While most of the Project's third line of research, software development as described in Section 6, is done in-house, that too takes advantage of cooperative efforts from a number of sources.

The remainder of this section summarizes a few principal features of each of the three lines of research.

---

*As of January 1, 1989, the *Large International Rivers Project* (LIR) has been transformed into a broader *Water Resources Project* (WAT) which is continuing all activities initiated within LIR. Therefore in all statements referring to future activities we will use WAT instead of LIR.

3.1. Decision Support Systems and Negotiation Analysis

3.1.1. Decision support systems

As evidenced by the Project's title and the following excerpt from the July 1988 meeting of the Project's Advisory Panel, one objective is to contribute to advancing the general methodology of decision support systems.

> "Work should continue towards the establishment of a general methodological framework for the development of a DSS for large river systems capable of examining a variety of common issues and problems with respect to the management of water quality and quantity. There is evidence of a growing interest in the use of such methodology and there currently appears to be a number of opportunities available to test the applicability and usefulness of such methodology both for planning and management and for assisting in the negotiation of transboundary conflicts involving water resources."

The conceptual development of decision support systems has been largely grounded in the field of decision analysis, which in turn was built on the concept of rational economic man of eighteenth century mathematicians such as Cramer and Bernoulli (see A.P. Sage, 1981). In the application of such concepts, the use of computer-based modern information systems has evolved from data processing to information management and finally decision support. While those in the field agree that the main function of such systems is to help people make better decisions in complex situations, there are several types of systems that serve such purposes (see Lewandowski *et al.*, 1987), and there is not yet a generally accepted single definition of decision support systems (Sol, 1985).

Many authors (see, for instance, Parker and Al-Utaiba 1986, Mittra 1986) share the view that DSSs are most appropriately aimed at ill-structured decision problems, where an ill-structured problem is defined as one that fails to meet the following criteria distinctive of a well-structured problem (Sol, 1985):

1. that the set of alternative courses of action is finite and limited;
2. that the solutions are consistently derived from an empirical model that shows a good correspondence with reality; and
3. that the effectiveness and efficiency of alternative actions can be numerically evaluated.

Clearly, many problems of development planning, land-use, and water management fall into the category of ill-structured decision problems.

One approach to DSSs for water management that has been used at IIASA and elsewhere is driven by the recognition that decisions need to be made at a number of hierarchical levels. Thus a number of researchers have looked to the theories and methods of multilayer hierarchical control structures (see for instance Findeisen *et al.*, 1980). A basic conclusion from these theories is that higher layers of the decision making hierarchy act over longer time horizons, make more aggregated (less detailed) decisions, and use more aggregated information, than do lower layers of decision making. Therefore, the design and structure of a decision support system should be compatible with the different information needs, and different decision problems, of the various levels of planning or management within the decision hierarchy. Previous IIASA research along these lines, completed in 1985, developed two decision support systems for two regional water management systems, one in the Netherlands and the other in the German Democratic Republic (see Orlovski, S. Kaden and P. van Walsum, 1986). The authors were primarily interested in the interactions between one upper-level decision maker, referred to as the Policy Making Authority, and a number of local (lower-level) decision makers.

However, the LIR Project's focus on *international* river basins distinguishes it from the regional DSSs of IIASA's Regional Water Policies Project through 1985. In the international case, it is unrealistic to assume a single hierarchical decision structure, though it can be useful to consider partially conflicting, and often different, hierarchical structures in different countries. As will be discussed a bit more in the next section, it is therefore more useful to design a DSS that can be used either *jointly* by a number of decision makers at the same level (see Figure 1a), or *separately* by decision makers representing different riparian countries, each having its own information and models (see Figure 1b).

In addition to arguing for a hierarchical structure, experiences with DSSs also indicate the importance of modular designs. In a large river basin the scope of water management and land-use policy is enormous, and it is impossible to analyze simultaneously the implications of all possible decisions and actions. That is, though it may be a truism that "everything effects everything else," it is also true that any effort to address all aspects of river basin management at once quickly overwhelms the capabilities of the people involved, the software, and the hardware. Thus to be useful a DSS must be designed so that different dimensions (e.g., water quality, land-use patterns, hydroelectric generation, ecological relationships) can be looked at in relative isolation of each other, or examined in selected combinations.

Finally, in this section, we should recall the usual DSS logic, as derived from decision analysis, and flag several of its characteristics that require some new thinking in order to be effectively adapted to international and other negotiation situations. Though the following steps need not be taken in the order presented here, they are generally recognized as basic to developing a DSS.

1. Identification and formulation of the decision problem. This involves creative cooperation between the clients concerned with a specific river basin and the developers of the DSS. It includes:

   – identifying issues important to the clients;

   – identifying (and sometimes selecting only a few) phenomena that are of greatest importance;

   – identifying and, if possible, expressing in a synthetical (mathematical) form the objectives of the clients;

   – identifying the possible decisions (decision variables or controls) that should be considered and could be applied in practice;

   – identifying the relationships between decision variables and objectives (impacts);

   – identifying the structure of the decision making process, taking into account competences and possible areas of influence subordinated to or associated with distinguishable decision makers;

   – identify the constraints (technical, economical, political) that can be (and very often are) imposed on decision processes and the decisions themselves; and

   – describe interactions between the system under study and the environment in which the system operates.

2. The second step is to create a quantitative description of those aspects of a decision situation that can be modeled, and that are susceptible to computer analyses and impact assessment. The objective is to select and implement appropriate models and data describing relationships between decision (control) variables and various physical, environmental, economic and social impacts (for instance, costs, reliability of water supplies, pollutant concentrations, etc.) directly relevant to the clients' stated objectives.

3. Once a computer model has been completed, the remaining step is to close the loop with the decision makers by introducing mechanisms for evaluating impacts predicted by the model for various management decisions and policy options. A schematic of this stage is shown in Figure 2.

Applying this logic in practice is never entirely straightforward. And where there is not a single "client," but rather representatives attached to different sovereign states, additional confounding influences make themselves felt. As discussed below there is a competitive, or "distributive," component to *all* negotiations, and the distributive side of a negotiation invites tactics that confuse the above logic of DSSs. To break new ground in these situations, we therefore have to go beyond the theory of DSSs built for relatively cohesive hierarchical decision processes.

3.1.2. Negotiation analysis

In focussing on international river basins, the WAT Project must provide support for a particular class of decision problems -- those with no clear procedure for resolving competing interests. There is no "World Government" with binding procedures that a party can invoke unilaterally. Thus DSSs for international issues should be designed for sovereign parties likely to have some conflicting interests with their counterparts, and likely to have some conflicting views about what is considered legitimate, or fair, in going about resolving those differences. To understand the special features of this class of problems, we turned to the field of negotiation analysis.

In the last ten years or so a number of scholars have tried to span traditional research fields focussing individually on, for example, diplomacy, labor-management relations, and business negotiations. Each field concerns a particular type of negotiation, and the objective has been to extract lessons and principles from each that are applicable more broadly. It is to the results of this class of research that we turned for guidance in making our DSS useful for international river basins.

3.1.2.1. *Distributive and Integrative Bargaining*

One important lesson that has emerged is the distinction between the integrative and distributive dimensions of most negotiations. To understand the distinction, consider one stereotype that is popularly associated with the word negotiation -- that of a village market where a buyer and a seller haggle about the price of some item. The higher the price they settle on, the more money ends up in the seller's pocket; the lower the price they agree to, the more money stays in the buyer's pocket. This is straightforward distributive bargaining -- what one gets the other gives up.

But almost all negotiations have another dimension. By combining resources, or by well designed trade-offs, two parties can create additional value above and beyond what each brought to the negotiation. Most international river projects are dominated by value creation. Joint hydroelectric projects, for example, are undertaken precisely because they provide more cheap power than the sum of the unilateral alternatives available to the parties involved. Efforts to jointly create new value, to "make the pie bigger," are labeled "integrative bargaining" to distinguish them from the distributive dimension of all negotiations.

One perspective the LIR Project could have taken would be that of an advisor seeking to help one party to a negotiation do as well as possible on the distributive dimension. This would be well within the tradition of designing DSSs to address, in any one application, the decision problem of a single client, whether that client is an individual, a firm, a government department or ministry, or a country. There are also well-established traditions built on the conviction that the overall social welfare is best served if two parties each try their utmost to win distributively. The adversarial legal systems throughout the world are the best established example.

However, we chose not to pursue a DSS designed to give its user the best advantage on distributive dimensions of a negotiation. The reason is the strong argument in much of the literature that successful tactics for distributive bargaining often work at cross purposes with integrative bargaining. As stated by Weeks, "although both creating [integrative] and claiming [distributive] processes are going on simultaneously in nearly every negotiation, the tactics used for creating and for claiming value differ dramatically. Thus the negotiator is constantly torn between the good communication, openness, trust, creativity, and joint problem- solving of integrative tactics, and the hiding of information, making of commitments, exaggeration of the cost of concessions, distortion of information, lying, and threatening of distributive tactics" (Weeks, 1986). This leads to what Lax and Sebenius call the Negotiator's Dilemma (Lax and Sebenius, 1986). The essence of the Negotiator's Dilemma is very similar to that of the more familiar Prisoner's Dilemma and is illustrated in Figure 3. Two parties can do well in a negotiation if they both adopt integrative tactics, while they stand to do less well if they both adopt distributive tactics. If one adopts integrative tactics, however, while the other opts for distributive tactics, it is likely to lead to a very attractive outcome for whomever chose the distributive route, and a disaster for whomever chose integrative tactics.

According to the Negotiator's Dilemma, if we build a DSS for effective distributive bargaining that is sufficiently successful to be widely used, our product will in the end be pushing more and more negotiations toward the lower right corner of Figure 3. It would be more constructive if the more our DSS is used, the more negotiations get pushed toward the upper left corner of Figure 3. To this end we have chosen to conduct the LIR Project, and build our DSS, to promote successful integrative bargaining.

3.1.2.2. *Principled Negotiation*

One well-stated set of guidelines for promoting successful integrative bargaining is that offered by Fisher and Ury (1981) under the label "Principled Negotiation." In its most concise form, Principled Negotiation boils down to four elements.

1. Separate the people from the problem.

2. Focus on interests, not positions.
3. Invent options for mutual gain.
4. Insist that the result be based on some objective standard.

Even without going into further details elaborated by Fisher and Ury these principles immediately give some guidance that has been incorporated by the LIR Project. Principle 3, "Invent Options for Mutual Gain," emphasizes that the Project and its DSS should not aim simply to analyze reactively river management and development alternatives, but to foster inventiveness and help parties generate creative new alternatives that are improvements from all perspectives. Among other things, this argues for software that makes it easy to sketch out new river management and development designs and get a quick sense of how they perform under different assumptions and according to the different viewpoints of various parties. Beyond the summary statement of principles above, additional research by Fisher and Ury, as well as by others, has guided the Project to search for empirically successful features of inventive river basin agreements in the past. In collaboration with the LIR Project, McDonald (1988) has catalogued a number of such features and illustrated them with 56 examples taken largely from existing river basin agreements. The examples are available on floppy disks and are cross-indexed so that they can be quickly searched by a personal computer to find suggestive examples analagous to a user's own situation. We will continue to expand this computerized database of integrative bargaining examples throughout the course of the Project, based on the proposition that the more easily negotiators can review possibly analagous illustrative successes, the more likely they will be to invent modifications, or new options, leading to mutual gain in their immediate situation.

3.1.2.3. *Third Party Analysis*

In their further development of Principle 1, "Separate the People from the Problem," Fisher and Ury effectively recast negotiations as exercises in joint problem solving. In doing so they elevate the practice of ***joint analysis*** to the top rank among integrative bargaining strategies. Through joint analysis each party can learn about the other's interests, assumptions, and reasoning; divergences can be addressed before they become too advanced and entrenched; a tradition of cooperation and trust can be fostered; and resources can be pooled. McDonald (1988) also discusses ***third-party analysis*** as a supplement to joint analysis, or even as an alternative in those cases where parties haven't the resources, the expertise, or the degree of cooperation needed for joint analysis.

Within the framework of principled negotiation, the term "third-party analysis" refers to a resource equally available to all parties. Thus, the term excludes situations where the third-party is, say, a consultant working solely for one party. Third-party analysis may come in a variety of forms. In the 1967-1984 Skagit River Basin negotiations between Seattle and British Columbia, third-party analysis provided by the International Joint Commission served often to resolve analytic disagreements between the parties (Alper and Monahan, 1986). In the development of the 1987 Zambezi Action Plan, the third-party analysis by UNEP's consultants served more to coordinate and synthesize analyses carried out by each of the basin states (UNEP, 1987b). In connection with the Law of the Sea negotiations, third-party analysis by the Massachusetts Institute of Technology (MIT) provided neutral evaluations of alternative proposals for sea-bed mining arrangements. Sebenius (1984) argues that because the MIT group had built its analyses entirely independently of all parties, it was widely accepted by the negotiators as unbiased, and therefore credible and useful. This case is worth noting as one counterexample, in a negotiating situation, to the proposition that only analyses built in close cooperation with prospective users are of any relevance and use.

In the LIR Project's case studies for both the Danube basin and the Zambezi basin, the Project's own role comes closest to that of a third-party analyst. However, it is too early to say whether that role will closely resemble one of the three examples just given, or will evolve somewhat differently. Sections 4 and 5 below describe the initial evolution of LIR's involvement in both cases.

3.2. Case Studies and Other Applications

In contrast to the Danube, which flows through three Central European capitals plus a number of other major industrialized cities, the Zambezi is a rural, relatively undeveloped river. There are however significant development pressures already on the horizon. Therefore at the request of several basin states, UNEP was invited to assist the countries of the region in developing a multi-lateral, multi-issue arrangement for collectively managing environmental issues in the basin. The first milestone in this process was the signing, by five basin states in May 1987, of a Zambezi Action Plan (ZACPLAN) encompassing both research activities and the preparation of national and international legal machinery. The implementation of ZACPLAN is the responsibility of the Southern African Development Coordination Conference (SADCC).

Based on its own review of the Zambezi River's hydrology and biology (Pinay, 1988), plus discussions with various officials in SADCC, UNEP, and Zimbabwe, the LIR Project has begun assembling data and models particularly applicable to issues of apparent concern within the basin. These are described in Section 4. Also described is a 1989 workshop to be sponsored jointly by IIASA and SADCC and held in Zimbabwe. The workshop will present and distribute the LIR Project's Zambezi work, instruct analysts from the basin governments in its use, and define further work to be done both at IIASA and within the basin states prior to a subsequent IIASA/SADCC meeting for under-secretaries responsible for resource conservation and land utilization within the basin states. The second meeting is scheduled for late 1989 or early 1990.

The Danube case study concerns water quality management and may evolve into a separate study of environmental assessment addressing the Gabcikovo-Nagymaros (GNV) Project on a 150 km stretch of the Danube between Czechoslovakia and Hungary. Austria is also involved in the GNV Project as a provider of capital in exchange for future hydroelectricity. We chose to focus our Danube work on these problems following a review by Linnerooth (1988) of the negotiating history and prospects for future international cooperation in the Danube basin.

The objectives of the GNV Project are hydropower generation, flood control, and improving the shipping channel. The project is expected to also have impacts on the local ecology, water quality, and groundwater table. Substantial research on all these issues has been carried out by the Czechoslovaks and Hungarians, and additional research is likely to continue, both in the remaining construction period and during subsequent full operation. The task is to assure facilities and operational practices that most effectively meet the objectives while minimizing adverse impacts. The course of the LIR Project's initial participation in GNV activities, and the effect of this participation on the Project's software development, are described in Section 5.

Particularly at its beginning, we made efforts to describe the Project to a number of interested audiences to develop collaborators and further applications. Presentations were made at:

- the George Washington University Workshop on Management of International River Conflicts, held at IIASA, 22–25 September 1986;
- the International Symposium on the Impact of Large Water Projects on the Environment, organised by UNESCO and UNEP in cooperation with IAHS and IIASA, held in Paris, 27–31 October 1986;
- the Coordination Meeting for Implementation of World Climate Programme-Water Projects organised by WMO in Geneva, 1986; and
- the meeting of the UNEP Working Group on Large Scale Water Development Projects, held at IIASA November 30 – December 2, 1987.

Section 7 lists collaborating individuals and institutions that evolved from these and other initiatives. In addition, there have been initial expressions of interest for applications addressing the following cases:

- USA and Canada with regard to St. Lawrence River;
- Egypt in connection with the Nile;
- Portugal, where interest has been expressed by two different groups working on water management problems for the Northern Region in Portugal and for the Tagus River,
- Italy for the Po River basin,
- USSR in connection with plans to build a channel between the Danube and Dneiper Rivers, and
- FRG, in connection to Elba River.

3.3. Software Development

The central software package, which is, as of the time that this is being written, nearing completion, is called IRIS. The acronym stands for *I*nteractive *RI*ver *S*imulator. Its development emphasizes graphics and menu-driven routines that are easy to use and interpret. For hardware, the focus is on personal computers, as they may be the only technology reliably available in some parts of the world. IRIS has three elementary components:

1. Routines for performing two basic functions:
   (i) providing a graphics-based, menu-driven interface between the user and the models and data;
   (ii) managing data and the transfer of data within the DSS.
2. Various models that will be used to simulate processes and phenomena of interest in specific applications.
3. Supplementary programs to analyze and display data necessary for making decisions.

Most of the programming at IIASA and in collaborating institutions is written in FORTRAN 77. Therefore, all the main software components have been written in FORTRAN. Some supplementary programs have been written in "C".

An essential characteristic of the decision support system is the graphical features for presenting information and organising interactions with the user. The graphics software is supported by a graphics toolkit called CAPLIB. This, plus two utility programs called MAPEDT and MAPOVL have been purchased from Resources Planning Associates, Ithaca, NY, USA. Because of the hardware requirements of these programs, we decided to develop two versions of the DSS software for two different computer graphics cards (standards) used in PC-AT microcomputers.

1. The VECTRIX card allows the display of videodigitized maps with transparent coloured overlaps at a high resolution (i.e., more picture elements per unit area in the display). The Vectrix colour board also requires a high quality display monitor attached to a PC microcomputer (see Figures 7 and 8).
2. The Enhanced Graphics Adapter (EGA) card allows the display of opaque colours, and in our case will not permit the display of videodigitized maps. This colour card, and its associated monitor, are more common and less expensive than the Vectrix card and monitor.

Both types of graphics boards can be attached to an IBM PC XT/AT or strictly compatible microcomputer equipped with 640 K RAM memory (extensions desired!), a numeric co-processor, and a system clock. The graphical libraries require the use of an MSDOS (version 3.1 or higher) operating system. A more detailed description of IRIS is provided in Section 6.

4. ZAMBEZI CASE STUDY

4.1. Summary

In the case of the Zambezi River there are no pressing joint projects of immediate political concern. Moreover, the river is in a developing region of the world, and is relatively remote from urban centers. The basin countries have nonetheless taken a substantial first step in creating an international basin management mechanism through the adoption of the Zambezi River Action Plan (ZACPLAN) in 1987 by five of the eight basin states. ZACPLAN was drafted from 1985-1987 under the auspices of the United Nations Environment Programme (UNEP), which also partially funds the LIR Project's work on the Zambezi. In support of the ZACPLAN process, and with UNEP funds, a workshop on Zambezi applications is being organized jointly by IIASA and the Southern African Development Coordination Conference (SADCC), which is responsible for ZACPLAN implementation. The workshop will be held in Zimbabwe during the first half of 1989.

A principal purpose of the workshop will be to transfer to riparian countries and SADCC the computer software developed by the LIR Project, plus models and data that we have assembled relevant to the Zambezi basin. The workshop will be built around training sessions and demonstration applications focussed on basin issues that appear especially important based on our visits within the basin and our supplementary research at IIASA. In particular, these include land degradation in the basin, reservoir operation, and hydropower production.

We believe that the transfer of methods, software, models, and data that have been developed, collected, and combined into a coherent decision support system can promote progress in development planning, management practices, and joint problem solving in shared river basins such as the Zambezi. However, the early 1989 workshop is not planned as just a one-shot interaction. There is scheduled for late 1989 or early 1990 a further conference for under-secretaries responsible for natural resource conservation and land utilization in all SADCC countries. This will be designed to present results from cooperative research, initiated at the first workshop, between IIASA and the SADCC countries to refine and expand applications of the Project's work to concerns on the agendas of the basin governments. From among the African participants in the first workshop, we expect to recruit several to work at IIASA on the joint development of the decision support system, and its applications, to be presented at the second meeting.

The following sections summarize the development of ZACPLAN, IIASA's involvement in the process, the issues in the river basin that are driving the Project's software development and preparation of demonstrations, and the data and models assembled to date as part of the case study.

4.2. Background

The Zambezi basin includes parts of eight African countries (see Figure 4) all of which are considered developing countries and therefore face different issues than the countries in the Danube basin. Though the Zambezi River is currently under less development pressure than the Danube, the Zambezi basin countries, with some help from the United Nations, have already begun to address the problem of collectively managing environmental issues in the basin. Following a number of resolutions adopted by the UN and other international bodies, UNEP launched a comprehensive program on Environmentally Sound Management of Inland Water (EMINWA) to assist governments in the integration of environmental concerns in the management of water resources. In response to requests from the governments of three Zambezi river basin countries (Botswana, Zambia, and Zimbabwe) for help in the development of regional cooperation and in the promotion of sustainable development, UNEP decided that the first element of implementing the EMINWA program should concentrate on the Zambezi river system. As a first step UNEP assisted the governments of the Zambezi river basin countries in developing the Zambezi Action Plan (ZACPLAN). In May 1987 an "Agreement on the Action Plan for the Environmentally Sound Management of the Common Zambezi River System" was adopted and signed by representatives of five Zambezi river basin countries (Botswana, Mozambique, Tanzania, Zambia, and Zimbabwe) (UNEP, 1987a).

During the period when ZACPLAN was being prepared, UNEP was also pursuing additional initiatives to foster improvements in the way governments evaluate and select environmentally sound alternatives when planning and managing water resources in large international water systems. One approach is through the use of decision support systems. UNEP therefore contributed to our research project, requesting that we develop such a decision support system for the Zambezi river basin. The selection of the Zambezi river basin also meets the objectives of the Ford Foundation, which is interested in helping developing countries improve and harmonize their development and resolve possible transboundary conflicts.

Generally speaking, two things are happening at the same time in the Zambezi basin. At a political level, the basin states are trying to create, through the ZACPLAN process, an effective multilateral, multi-issue mechanism for the sort of integrated basin management espoused in UN political declarations and by policy theorists seeking to assure collective efficiency. Creating such a joint mechanism would be a challenging process under the best of circumstances, and many of the basin states face pressing economic and/or security problems that limit the resources and energy they can devote to political institution building for environmental management.

The second level at which things are happening in the basin is at the operational level of individual government ministries and departments. These are responsible for assuring drinking water supplies, or irrigation water, or providing hydroelectric power, or implementing land reform, or controlling the tse-tse fly. All these projects affect the river and the basin in one way or another, but the responsible departments can hardly hold off until the ZACPLAN process comes up with an operating joint management mechanism.

Although the LIR Project's Zambezi case study is focussed around the ZACPLAN process as is described below, we have visited a number of ministries in one basin country, Zimbabwe, to learn how our work could best address their immediate concerns. We intend to maintain and expand these contacts, with the objective that the DSS being developed will be applicable both to the international ZACPLAN process and to internal departmental processes in each basin state. We feel it important that the LIR Project's contribution be something that the internal process share in common with ZACPLAN implementation, not something that differentiates between the two.

4.3. ZACPLAN

ZACPLAN is a thin document (24 pages including appendices), though the UNEP diagnostic study on which it is based (UNEP, 1987b) is more substantial (101 pages including appendices). ZACPLAN covers a lot of ground. It addresses issues ranging from monitoring climate data and runoff, to flood plain management, to human resources development and community participation in water projects. The ZACPLAN document signed in May 1987 includes 19 specific projects, a schedule for carrying them out, and a table of proposed sources for funding. The proposed budget for 1987–89 totaled $12 million, estimated to cover the first eight projects, which are referred to as "Category I" projects and are summarized below. It was proposed that $4.8 million would come from the participating countries, and that $7.2 million would come from donors and international organizations.

The eight Category I projects are as follows.

ZACPRO 1: Compiling information on all completed, current, or planned development projects and conducting evaluations of all major projects.

ZACPRO 2: Compiling a list of all relevant national and international legislation, developing a regional convention and associated protocols, and assisting in the preparation of new national legislation.

ZACPRO 3: Surveying relevant scientific and administrative institutions, manpower requirements, research facilities, and equipment in the basin states.

ZACPRO 4: Developing or strengthening relevant national research laboratories and institutions.

ZACPRO 5: Designing and initiating unified basin-wide monitoring of indicators covering water quantity, water quality, meteorology, land use, land cover, groundwater, sediment loads, flooding, and soil moisture.

ZACPRO 6: Developing an integrated water management plan for the Zambezi Basin.

ZACPRO 7: Designing and implementing promotional campaigns for community practices that further good sanitation, soil conservation, maintaining sufficient clean drinking water, and forest protection.

ZACPRO 8: Developing unified engineering planning and design criteria and manuals for drinking water supply and sanitation projects.

As will be seen below, the implementation of ZACPLAN is beginning at the more modest end of the spectrum covered by these eight projects. At this stage, we feel the immediate objectives of ZACPLAN's managers boil down to three:

(i) maintain the current political will for cooperation among the basin states,

(ii) improve on existing data and understanding of basin processes, and

(iii) build up their analytic capacity to evaluate, and improve upon, proposed joint development projects and management arrangements.

The LIR Project's potential contribution is principally to the third of these objectives. The Project can also contribute less directly to the second objective given that some of the most important first steps in joint management involve cooperatively collecting data and modeling river processes. Realizing the Project's potential involves two sorts of initiatives:

(i) developing institutional connections with potential users and research institutions from Zambezi basin countries in order to establish an active, constructive role as a third-party analyst within the basin, and

(ii) collecting relevant data sets and models, and conducting analyses using IRIS that address the natural and social processes on the agendas of the basin states.

The rest of this section deals with the principal institutional dimensions of ZACPLAN. (Attachment 1 provides a more complete list of the Project's contacts in the basin.) Section 4.4 then summarizes the Project's research to date on issues of concern within the basin.

4.3.1. Implementing ZACPLAN

Implementing ZACPLAN is the responsibility of the Southern African Development Coordination Conference (SADCC). This development was a bit of a surprise to UNEP, which expected ZACPLAN to follow the pattern of UNEP's Regional Seas Programmes, which are managed by UNEP secretariats and funded through UNEP trust funds. However, the five signatories included the option of SADCC management, and this option came into effect upon the approval of the SADCC Council of Ministers in July 1987. Therefore, to understand how the LIR Project might contribute to ZACPLAN's implementation, it is important to understand some of the history and operation of SADCC.

SADCC was established in 1980 by nine countries: Angola, Botswana, Lesotho, Malawi, Mozambique, Swaziland, Tanzania, Zambia, and Zimbabwe. It is expected that an independent Namibia would join SADCC; otherwise no further expansion is envisioned. The principal objectives of SADCC are two: integrated development, and reducing dependence on South Africa. The approach is decentralized. SADCC has established a number of substantive sectors (some divided further into subsectors) each of which is the responsibility of one member country. For its sectors each country must provide office space and staff and organize (usually through an aid donor) the necessary technical expertise to coordinate projects. SADCC itself (it does have a small headquarters in Gaborone, Botswana) does not undertake projects, receive aid, or enter into contracts. Hanlon (1984) describes its role as a "marriage broker" between donors, investors, and countries. SADCC is exactly what it says it is, a "development coordination conference." It should not be mistaken for a regional development authority. It has consciously decided to seek progress one project at a time, and shuns grandiose development visions. It has also sought to avoid divisive issues, and rather focus on the huge agenda of projects that more clearly benefit all members, for example, transport and communication.

One of the major sectors of SADCC deals with agriculture and is the responsibility of Zimbabwe. Within the agriculture sector there are seven subsectors, one of which deals with Soil and Water Conservation and Land Utilization (SWCLU) and is assigned to Lesotho. It is to the SWCLU Unit of SADCC that the responsibility for implementing ZACPLAN has been assigned. Although the irony (and problems) of ZACPLAN responsibility being located in a relatively poor, non-basin state is lost on no one, ZACPLAN's assignment to the SWCLU Unit is recognized as in line with SADCC's structure and political support.

As a result of a visit to Maseru in June 1988, we learned that the SWCLU Unit is stronger than we had expected based on outdated sources. It currently has a professional staff of three, which it plans to double. It will move into new facilities shortly. Its budget is $1.5 million for 1988, $2.2 million for 1989, and $2.8 million for 1990. This will be funded largely by the Swedish International Development Authority (SIDA). The Unit's work from 1985–87 was funded by both SIDA and the Kingdom of Lesotho. The Unit has published 16 reports and produces a regular newsletter with 2300 copies of each issue in English and 150 in Portuguese.

Still the Unit's agenda remains quite large relative to its resources, and ZACPLAN implementation is behind the schedule envisioned in May 1987. One consultant's report, commissioned by the SWCLU Unit, had sought to develop a more specific plan of action for implementing ZACPLAN. After some criticism from member states, an effort was initiated to hire a second consultant, supported by a group of Nordic funders, to improve on the report, ideally leading to specific funding commitments by the Nordic group for specific projects within ZACPLAN. The target date for completing the improved report was December 1988, but at this writing we do not know its status.

Because of the limited resources that the SWCLU Unit can devote to ZACPLAN, our visit to Maseru and a subsequent visit by an SWCLU representative to IIASA rather quickly developed an immediate contribution the Project can make. SADCC and IIASA will cosponsor a workshop for representatives of SADCC member countries, to be held in the first half of 1989 in Zimbabwe. The principal purpose will be to present and distribute IRIS, and demonstrate its application to issues of concern in the Zambezi basin. An agenda for the workshop is given in Attachment 2. Further development and application of IRIS could then take place both at IIASA and within the basin states. A subsequent conference, based on this research, for SADCC member under-secretaries responsible for natural resource conservation and land utilization is being planned for the end of 1989 or early 1990.

4.4. Issue Identification, Data Collection, and Model Development for the Zambezi Basin

During 1987 and 1988 the LIR Project conducted an extensive review of data and studies addressing Zambezi basin hydrology, ecology, land use, and development (Pinay, 1988). This was supplemented by initial research, by a participant in IIASA's 1988 Young Scientists' Summer Program, on social, political, and economic considerations likely to affect joint basin management efforts (de Campos Silveira, 1988), and by a two and a half week trip to UNEP headquarters in Nairobi, the SADCC SWCLU Unit in Maseru, the Lake Kariba Research Station, and a number of Zimbabwean government ministries in Harare (Salewicz and McDonald, 1988). These activities were all focussed on three objectives:

(i) learning how best to focus the development of a decision support system (DSS) to make it most likely to facilitate cooperative, productive Zambezi management;

(ii) determining what material would be most valuable to the basin states to include in the early 1989 workshop in Zimbabwe, and what would be the most effective way to present and transfer it, and

(iii) collecting data and models to be used as part of the DSS, that are directly relevant to the issues that appear to be of likely concern to basin states.

Before summarizing how these activities have guided the acquisition of data and models, and the preparation of demonstrations for the first workshop, the fact that the 1988 trip to the Zambezi basin included no stops in basin states other than Zimbabwe deserves comment. Of the basin states Zimbabwe is strongest economically and has, we understand, the best developed research and operational infrastructure. We take as further evidence of this the relative ease with which we arranged meetings in Zimbabwe, given that the initiatives we took in, particularly, Mozambique and Zambia were essentially identical to those for Zimbabwe. Given the closer interaction with SADCC that developed from the trip, we now look forward to active cooperation in basin states in addition to Zimbabwe. Nonetheless, one lesson we have taken from our experience is the challenge, due to disparities in basin state infrastructures, that ZACPLAN faces in keeping all countries actively engaged and assuring that the underlying interests in all countries are in fact accurately represented in the process. Otherwise any ZACPLAN convention or programs risk being based on misperceptions and lacking the internal commitment within basin countries necessary for implementation. It is similarly a challenge for the LIR Project to assure a balanced, mutually beneficial contribution.

From the Project's research at IIASA, the visits in Africa, and the SADCC visit to Laxenburg we have built, as a guide to our software development activity, a list of demonstrations that it would be *desirable* to have for the two workshops to be held in the basin (see Table 1). The list is, not unexpectedly, longer than what we can accomplish with current resources. For the immediate future, the specific demonstrations that we plan to have prepared for discussion at the first workshop are included in the workshop's agenda in Attachment 2. At that workshop the list will be revised, the options will be ranked, and we will work out what subsequent work can best be contributed by IIASA and what can be carried out within the basin countries and the SWCLU Unit. The following sections provide some elaboration on why the issues in Table 1 were chosen. More complete information is provided in the papers by Pinay, de Campos Silveira, and Salewicz and McDonald.

Table 1. Desirable Demonstrations for Zambezi Workshop

Presented list of desirable demonstrations reflects issues identified during study tour and also Project capabilities to develop and/or implement respectable models.

1. Water balance for the basin.
2. Hydrological and ecological consequences of operation of reservoirs on Zambezi River and Kafue River.

3. Evaluating release rules for reservoirs in light of both hydropower objectives and ecological objectives.
4. Effects on the water balance of diverting water from the Okavango swamp to South Africa.
5. Hydrological and ecological consequences of constructing new reservoirs on Zambezi River.
6. Erosion and siltation as functions of land-use practices and rainfall pattern.
7. Effects of possible climate change on hydropower performance of the river and the ecology.
8. Fishery dynamics in Kariba in response to alternative fishing policies, release policies and nutrient levels in the lake. Nutrient levels are, in turn, a function of land-use and rainfall.
9. Propagation of pollution caused by accidental spill (oil drilling).
10. Designing cost-effective monitoring networks, taking theoretical considerations into account along with practical concerns of access, maintenance, and reliable readings.
11. Getting the most out of incomplete data.
12. Designing policies (e.g. fishing, dam releases) that jointly serve research objectives and economic objectives.

4.4.1. Hydroelectricity

The principal use of the river is for generating hydroelectricty. There are three major hydroelectric facilities in the basin (see Figure 4). Kariba, which was completed in 1959, is on the border between Zambia and Zimbabwe. Cabora Bassa, completed in 1975, is in Mozambique, and the Kafue (1972) - Itezhitezhi (1977) system is in Zambia. Hydroelectric capacity comfortably exceeds demand in the Zambezi countries *if* demand is defined as the "ability of the end-use customer to pay the asked for price which effectively leaves out 70 to 90 percent of the population, who at present do not have this ability to pay" (Bhagavan, 1985). If attempts are made to meet this larger need, current capacity is inadequate.

There are two approaches to generating more hydroelectricity: building more facilities, and more effective operation of current facilities. A number of new dams have been proposed over the years. Some would lie entirely within one country (e.g., proposals for new dams downstream of Cabora Bassa), while some would be clearly international (e.g., those proposed for Batoka Gorge and Mupata Gorge between Zambia and Zimbabwe). Some of the developments that would improve utilization of current facilities are not hard to identify, though they may be difficult to accomplish. In particular, Cabora Bassa's production has been way below its potential due to sabotage of power lines by RENAMO. Hopefully, this situation will change as a result of a June 1988 agreement between South Africa, Mozambique, and Portugal to cooperate in repairing and protecting the power lines. Less clear opportunities to improve utilization through coordinated reservoir operation will require international cooperation among basin states.

In addition to target demonstrations addressing increased hydroelectricity generation from new or current facilities, Table 1 also includes work on the impacts of dam operations on fisheries and local ecosystems, and with the hydropower impacts of a possible change in regional climate. Though the Zambezi's dams are principally for electricity production, they have created a major commercial fishing industry on Lake Kariba and at least the potential for significant fishing in Cabora Bassa. They have also changed other ecosystems both upstream and downstream of the dams. Though at least Itezhitezhi is operated to maintain partially its principal downstream ecosystem, the Kafue flats, to our knowledge ecological concerns are otherwise not taken into account in dam operation. Nor is it at all clear how they might be included, given the relatively poor understanding of the relationships between dam operation and ecosystems. The interest in such issues evidenced in our review of written material, and our conversations with those involved in the basin, led to the inclusion of these items in Table 1.

The inclusion of possible climate change impacts comes only partly from evidence within the basin, specifically drought problems since 1981. In addition, it has been included in light of concerns that reduced hydropower production in other important river systems may be due to climate change (The Economist, 1986, 1988), and because of IIASA's other activities addressing climate change impacts. IIASA has recently published two major volumes on possible agricultural impacts of climate change, and has begun new work with National Science Foundation funding on impacts on water resources. Given the LIR Project's case study of the Zambezi river basin, IIASA's Climate Impacts Project has recently submitted to UNEP a proposal to study the impacts of climate change on water resources in the basin. The proposal is a joint submission with the Pacific Institute for Studies in Development, Environment and Security.

4.4.2. Land-use and land degradation

A second very important issue identified by Pinay (1988), and that which was most frequently mentioned during our visit to Africa, is land degradation within the basin. As indicated by its title, this is also a major concern of the SADCC SWCLU Unit coordinating ZACPLAN. While we have collected written material relevant to a number of basin states, it was only in Zimbabwe where we had first-hand conversations. There it is the pressure to expand peasant agriculture into marginal land that threatens land degradation. Prior to independence in 1980 the black farmers were anyway restricted to marginal land which could not support the population density, and to this day none of the communal lands in Zimbabwe is agriculturally self-supporting. In the Zambezi Valley the carrying capacity of the land is not high, and even with one of the lowest population densities in the country, the population exceeded the land's carrying capacity three years ago. Since independence, the expansion of rural agriculture into additional marginal areas is driven by two forces. The relatively more controlled force is the government's land reform, or resettlement programs, to provide rural farmers some of the benefits of independence in the form of land. Second is the less controlled movement of squatters into new areas whenever they are declared free of tse-tse fly under the tse-tse fly eradication program.

Pressure on the land will continue to grow in all basin states. Annual population growth rates estimated for 1990 based on data assembled by IIASA's Population Program range from 2.7% in Mozambique to 3.7% in Tanzania and Zambia. Deforestation rates have been estimated for Malawi, the most densely populated country, at 3.5%/year in 1980, and at over 3%/year in some areas of the third most densely populated country, Zimbabwe, even before its independence and land reform programs (SWCLU, 1987). Whatever the causes of agricultural expansion into marginal lands in the various basin countries, the potential adverse effects are largely the same: soil and nutrient loss leading to decreased agricultural potential.

Thus for LIR's DSS to be relevant to the Zambezi basin, it is desirable that it handle issues of land degradation. This means the ability to incorporate models of erosion hazard, soil loss, and nutrient loss, and the ability to handle data on slope, soil type, rainfall energy, vegetation cover, cropping or grazing patterns, soil conservation practices, and other variables used by erosion models.

4.4.3. Monitoring

As emphasized in our interim report to the Ford Foundation and in ZACPLAN itself, there is much room for improvement in monitoring all sorts of variables in the basin, from precipitation to sanitation practices. Better data are needed, as stressed in ZACPLAN, to help design well-informed, cooperative development and management plans. Thus, it is desirable that the DSS be applicable to issues of monitoring system design, and be useful even when data are very spotty. To some extent the LIR Project can turn to related work in IIASA's Environment Program on designing environmental monitoring systems, and within the System and Decision Sciences Program on dealing with incomplete data. Yet the effort must keep in mind the practical difficulties of monitoring in those areas where there is a limited infrastructure of appropriate technology, trained manpower, access, and communications.

4.4.4. Research

Within the basin we have talked with fewer researchers than with government managers. The researchers we did talk to stressed the relative lack of basic research and scientific knowledge in the basin. This is important to ZACPLAN's ambitions of a regional land-use plan and legal conventions because governments cannot be expected to negotiate formal agreements without being able to evaluate whether specific proposals further their interests, or work against them.

Basic research is often far down among government priorities in developing countries. Because of that, and not in spite of it, it would be desirable if the LIR DSS could help identify strategies that well serve research objectives, with little or no impact on economic and other objectives (Walters, 1986).

4.4.5. Water diversion

Zambezi water is used for irrigation in at least Zambia and Mozambique, but there seem to be no immediate plans for new major withdrawals or diversions of Zambezi water. There is, however, initial discussion of diverting Zambezi water from Botswana to South Africa, and it is estimated that by the turn of the century Zimbabwe's population will exceed the water supplies available through conventional water development. Thus, an ability of the DSS to address possible medium or long-term water diversion schemes would be a plus.

4.4.6. Fisheries

It is evident from Pinay (1988) that fishing, which has long been important to people on the river, particularly in the Kafue flats and the area of Lake Kariba, is greatly affected by current and proposed developments on the river. The impoundment of Kariba greatly increased fish catches, though there is evidently some concern now about overfishing. No new commercial licenses for pelagic fishing have been issued on the Zimbabwean side since 1986. Though the infrastructure of commercial fisheries on Cabora Bassa is much more limited, and the fluctuation in reservoir levels constrains the fish populations, Pinay anticipates a significant potential for future exploitation.

Thus the ability to illustrate the impacts on fisheries resulting from different development and management policies has been included on the motivating list of desirable demonstrations.

4.4.7. Conservation and recreation

National parks, safari areas, and reservations are frequent, particularly along the Middle Zambezi. To the extent that the ecology of these areas is vulnerable to basin management practices, it would be advantageous if the DSS were to include models of such vulnerability.

4.4.8. Less important issues

Having noted issues that should be kept in mind while designing software to assist planning in the Zambezi basin, it is worth identifying three issues that seem likely to be of minor importance, based on our research and discussions to date: navigation, pollution, and flood control.

4.5. Collected and Potentially Available Data

We won't be able to provide all the demonstrations listed as desirable in Table 1 in time for the first 1989 workshop in Zimbabwe. Largely in response to the relative importance of issues as discussed above and in the references, but also partly in response to the availability of data and models, we have focussed our attention on collecting materials and data to analyze problems of soil erosion, reservoir operation, and hydropower generation.

To analyze soil erosion processes we are including a soil loss estimation model, called SLEMSA, developed in Zimbabwe specifically for Southern African conditions (Stocking, 1987; Elwell 1980). Much of the data necessary to implement the model is on hand at IIASA, and the remaining data is being sought through UNEP's Global Resource Information Database (GRID) and other sources.

Concerning reservoir operation and hydropower generation, quite a bit of data has been obtained from the Zambezi River Authority, which is responsible for the operation of Kariba dam.

1. Historical monthly flows recorded at gauging stations at Port Livingstone and upstream of Lake Kariba. Data cover the period from October 1924 until September 1986.
2. Synthesized (calculated on the basis of rainfall measurements and flows from tributaries) monthly inflows to Lake Kariba from the lower catchment. Data cover the period from October 1924 until September 1985.

3. Estimated monthly values of rainfall on Lake Kariba covering the period from October 1924 until September 1985.
4. Estimated monthly values of evaporation losses from Lake Kariba covering the period from October 1924 until September 1986.
5. Monthly values of turbine discharges from Kariba Dam from October 1962 until September 1986.
6. Monthly spillway discharges from Kariba Dam since October 1962 until September 1981. There have been no spillway discharges since 1981 due to low flow conditions in the river.
7. Tables relating water level in Lake Kariba to the area of the lake and its effective storage.
8. Four volumes of Annual Reports and Accounts published by the Federal Power Board and covering the period from July 1959 until June 1963. These reports contain technical information about Kariba Dam, operation of the dam, and electricity generation.
9. An almost complete set of annual reports of the Central African Power Corporation covering the period from July 1963 until June 1987, except for July 1964 to June 1965. These reports contain complete information on month-by-month operation of Kariba Dam, inflows to the reservoir, reservoir storage, releases, etc.
10. Rule curve for Kariba Dam.
11. Inflows, turbine flow discharges, volume and area vs. water level functions, and historical levels of the reservoirs at Itezhitezhi and Kafue.
12. Rule curve, volume and area vs. water level relationships for the Cabora Bassa Dam in Mozambique;
13. Values of observed historical water levels in Cabora Bassa.

5. DANUBE CASE STUDY

5.1. Summary

The prospect of a multi-lateral, multi-issue basin authority in the Danube River Basin is remote. Aside from the Danube Commission's work on navigation issues, and some possibilities for broad cooperation in the field of water quality management (as a follow-up activity to the Bucharest Declaration), the basin states have explicitly chosen to pursue cooperation largely on an ad-hoc bilateral basis as issues come up where it is in the immediate self-interest of two states to work together. One such issue is the construction of a major hydropower and barrage system, known as the Gabcikovo-Nagymaros Project (GNV), along a 150 km stretch of the Danube between Czechoslvakia and Hungary. Also involved in the project is Austria, which is providing financing and will import electricity from the completed project.

Construction began in 1978, but the project has been controversial, drawing heavy criticism from Hungarian environmentalists. They contend GNV would destroy wildlife, pollute the water supplies of three million people, and be economically senseless. At the moment GNV is going forward, with the Hungarian Parliament having voted 317-19 on October 7, 1988 to continue with the project. However, GNV's managers on both sides of the border remain attentive to environmental issues and cite particularly groundwater quality as a concern, the management of which will require continuing cooperation throughout GNV's operation.

Both experience and theory suggest that in such joint management negotiations it is often difficult to identify and explore new alternatives, whether they are minor modifications or more substantial initiatives, that might provide creative solutions to differences of opinion. For example, it is difficult to suggest a new possibility for consideration without implying an endorsement, and such an implied endorsement may be more of a commitment than any party is willing to make. Experience and theory also suggest that in such instances progress can sometimes be facilitated if the parties agree to analyze *jointly* some of the issues, or if issues are analyzed by a third party who is more free to explore alternative assumptions and arrangements.

In the case of GNV, IIASA's *Water Resources Project* may gradually come to be one such third party. Austria, Czechoslovakia, and Hungary all have member organizations in IIASA, and all support the use of IIASA as one forum, though hardly the only one, to pursue mutually beneficial progress. To date a number of models and data sets relevant to GNV have also been provided to the Project by various Hungarian sources. The GNV Case Study therefore presents an opportunity both for IIASA to contribute directly to substantive progress on a water project of major importance to three IIASA countries, and for the LIR Project to draw conclusions on how its software is used, and can be improved, for joint management negotiations like those related to GNV.

To fulfill a constructive role of third-party analysis IIASA's research must be responsive to the schedules and concerns of the principals. Sometimes this is likely to require quick turnaround on deadline. But sometimes it means progress at a more deliberate pace than would be the case if the only objective were software development. The sections below describe how, to date, the Project has written flexible software and assembled data in preparation for a variety of possible analyses. This has been done in parallel with continuing discussions to better understand the issues as seen from all different perspectives, and to learn what analysis the Project can contribute when, to be most constructive.

We begin, however, with some background on the geography and negotiating history of the Danube Basin.

5.2. Geography and History

A map of the Danube River Basin is shown in Figure 5. Flowing over 2,850 km from the Black Forest in the Federal Republic of Germany to the Black Sea in Romania and the USSR, the Danube is second in size among Europe's rivers only to the Volga. It is also one of the world's most international rivers with eight riparian countries, including the FRG, Austria, Czechoslovakia, Hungary, Yugoslavia, Romania, Bulgaria, and the Soviet Union, and it transfers water from the non-riparian countries of Albania, Italy, Switzerland, and Poland. Near its source, the Danube has the character of a mountain river flowing through the FRG and Austria (passing Regensburg and Vienna) into Czechoslovakia, where at Bratislava it forms the border between Czechoslovakia and Hungary. Flowing south through the Great Hungarian Plain (passing Budapest), it turns eastward into Yugoslavia (passing Belgrade) and later forms the border between Yugoslavia and Romania with the famous narrows at the Iron Gate. The lower, marshy section of the river serves again as a geographic boundary on the long stretch between Romania and Bulgaria, and shortly before the Black Sea it separates Romania and the Soviet Union, emptying into a spectacular delta. During this journey from the Black Forest to the Black Sea over 300 tributaries flow into the Danube.

The geographic variety of the Danube is matched by the cultural, economic, and political diversity of the countries through which it flows. Table 2 shows the different economic and Danube-related alignments of the eight riparian countries. In addition, two UN organisations, the Economic Commission of Europe and the World Health Organisation, have been active in matters related to the Danube.

Table 2.

Country	*Economic*				*Danube-related*	
	EEC	EFTA	OECD	CMEA	BT	DC
FRG	X		X		X	Obs
Austria		X	X		X	X
Yugoslavia			Obs	Obs	X	X
CSSR				X	X	X
Bulgaria				X	X	X
Romania				X	X	X
Hungary				X	X	X
USSR				X	X	X

DC = Danube Commission BT = Bratislava Treaty 1955

Although the Danube flows through eight countries, there is no overall organisation responsible for water resources management, development, and utilization in this basin. In Bucharest in 1985, the eight Danube riparian countries signed a common declaration addressing cooperation in the field of water resources management in order to conserve and rationally utilize the water resources of the Danube. This document, known both as the Bucharest Declaration and as the Danube Declaration, is contained in the paper written by Hock and Kovacs (1987). The Bucharest Declaration creates a political basis, but not an institutional basis, for cooperation. At its most concrete sections, it "declares" that the Danube basin governments will strive to develop and implement a coordinated water quality monitoring program "in the framework of their bi- and multilateral cooperations," and a timetable is established. But there is no description of an institutional mechanism for assuring that such a monitoring program is either developed or implemented. Perhaps for this reason, the timetable of the Bucharest Declaration has not been met. Nor are there any clear expectations of wide, multilateral, operational cooperation getting underway in the near future.

The Bucharest Declaration, however, makes specific reference to cooperation with the UN agencies, and in response, one initiative has been undertaken by the World Health Organisation (WHO). In 1986, WHO prepared a proposal (WHO 1986) for a project that would be conducted by riparian countries in order to help protect Danube water quality. IIASA responded to this initiative and hosted a meeting of WHO and the riparian Danube countries. The objective of the meeting, which was held April 22–24, 1987, and sponsored by UNDP/WHO and IIASA, was to create a basis for cooperation among the relevant governmental bodies from riparian countries in the framework of the WHO project.

Some progress was made at the meeting, but in fact *multilateral* cooperation on water quality issues is developing extremely slowly. Linnerooth (1988), in her review of negotiations concerning the Danube, notes that the slow pace is typical of experience in other river basins. She attributes it to differences in bargaining power between upstream and downstream countries, the scientifically complex and ill-defined nature of water quality problems, the political difficulties of establishing a basin-wide authority that infringes on national sovereignty, and the mismatches between the bureaucracies and practices in the different basin countries.

Linnerooth emphasizes that cooperative progress on the Danube will proceed through incremental bilateral negotiations. This pattern is both consistent with the explicit language of the Bucharest Declaration and experience in other river basins. One first such bilateral step is a 1986 Austrian-Czechoslovakian Agreement on Testing the Water Quality of the Frontier Waters. In this case Austria, the upstream country, has a common interest with Czechoslovakia in improving the quality of the badly polluted March, a river forming the border between the two countries and an important tributary to the Danube.

Recognizing that practical progress on the Danube will be largely through incremental, bilateral negotiations, we supplemented our involvement in the multilateral WHO project by establishing direct contacts with ministries which are responsible for water management, and for pursuing bilateral opportunities in Austria, Czechoslovakia, and Hungary. Collectively, these initiatives led to the Project's focus on the Gabcikovo-Nagymaros Project (GNV). The next section describes the GNV Project. Subsequent sections summarize, first, some lessons from other examples of third-party analysis in water issues and, second, the course of deliberations to date surrounding the Project's interest and involvement in GNV's progress.

5.3. The Gabcikovo-Nagymaros Project (GNV)

The GNV Project involves the construction of a huge hydropower and barrage system along a 150 km stretch of the Danube on the border between Czechoslovakia and Hungary. The idea of building a series of dams and hydroelectric stations on this part of the river was originally raised in the 1950s. Because of its expense, however, the plan was dropped in 1963. Ten years later it was revived, and in September 1977 a final treaty was signed between Czechoslovakia and Hungary to proceed with the project. Construction began in 1978, and completion is scheduled for 1994. But almost from its very beginning, the Project has caused controversy and disputes among different professional and social groups.

5.3.1. GNV's objectives

GNV advocates give a number of reasons for their support. As Hock and Kovacs (1987) point out, the need for canalization along the stretch of the Danube upstream of Budapest was first raised on account of navigation concerns. Member countries of the Danube Commission have an obligation to ensure, between their borders, the undisturbed traffic of ships having a submergence of 2.5 m, and they have accepted a recommendation to increase this depth to 3.5 m if possible. Between Bratislava and Györ this goal cannot be achieved by standard river regulation. Although considerable money has been spent for dredging and river regulation structures, the navigable depth is only about 2.0 m during most of the year, and it is even less in low-water periods. The interest in maintaining a navigable channel is heightened by the prospect of completing the Rhine-Danube canal, which will increase the importance and capabilities of the Danube for transport between Eastern and Western regions of Europe.

A second objective of GNV is flood control. Hungary and Czechoslovakia suffered enormous damages during major floods in 1954 and 1965, and flood protection in the absence of the GNV Project has proved very expensive. As the value of areas adjacent to the Danube increases with continuing development, the interest in reducing flood risks increases correspondingly.

The third objective is hydropower generation. Growing energy demand in Czechoslovakia and Hungary, along with very limited indigenous energy supplies, makes development of the Danube's hydropower potential very attractive. Energy production is also the prime interest of the third party involved in GNV – Austria. Several years ago Austria considered a plan to build a hydroelectric power station in Hainburg, 49 km east of Vienna. After a long dispute, including extensive protest demonstrations, the project was cancelled in 1985 by then Chancellor Sinowatz (Glenny, 1987). Cancellation left unsolved Austria's energy supply problem, specifically the import of more than 13% of its electricity during the peak period in winter, despite the fact that over a full year the country is a net electricity exporter. Thus when GNV construction faced serious financial difficulties in Hungary in 1984, the Austrian government guaranteed a loan offered by a joint Swiss-Austrian consortium led by the Austrian Länderbank, to be paid back in the form of electricity over a period of twenty years.

5.3.2. Overall description of the GNV system

GNV includes two subsystems (Figure 6):

- Central to the upper subsystem is a weir under construction between Hrusov and Dunakiliti that will close the main arm of the Danube and divert the discharge into a 30-km diversion canal. The weir will create a reservoir covering approximately 60 square kilometers. The diversion canal will carry the reservoir's main outflow 17 km to drive turbines with a peak capacity of 700 MW installed in a power station at Gabcikovo. Also at Gabcikovo the canal includes a a navigation lock. 13 km below the power station the canal returns to the main arm of the Danube at Palkovicovo.

- The lower subsystem is located more that 100 km downstream at Nagymaros and consists of three main parts: the weirs closing the river bed, the hydropower plant, and the navigation lock. The primary objective of the Nagymaros dam will be to control and compensate for daily fluctuations in the Danube's water level, since the Gabcikovo plant will be operated as a peak, not continuous, facility. The upstream Dunakiliti dam will cause raised water levels of up to five meters during peak electricity demand. At the Nagymaros dam, which is 25 km north of Budapest, there will also be a hydropower plant with 140 MW of peak capacity.

5.3.3. Environmental concerns

The agreement signed in 1977 by Czechoslovakia and Hungary was based on plans initiated much earlier, when possible long-term environmental consequences of the GNV Project were less well understood and results of what studies were available had not been synthesized in an environmental impact assessment. Between 1978 and 1983 there was considerable criticism of the scheme in Hungary, and in early 1983 the Hungarian National Council for Nature and Environmental Protection pointed out that there had been no serious examination of GNV's environmental impacts (Csepel, 1984). Growing concerns and opposition to GNV's construction led to additional studies in Hungary to analyze possible adverse impacts and to propose measures that would diminish or neutralize the negative effects of the hydropower design. The most important environmental concerns are discussed below.

The first group of concerns is associated with the 30 km derivation canal from Hrusov to Palkovicovo. Diverting the river flow will considerably lower the water level in the old Danube bed and thereby depress the groundwater table. It is estimated that the groundwater table may drop by 1.5–6 m (Csepel, 1984), which may affect the yield of arable and forest land. In order to minimize adverse effects of a decrease in the groundwater level additional studies were made. Two options were investigated (Hock and Kovacs, 1987): (i) replacing by irrigation the water no longer available for plants near the river, or (ii) constructing a combined drainage and recharge system which can control the water table according to agricultural requirements. The second alternative was finally chosen based on the argument that it will not only prevent damages, but actually improve agricultural conditions. The choice was based on field and laboratory experiments, simulation models, and experience with several similar systems already in operation, e.g. along the canalized stretches of the Rhine and the Rhone.

Diversion of the flow from the natural river bed into the artificial canal also raises a second set of concerns about adverse effects on the ecosystems of the natural river bed as its flow is reduced. The hydropower requirements for the minimum allowable discharge in the natural river bed vary from 50 to 500 m^3 s, whereas the minimum natural discharge is about 700 m^3 s^{-1} and the multiannual average value is 2000–2200 m^3 s^{-1} (Hock and Kovacs, 1987). As is the case in the Zambezi basin, the understanding of how reduced flows will effect ecosystems is quite limited. It was therefore decided that the final values to use for flow diversions would be chosen partially contingent on operational experiments to evaluate the impacts of different diversion levels involving minimum flows between 50 and 200 m^3 s^{-1}, with some river training being implemented in any event to maintain a unified bed even in the case of such small discharges. However, even the value of 200 m^3/s is smaller than the minimum natural discharge, and the consequences of such a difference are extensively questioned.

A third set of concerns relates to the quality of water supplies along the river. The flow diverted into the artificial canal will be stored in Hrusov reservoir, and in order to produce the planned amount of electricity in Gabcikovo will be released for between only five to seven hours a day. Although the Nagymaros dam will partially compensate for the flow fluctuation, in several key areas between the two dams the water level may vary by 1.5 m every day (Csepel, 1984). This would lead to some reverse flow in the tributaries of the Raba, Rabca and Mosoni-Duna and will interfere with the dispersal of Györ's sewerage. Such a result would threaten the water supplies of about 200 villages.

A second water quality problem is the maintenance of the self-purification capacity of the river. The velocity will considerably decrease upstream of the barrages, a fact that modifies both the oxygen balance and the structure of the aquatic ecosystem. The most important source of water supply in the region and for Budapest is bank-filtered water from the Danube. Wells tapping the alluvial gravel filling the flood plain provide the water, and the wells are directly recharged from the river. The gravel layers in the river bed act as natural filters, and the well water is therefore suitable for direct consumption without any pretreatment. Canalization may endanger the quantity and quality of bank-filtered water along the backwater stretches by the deposition of fine silt and suspended pollutants over the gravel layer, which would increase resistance to percolation and may create anaerobic conditions in the groundwater resulting in an increase of iron and manganate content. Finally, lowering the water level downstream of the barrages may also decrease the yield of wells, if considerable dredging is implemented to increase the head utilized at the power station.

5.4. IIASA's Role

What might be a productive role for IIASA as Czechoslovakia and Hungary work together to address environmental concerns while assuring that GNV meets its objectives? In Section 3 we spoke of the constructive role of third-party analysis in joint management negotiating situations. It can supplement the analytic resources of the principals; it can serve as a relatively open and neutral source of analysis; and the third-party is freer to explore new possibilities than are the parties for whom any willingness to explore a new alternative may be misread as an endorsement of that alternative. We also cited different ways third-party analysis has helped particular illustrative negotiations in the past.

As is evident from the sections immediately below, it would be premature at this stage to try to model IIASA's work on GNV after one or the other of the examples given in Section 3. Nonetheless, even for the current activities of the Project there are several lessons we can take away from the examination of successful third-party participation in joint river management and development in the past (McDonald, 1988). First, if the LIR Project is to be a source of efficient, complementary analytic horsepower similar to that provided by successful third parties in similar situations, we will have to be familiar with, and able to draw on, a range of analyses relevant to GNV. Moreover, we will have to be able to bring them to bear efficiently on the concerns of the principals, and we will have to communicate insights effectively. We will also have to assure flexibility to explore the implications of alternative assumptions, data, and models. These objectives reinforce the current research's focus on graphic, menu-driven software that can flexibly adjust to a wide variety of proposals, and can incorporate a range of data sets and alternative models of river basin processes.

Second, if the Project is to be in a position to take advantage of its third-party role to be constructively creative and exploratory, we must stretch our collection of data and models, plus our definition of software flexibility, to be even broader than we first imagined necessary. An example which is not immediately analogous to GNV nonetheless illustrates the point of preparing for unexpected resolutions. Between 1967 and 1980 the city of Seattle, Washington in the U.S. and the Canadian province of British Columbia were involved in frustrating negotiations over raising the Ross Dam on the Skagit River. Seattle wanted to raise the dam to increase its supply of electricity; British Columbia objected due to the flooding in British Columbia that would result. Significant progress was only made when the discussions moved beyond the zero-sum characterization whereby one side's gain was the other's loss -- i.e., either electricity was supplied and the Skagit valley was flooded, or the valley was preserved and Seattle did without the electricity. By the early 1980s the discussions began to focus not on the dam, but on Seattle's true interest -- electricity. Negotiations shifted to a discussion of an unspecified alternative source of electricity -- a "paper dam" as it was put by one of the negotiators (Alper and Monahan, 1986) -- equivalent to a raised Ross dam. This led to the Skagit River Valley Treaty in 1984 whereby it was agreed that Ross Dam would not be raised and that British Columbia would sell Seattle electricity equivalent in amount and cost to what would have come from raising the dam. The lesson for IIASA is to prepare for looking beyond the framework of issues that is accepted as limiting at any given stage in the discussions.

5.5. Summary of the Project's Danube Activities To Date

As the LIR Project's focus moved to the GNV Project in the wake of the April 1987 IIASA/UNDP/WHO meeting described earlier, interactions with Hungary moved at the quickest pace. A principal reason was that Prof. György Kovács, Leader of the LIR Project until his unfortunate and untimely death in April 1988, was a former Director-General of VITUKI in Budapest, and a number of ties had been established between the Project and various Hungarian researchers and institutes. In early 1988 the Hungarian representative to the Joint Hungarian-Czechoslovak Transboundary Water Commission, who is also Head of the Hungarian National Water Authority, visited IIASA with his top technical advisor. Unfortunately his Czechoslovak counterpart, the Minister of the Slovak Ministry of Forestry and Water Management, could not accept a similar invitation due to internal reorganizations at the time.

The Hungarian visit led to a proposal for joint research drafted by the Hungarian Research Centre for Water Resources Development (VITUKI) in collaboration with other respective Hungarian research institutes. All results of the study would be transferred to IIASA and installed on IIASA computers to make them available to other parties interested in GNV. More than 90% of the funding (equal to over US $200 000) would be provided by the Hungarian government.

Before going ahead with the VITUKI proposal IIASA solicited reactions from the Czechoslovaks and the Hungarian National Member Organization (NMO), and currently IIASA representatives are carrying on discussions with all parties in Prague and Budapest to define specific IIASA work that is viewed by all as mutually constructive. The task is to focus on issues (for example, groundwater quality management) that all agree will be continuing challenges for the joint operation of GNV, and to focus on them in a way that indeed contributes to a mutually satisfactory resolution. Within IIASA the *Water Resources Project* is continuing to prepare itself by assembling a broad range of data and models with possible relevance to the Danube and GNV, by completing the development of IRIS, and by preparing demonstrations of its capability. Further IIASA involvement in GNV study depends on the agreements with interested countries and appropriate funding.

The third principal in the GNV Project is Austria. Austria has a central interest in the hydroelectric production from GNV, though it is less likely than Czechoslovakia and Hungary to be directly affected by GNV's environmental impacts. Nonetheless, the lesson from history for the LIR Project as a third-party analyst is to keep a very open mind about what analyses the principals might ultimately find useful, and where they might look for resolutions to differences. Therefore, the Project has maintained contact with the Austrian Ministry of Agriculture and Forestry, with the Zentralanstalt für Meteorologie und Geodynamik, and with the University of Agriculture in Vienna. Through these interactions the Project has obtained several specific data sets and models as detailed in the next section. In addition, the University of Agriculture group is preparing reports summarizing Austrian research to date on the following topics:

(i) legal and institutional aspects associated with water management of the Danube

(ii) navigation

(iii) hydropower generation

(iv) flood control

(v) irrigation

(vi) water supply

(vii) groundwater pollution

(viii) recreation and tourism

To conclude this section, the following list briefly summarizes the Project's publications and assembling of data and models related to the Danube and to GNV.

1. Hock and Kovacs (1987) provide an extensive description of hydrological conditions of the river system and the water management problems occurring within the catchment.
2. Linnerooth (1988) supplements the work by Hock and Kovacs by analyzing the history of negotiations involved in managing the Danube. In the last section of the paper she discusses the role of the analyst in supporting negotiations on the shared use of water resources by furthering mutual learning and joint problem solving.
3. VITUKI developed and consequently transferred to IIASA a model simulating the propagation of non-conservative pollutants released accidentally into the river (VITUKI, 1987a). This model was developed independently, but recently has been implemented in the framework of the software package IRIS.
4. The Institute of Meteorology and Water Management (Warsaw) developed and transferred to IIASA a model that describes propagation of a temperature wave along the river (IMWM, 1987). Temperature waves result from the discharge of heated water from one or more electric power plants (conventional or nuclear). The model predicts the temperature at various locations, given different capacities and different cooling systems of the power plants. Implementation of this model in the framework of the interactive decision support system is underway.
5. From the Austrian Federal Ministry of Agriculture and Forestry and collaborating research institutes the Project has obtained a model describing heat exchange in the Austrian reach of the Danube. The model is accompanied by appropriate data and has been used to study and select locations of thermal power plants in Austria.
6. VITUKI developed and transferred to IIASA a data base containing observations (measurements) of approximately 40 quality indices at 10 cross sections of the Danube between Bratislava and Mohacs in 1970–86 (VITUKI, 1987b). The sampling frequency varied from one to two weeks. This data base is supported by a PC-based, interactive and user-friendly program that allows the editing and display of data.
7. The Bayerisches Landesamt für Wasserwirtschaft in Munich has given us data files containing monthly discharge series for 48 gauge stations (24 on the Danube and 24 on its main tributaries) covering the period from 1931 until 1970 (RZD, 1986). These files also contain data characterizing water balances in the Danube basin, extreme flows, and selected probabilistic characteristics of flows.
8. Supplementary flow data for the Danube and its tributaries were also obtained on tape from the Austrian Hydrographisches Zentralbuero, Bundesministerium für Land- und Forstwirtschaft, Vienna.
9. A detailed data base was prepared by VITUKI (VITUKI, 1987c) containing daily flow discharges for 60 gauge stations on the Transdanubian (western part of Hungary) rivers. These data are for the years 1965–84.
10. Climatic conditions of the river basin were investigated and a model was developed to estimate changes in runoff conditions due to climate changes (see Kovács 1987a and 1987b).

VITUKI is also preparing a paper on legal and institutional aspects of Danube water management, similar to that undertaken by our Austrian collaborators. Finally, in collaboration with VITUKI and WHO/Europe, IIASA organised in June 1988 a workshop on "Effects of Barrages on the Quality of the Danube," which involved approximately 30 participants from Austria, Hungary, the Federal Republic of Germany and Yugoslavia, and assembled additional information on water quality issues.

6. INTERACTIVE RIVER SYSTEM SIMULATION

As previously mentioned in Section 3, one of the main goals of this project is to evaluate the effectiveness of using decision support systems in aiding those responsible for managing or negotiating agreements over the conflicting use of rivers shared by more than one country. When the project began it seemed to us that any decision support system developed to aid those involved in any negotiations regarding a particular international river basin would have certain characteristics. These features would be common to all decision support systems designed to provide a neutral unbiased framework for the study of river basin development and management issues. These characteristics include:

a) the ability to simulate single or multiple sets of flows, qualities and hydropower generation scenarios throughout any selected portion of a single or multiple river system;

b) the ability to study transient as well as steady-state impacts under any changing future basin development scenario;

c) the ability of users to interact with the program and its data before, during and after any simulation, and the ability of users to display the input and output data as desired and in ways most meaningful to them;

d) the ability to be acceptable to all parties in conflict by being free of any assumptions regarding the configuration of the system being simulated, the flow and quality constituent inputs, the future development of the basin and hence the future demands or targets for water quantity, quality and energy production, and the prediction of concentrations of various quality constituents;

e) the ability to examine a wide variety of assumptions regarding numerous aspects of the river system, without changing any of the computer program itself (i.e. to incorporate all assumptions in the input data);

f) the ability of users to alter the design and operation of the system being simulated at any time during the simulation process, and to compare these different simulations;

g) the ability to communicate effectively and efficiently to all interested users of the system;

h) the ability to become a part of or to include other data or models of other aspects of a particular river system; and finally

i) the ability to be implemented on microcomputers that one would expect to be available in developing as well as developed regions of the world.

Recognizing that it would take time to establish contacts with potential users of decision support systems in any particular river basin, including the Danube and the Zambezi basins, we began the development of a decision support system that incorporated the above characteristics and that was able to be applied to almost any river basin, or multiple river basin configuration one could "draw into it." We were hoping we could develop much of the framework that could become, with some modifications of course, a decision support system for any particular river system. We think we have accomplished this. The system uses interactive computer graphics for data input, control of model operation, and output display. The program is menu-driven, with minimal input required from a keyboard.

Any simulation program to be used interactively on microcomputers cannot be so complex as to require more than a few seconds for each time step of the simulation, otherwise the efficiency of interaction between the model or program and the user decreases substantially. Fast response to user commands enhances the process of exploration and discovery – or analysis and synthesis – that can lead to creative solutions to problems, or at least to greater understanding and insight. Creative solutions and insight come from human minds, not computers, but computers, we believe, can aid humans in this process – interaction when the computer is fast enough. Hence we have had to compromise between complexity of code structure for reduced running times, and simplicity and clarity of structure for programmer's modifications and debugging. This has also led us to decide that we would not include various flow-routing options in our program. We assume mass balances throughout the system being simulated in each time step. Thus only average conditions are known in each time step. The duration of each time step is defined in the input data.

An important, and perhaps unique, feature of this interactive river system simulator, IRIS, is its ability to simulate the operation of a river system in a dynamic environment. Most, if not all, past simulation models of water resource systems permit only static snapshot simulations. A particular state of basin or regional development is assumed for some year in the future. Then a sequence of hydrologic flows and perhaps water quality constituent loadings are simulated for that particular condition to obtain some statistical measures of system performance for that particular year.

In our decision support system, we are able to simulate multiple flow and storage conditions (together with associated water quality and hydropower production) in each time step. This gives the user some measure of the reliability or risk at each time step. This approach also provides the user with the ability to alter the operation and/or design of the system being simulated at any time during the simulation (say in the year 2003) rather than having to simulate a sequence of years on into the future a number of times, one for each possible flow sequence.

The output data are voluminous. To permit their understanding, only the "highest, median, and lowest" values of each simulated variable (such as flows, storage volumes, constituent concentrations, hydropower and energy production at each of numerous sites in the river system) are saved for graphical display. During the simulation, the river system is color-coded, indicating to the viewer the ranges of the simulated variables relative to user-defined threshold values for those variables. This changing color display can be viewed over a videodigitized map of the area if a special graphics board is added to the microcomputer, or in opaque colors without a map background if the more common (and cheaper) Enhanced Graphics Adaptor (EGA) board is in the computer.

At the time of this writing, the basic decision support system is nearly complete. By the time this is being read, the model will be complete, at least to the extent that it can serve as a framework for all involved in any case study. We expect to modify or add additional features, as needed or as desired, to address specific river system issues.

Documentation of the model for users as well as for programmers will be completed by the end of 1989. By that time, the model will have been introduced to individuals working on the Zambezi and Danube basins, and to others not involved in this project, but who are in a position to use the decision support system for other river basins (e.g. in Italy, Portugal, Poland and the US).

The United Nations has expressed an interest in having our program to serve as an educational tool, and the US Corps of Engineers is giving us a pre-release version of their river system simulator for comparison studies. Undoubtedly the decision support system will continue to be improved for the duration of the project, as we obtain suggestions from various users.

We have taken a few pictures to illustrate some of the display capabilities of our decision support system. The computer, a PC-AT compatible model, together with a color and a monochrome display monitor, and a keyboard are shown in Figure 7. The telephone, barely shown behind the color monitor, can provide a link, through a modem, to other computers having other data bases or model results. The monochrome (single-color) monitor is not required, but is useful in many situations. In fact, the colour monitor is not required if various shades of a single color (such as green or brown) can be displayed on the monochrome monitor, but color displays are much easier to understand.

The display shown on the color monitor in Figure 7 is shown in more detail in Figure 8. This is a display of a portion of the Danube River as it travels from Germany through Austria, Czechoslovakia and Hungary into Yugoslavia and Romania. Alternatively, Figure 9 shows the Zambezi River together with a list of menu items that the viewer could see on the color monitor. During a simulation, the river being displayed would be color-coded, giving the viewer some idea of what is happening in various river reaches or at various sites along the river. At any time during or after simulation, the user of this river system simulator can display time series graphs of any particular simulated variable at any given site to study in more detail what is going on and what the relative risks are of some event that is not desired.

These time series plots could appear as in Figure 10. There are three functions plotted in blue. The highest is the highest value obtained for that value for all the flow replicates (series of streamflows) being simulated. The middle is the median, and the lower is the lowest value obtained. The two red lines are the two threshold values as defined by the user. On the lower of the two graphs, these two threshold values are set at 0, so they lie along the horizontal axis. The two parts of Figure 11 show the schematic (or network) representation of a simple (test) river system and/or the more realistic "real configuration" that users can draw into the computer as well. The real configuration can be made to look similar to the actual system. During simulation, both the network and the real configuration change colors, depending on the values of various variables.

Using appropriate function keys on the keyboard, the user can elect to view either the schematic by itself, the real configuration by itself, or both simultaneously.

This has been a brief overview of the IRIS program. More detail will be contained in the user's and programmer's manuals. In addition, there are on-line help files associated with each menu on each menu page. These files can assist beginning users of the program.

7. ADDITIONAL INFORMATION RELEVANT TO THE PROJECT

In this section additional information is provided which has not been sufficiently covered in the previous sections of the report.

Public presentations of project activities

- International UNEP/UNESCO/GDR Postgraduate Course on Ecological Approaches to Resources Development, Land Management, and Impact Assessment in Developing Countries – lecture describing LIR project activities and research methodology presented to the participants by project leader Dr. K.A. Salewicz;
- Presentation of project activities and research methodology to Dutch Evaluation Team visiting IIASA – given by Dr. K.A. Salewicz.
- New Advances in Decision Support Systems – IIASA Seminar Days– lecture presented by Dr. K.A. Salewicz
- Technical Tour in the Danube Basin of the staff and students from the Catania University – lecture on Danube-related studies and research presented to participants by Dr. K.A. Salewicz
- VI-th World Congress at International Water Resources Association in Ottawa, Canada, presentation of the paper "An offer from the analysts: decision support system for managing large international rivers" during special session by Dr. K.A. Salewicz
- IIASA/WHO/VITUKI Workshop on Effects of Barrages on the Quality of the Danube – project activities presented by Dr. K.A. Salewicz
- National meeting of the Operations Research Society of America and the Institute of Management Sciences, Denver, Colorado, October 1988 – presentation by Prof. D.P. Loucks.

Project Staff

Dr. Kazimierz A. Salewicz (Poland), project staff member since June 1987, Project Leader since November 1987. Educational background in control theory and large scale control systems. Professional experience includes mathematical modeling in hydrology, development of models and methods for decision making purposes, development of DSSs for water management purposes, computer graphics.

Professor György Kovács (Hungary), Project Leader until October 1987, then Senior Research Scholar until March 1988, distinguished hydrologist, member of the Hungarian Academy of Sciences.

Dr. Gilles Pinay (France), Research Scholar, hydrobiologist, associated with the project until June 1988.

Dr. Claudio Gandolfi from the Politecnico di Milano, Italy with a background in hydrological and hydraulic modeling, operations research and computer techniques. His professional experience includes development of computer models for aiding decision processes in water management and hydrological forecasting.

Professor Daniel P. Loucks (USA): Project Co-Principal Investigator from Cornell University, Ithaca, New York. Professor Loucks is a specialist in the development and implementation of systems analysis methods for water management and planning and in the application of interactive modeling with computer graphics to water and environmental management problems.

Y. Taher-Hutschenreiter is Project Secretary.

Project Funding

The project is funded, in part, by:

- The Ford Foundation, USA
- The United Nations Environmental Programme (UNEP), Nairobi, Kenya

Advisory Panel

Through December 1988, the Project Advisory Panel was chaired by Academician Zdzislaw Kaczmarek (Poland) and consists of:

- Professor Milos Holy, Czechoslovakia
- Professor Daniel P. Loucks, USA
- Dr. Hans P. Nachtnebel, Austria
- Dr. Sergei Orlovski, Soviet Union
- Dr. Andras Szollosi-Nagy, Hungary
- Professor Gert Schultz, FRG

List of Institutions Collaborating or Associated with the Project

Governmental and Non-Governmental Organisations

Southern African Development Coordination Conference Soil and Water Conservation and Land Utilization Unit

National Institutes

Hungary

Research Centre for Water Resources Development

USA

American Academy of Arts and Sciences

Cornell University

List of Institutions Providing Data, Models and Other Assistance

Governmental and Non-Governmental Organisations

World Health Organisation

Ford Foundation

Internationale Arbeitsgemeinschaft für Donauforschung

National Institutes

Austria

Hydrographical Central Office of the Federal Ministry of Agriculture and Forestry

Section IV of the Federal Ministry of Agriculture and Forestry

Zentralanstalt fuer Meteorologie und Geodynamik

Institut für Wasserwirtschaft, Universität für Bodenkultur in Vienna

Czechoslovakia

Water Resources Research Institute, Bratislava

Hungary

Central Meteorological Institute

Institute of Water Management

Poland

Polish Academy of Sciences, Institute of Geophysics

Warsaw Technical University, Institute of Environmental Engineering and Institute of Automated Control

Portugal

National Laboratory of Civil Engineering

8. ACKNOWLEDGEMENTS

We would like to express our gratitude to all institutions and individuals who have contributed in many ways to the Project. First we would like to thank the Ford Foundation for the support which was instrumental in starting this project, and we are priviledged to have their continuing support. Support from UNEP and CNRS of France is also highly appreciated and important for the success of the project.

There are many individuals who have supported the project and contributed in different ways, and we will not attempt to name them all. We would like, however, to express special thanks to Professor Robert E. Munn, former Leader of the Environment Program at IIASA, to the late Dr. Laszlo David of UNEP, who built the link between the LIR project and UNEP, and acknowledge our special debt to the late György Kovács, the first leader of the LIR Project. All contributions made by our supporters, even if not explicitly mentioned here, are very much appreciated, as are the help and contributions obtained from different collaborating institutions in various countries and continents. We would also like to express our deep gratitude to all former and current members of the Project research team.

Thank you all.

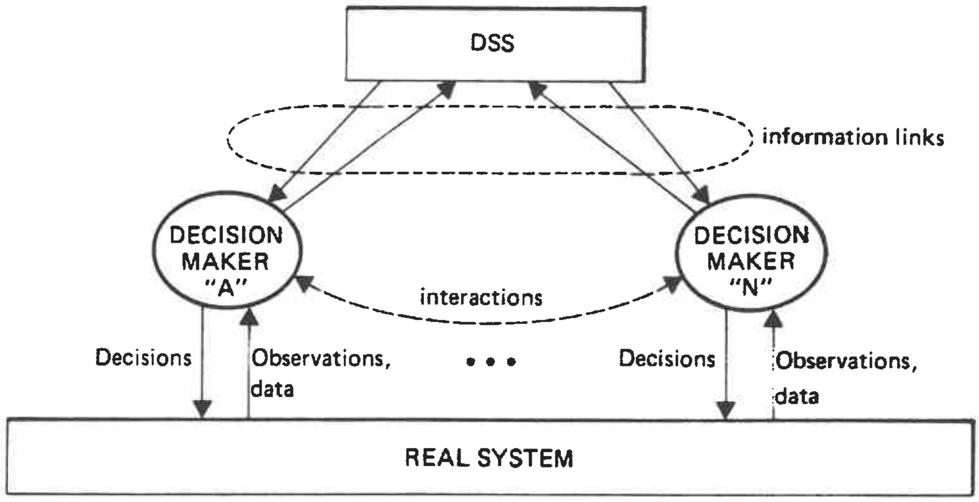


Figure 1a. Decision Support System used jointly by a number of decision makers.

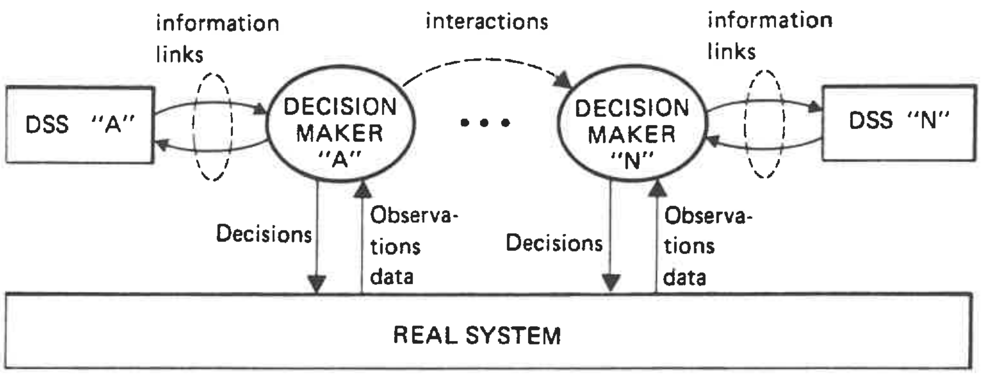


Figure 1b. Separate use of DSSs by decision makers, each having its own information and models.

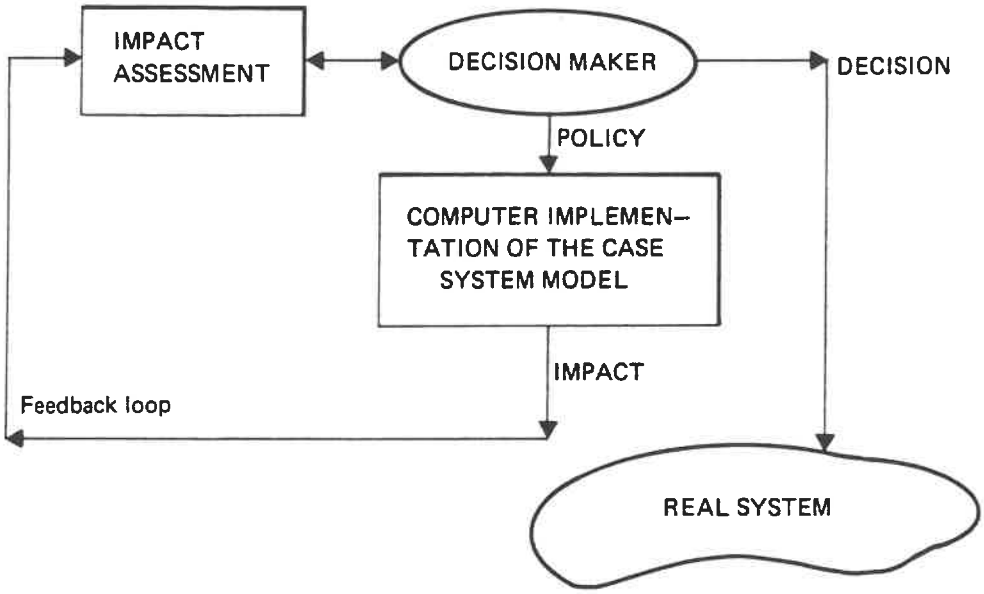


Figure 2. Scheme of the mechanism for evaluating impacts predicted by the model for various management decisions and policy options.

THE NEGOTIATOR'S DILEMMA

Party A's Choice \ Party B's Choice	INTEGRATIVE	DISTRIBUTIVE
INTEGRATIVE	Good, Good	Terrible, Great
DISTRIBUTIVE	Great, Terrible	Mediocre, Mediocre

Figure 3. The Negotiator's Dilemma (Lax and Sebenius, 1986).

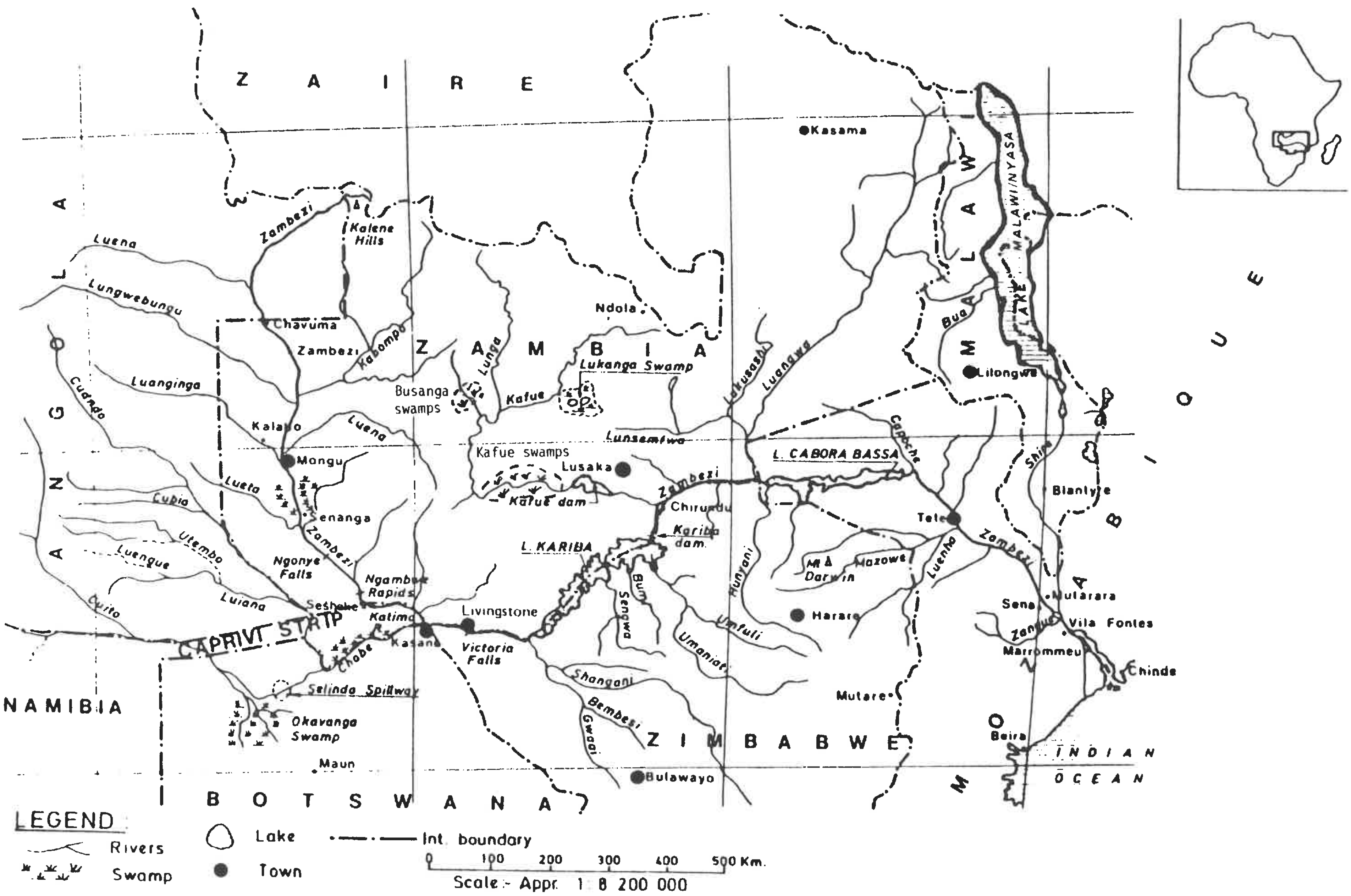


Figure 4. Layout of the Zambezi River Basin.

(817 000 km^2)

Figure 5. Map of the Danube River Basin.

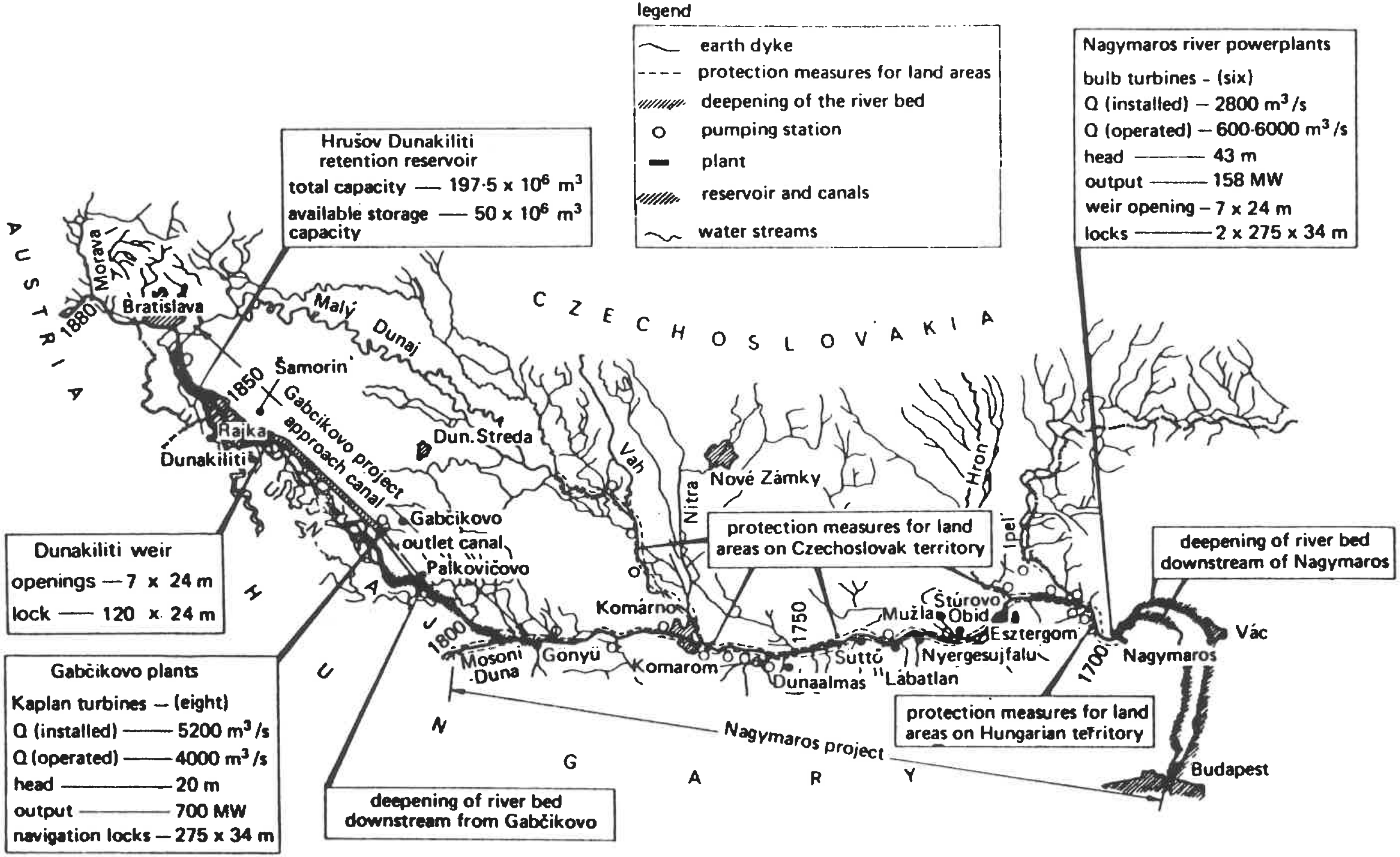


Figure 6. Layout of Gabcikovo-Nagymaros (GNV) hydropower scheme (Lokvenc and Szanto, 1986).

Figure 7. PC-AT microcomputer, display terminals and keyboard used for running the interactive river system simulation program.

Figure 8. Portion of the Danube River as displayed on the colour graphics monitor shown in Figure 7 above.

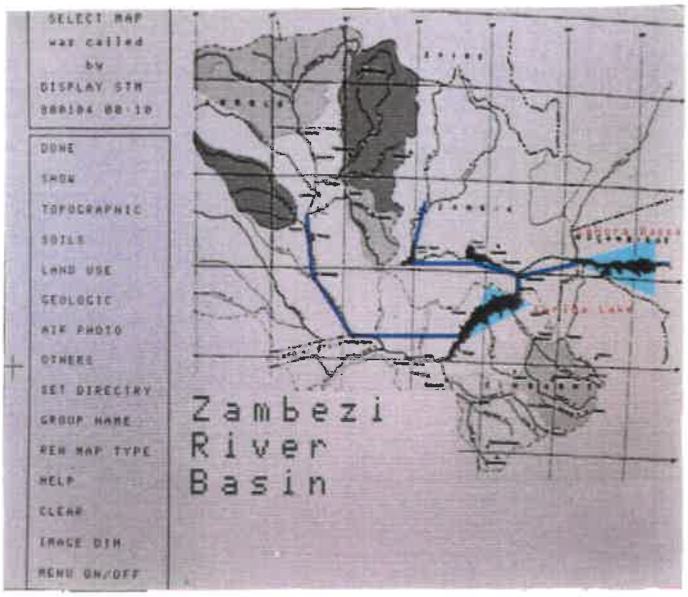


Figure 9. Computer graphics display of the Zambezi River along with menu items used to generate that display.

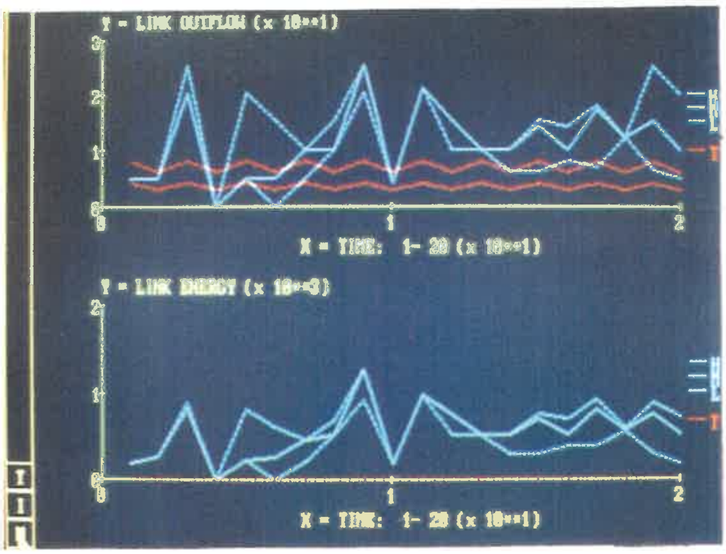
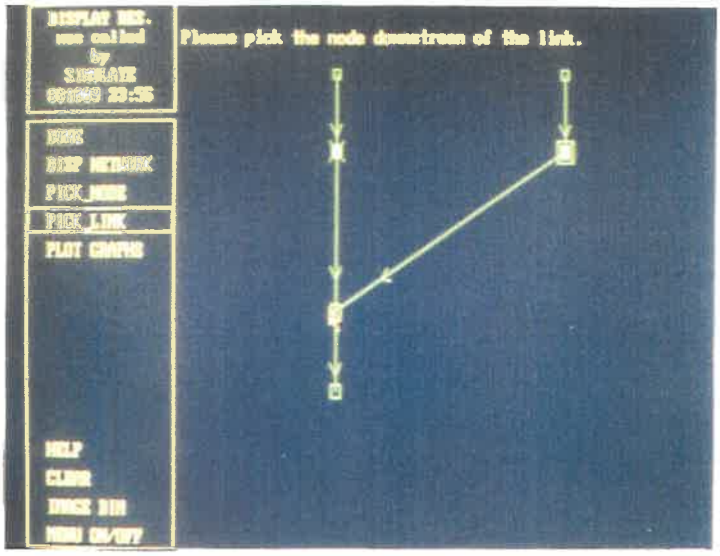


Figure 10. Time series plots of variable values together with their threshold values.



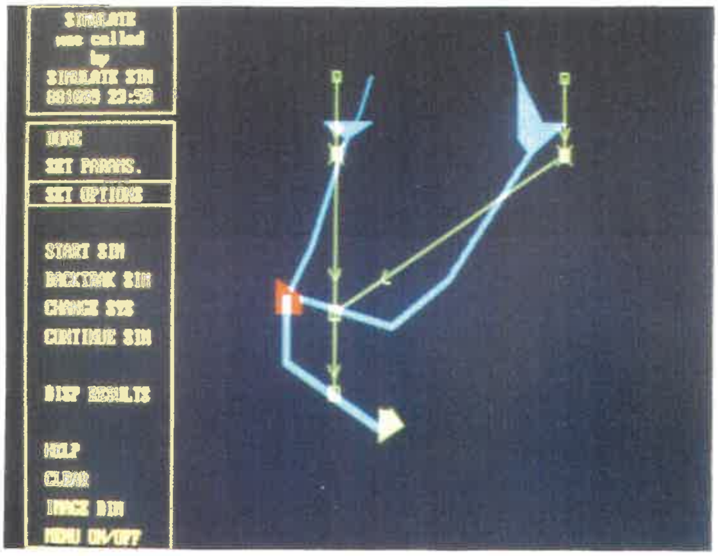
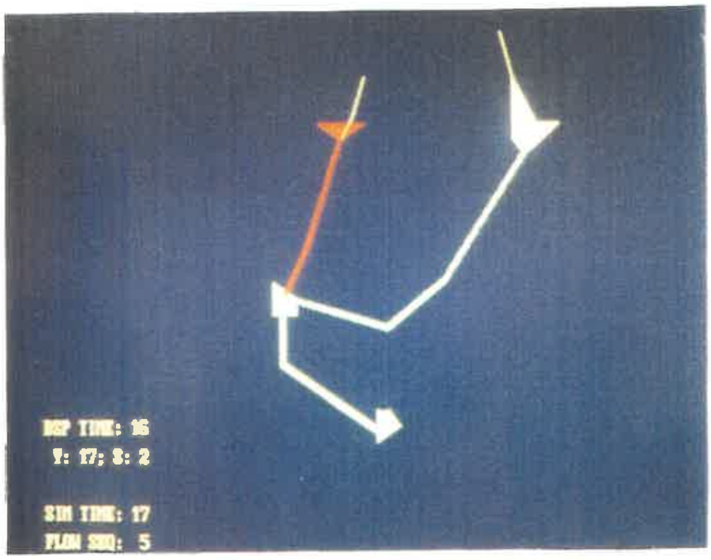


Figure 11a. Views of a test river system schematic and/or real configuration together with various menu items controlling their definition, or their simulation.



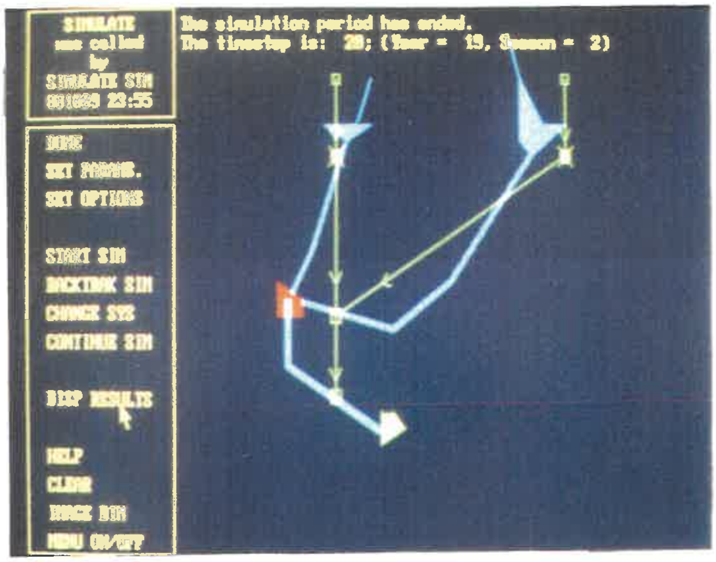


Figure 11b. During simulation the menu items are turned off and colors change depending on the relative values of various variables being simulated.

REFERENCES

Alper, D.K. and Monahan, R.L. (1986) Regional Transboundary Negotiations Leading to the Skagit River Valley Treaty: Analysis and Future Application. *Canadian Public Policy*, XII:1:163-174.

Bhagavan, M.R. (1985) The Energy Sector in SADCC Countries, *Ambio*, 14(4-5)214-219.

Csepel, A. (1984) Hungary Goes Cold on Project to Divert the Danube, *New Scientist*, 13 December 1984.

de Campos Silveira, S. (1988) *Management of the Zambezi Basin: Social, Political and Economic Considerations*. Manuscript.

The Economist, August 23, 1986, "Brazilian Energy: All Washed Up", p. 54.

The Economist, February 27, 1988, "The Nile: A Gasping Serpent," p. 74.

Elwell, H.A. (1980) *Design of Safe Rotational Systems*. Zimbabwe Department of Conservation and Extension.

Findeisen, W., Bailey, F.N., Brdys, M., Malinowski, K., Tatjewski, P. and Wozniak, A. (1980) *Control and Coordination in Hierarchical Systems*. IIASA International Series, No. 9, John Wiley, New York.

Fisher, R. and Ury, W.L. (1981) *Getting to Yes*. Penguin, New York.

Glenny, M. (1987) Political Waltz on the Danube Takes an Ugly Turn. *New Scientist*, April 30, 1982.

Hanlon, J. (1984) *SADCC: Progress, Projects & Prospects - The Trade and Investment Future of the Southern African Development Coordination Conference*. Special Report No. 182, The Economist Intelligence Unit, The Economist Publications, Ltd., London.

Hock, B. and Kovacs, G. (1987) *A Large International River: the Danube. Summary of Hydrological Conditions and Water Management Problems in the Danube Basin*. IIASA Working Paper WP-87-11.

Hungarian Academy of Sciences (1988), "STATEMENT OF POSITION On the Possibilities and Consequences of the Potential Abandonment of the Nagymaros Barrage," Budapest, October 1988.

IIASA (1986) Decision Support Systems for Managing Large International Rivers – An Outline. IIASA information material.

IIASA (1987) *Conceptual and Methodological Framework for the Implementation of the Project Decision Support Systems for Managing Large International Rivers*. Manuscript, IIASA.

IMWM (1987) *Model of Thermal Pollution Propagation*. Manuscript, IIASA.

Kovács, G. (1987a) Estimation of the Energy of Global Radiation in Hydrological Studies. *IDOJARAS*, Journal of Hungarian Meteorological Service.

Kovács, G. (1987b) Comparison of Models Interrelating Multiannual Precipitation and Actual Areal Evapotranspiration. *Hydrological Sciences Journal*.

Lax, D.A. and Sebenius, J.K. (1986) *The Manager as Negotiator*. The Free Press, New York.

Lewandowski, A., T. Kreglewski, T. Rogowski and Wierzbicki, A.P. (1987) Decision Support Systems of DIDAS Family, in A. Lewandowski and A.P. Wierzbicki (Eds.) *Theory, Software and Testing Examples for Decision Support Systems*. IIASA Working Paper WP-87-26.

Lewandowski, A. and Wierzbicki, A.P. (1988) *Theory, Software and Testing Examples in Decision Support Systems.* IIASA Working Paper WP-88-71.

Linnerooth, J. (1988) *Negotiated River Basin Management – Implementing the Danube Declaration.* IIASA Working Paper WP-88-04.

Lokvenc, V., M. Szanto (1986) Hungary/Czechoslovakia – The Binational Gabcikovo–Nagymaros Project. *International Water Power and Dam Construction,* Vol. 38, No. 11, November 1986.

Loucks, D.P. and Salewicz, K.A. (1986) *Interactive Modeling and Conflict Negotiation in Water Resources Planning.* Paper presented at the IIASA-George Washington University Workshop on "Management of International River Basin Conflicts", September 22–25, 1986, Laxenburg, Austria.

McDonald, A. (1988) *International River Basin Negotiations: Building a Database of Illustrative Successes.* IIASA Working Paper WP-88-96.

Mittra, S.S. (1986) *Decision Support Systems – Tools and Techniques.* A. Wiley Interscience Publications, New York.

Orlovski, S.A. and Loucks, D.P. (1985) Decision Support Systems for Managing Large Internatinal Rivers. Research proposal submitted to Ford Foundation.

Orlovski, S.A., Kaden, S. and Van Walsum, P.E.V. (1986) *Decision Support Systems for the Analysis of Regional Water Policies.* Final report of the collaborative IIASA Regional Water Policies Project. IIASA Working Paper WP-86-33.

Parker, B.J. and Al-Utaiba, G.A. (1986) Decision Support Systems: The Reality That Seems Hard to Accept. *OMEGA – International Journal of Management Science,* Vol. 14(2)135–43.

Pinay, G. (1988) *Hydrobiological Assessment of the Zambezi River System: A Review.* IIASA Working Paper WP-88-89.

RZD (1986) *Die Donau und ihr Einzugsgebiet. Eine hydrologische Monographie. Regionale Zusammenarbeit der Donauländer.* Edited by the Bayerische Landesamt für Wasserwirtschaft, Munich.

Salewicz, K.A. and Loucks, D.P. (1988) *Decision Support Systems for Managing Large International Rivers.* Interim Report on Project number 850–1034, submitted to the Ford Foundation. IIASA Manuscript.

Salewicz, K.A. and McDonald, A. (1988) *Trip to Africa in Connection With the LIR Zambezi River Study,* June 18–July 6, 1988. IIASA manuscript.

Sage, A.P. (1981) Behavioural and Organisational Considerations in the Design of Information Systems and Processes for Planning and Decision Support. *IEEE Tr. on Systems, Man and Cybernetics,* Vol. SMC-11, No. 9, September 1981.

Sebenius, J.K. (1984) *Negotiating the Law of the Sea.* Harvard University Press, Cambridge, Massachusetts.

Sol, H.G. (1985) Aggregating Data for Decision Support. *Decision Support Systems,* Vol. 1, 1985, pp. 111–121.

Sprague, R.H. (1980) A Framework for Research on Decision Support Systems, in G. Fick and R.H. Sprague (Eds.) *Decision Support Systems: Issues and Challenges.* Pergamon Press, Oxford.

Stocking, M. (1987) *A Methodology for Erosion Hazard Mapping of the SADCC Region.* SADCC Soil and Water Conservation and Land Utilization Programme, Maseru, Lesotho.

SWCLU (SADCC) (1987) *Monitoring Systems for Environmental Control.* Report from a Seminar held in Gaborone, Botswana, November 3-7, 1986, March 1987.

UN (1978) *Register of International Rivers – Water Supply and Management*, Vol. 2, No. 1, Pergamon Press, 1971.

UN (1987) Institutional Issues in the Management of International River Basins: Financial and Contractual Considerations. *Natural Resources/Water Series*, No. 17, New York.

UNEP (1987a) *Agreement on the Action Plan for the Environmentally Sound Management of the Common Zambezi River System - Final Act.* Harare, May 26-28, 1987.

UNEP (1987b) *Diagnostic Study on the Present State of Ecology and the Environmental Management of the Common Zambezi River System.* EMINWA Programme, prepared for the Conference of Plenipotentiaries on the Environmental Management of the Common Zambezi River System, Harare May 1987, UNEP, UNEP/IG.78 Background, paper 1, 10 March 1987.

VITUKI (1986) Report on the Conceptual and Methodological Framework for the Implementation of the IIASA Project on *Decision Support Systems for Managing Large International Rivers (LIR).* Manuscript, IIASA.

VITUKI (1987a) A Dynamic Dispersion Model for Routing Pollution Load Waves – Report and Operation Manual. Manuscript, IIASA.

VITUKI (1987b) Water Quality Data Base and Data Handling System for the Hungarian Danube Reach. Manuscript, IIASA.

VITUKI (1987c) Data Base for Gauging Stations of Transdanubian Water Courses in Hungary. Manuscript, IIASA.

Vlachos, E. (1986) *The Challenges of Transboundary River Basins.* IIASA-George Washington University Workshop on "Management of International River Basin Conflicts", September 22–25, 1986, Laxenburg, Austria.

Walters, C. (1986) *Adaptive Management of Renewable Resources.* MacMillan Publishing Company, New York.

Weeks, T.T. (1986) *A Checklist for Negotiators.* Unpublished draft, Harvard University John F. Kennedy School of Government, May 5, 1986.

WHO (1986) *Water Quality Protection of the River Danube.* ICP Proposal 2009i, Copenhagen.

ATTACHMENT 1

List of People Met by LIR Staff During Study Tour of Africa

UNEP, June 20–21 and July 5, 1988

Dr. Jaroslav Balek (Head, Water and Lithosphere Unit)
Dr. Gennady Golubev (Executive Deputy Deputy Director)
Dr. Mikiyasu Nakayama (Programme Officer, Water and Lithosphere Unit)
Dr. Iwona Rummel-Bulska (Head, Environmental Law and Machinery Unit)
Mr. Schmidt (Head, Clearing House)
Ms. Angela Abbronizio (Conference Affairs Officer)
Dr. Harvey Croze (Grid Coordinator)
Ms. Anne Burrill (Grid Analyst)
Mr. F. Duff (Finance Officer)

Mailing Address:

United Nations Environment Programme (UNEP)
PO Box 30552
Nairobi
Kenya

Tlx. 22068 unep ke
Tel. 520600
Fax 520711

Harare, Zimbabwe, June 22–25, 1988

Andries Klap (Programme Officer)
Johannes Schachinger (Programme Officer)

Mailing Address:

United Nations Development Programme (UNDP)
PO Box 4775
UDC Centre, Third Floor
First Street/Union Avenue
Harare
Zimbabwe

Tlx. 4668 zw
Tel. 79 26 81

Mr. Phannel Mugabe (Secretary for Natural Resources and Tourism)

Ministry of Natural Resources and Tourism
Private Bag 7753
Causeway
Zimbabwe

Tlx. 6082 zimtour harare
Tel. 794455

Street Address:

Karigamombe Centre
XIII-th Floor

53 Samore Mechel Avenue
Harare
Zimbabwe

Mr. T.P.Z. Mpofu (Director)
Ms. B. Sithole
Mr. B.B. Hungwe
Ms. S. Ncube
Mr. R. Mkwanda

Mailing Address:

Department of Natural Resources
PO Box 8070
Causeway
Zimbabwe

Tel. 705671

Street Address:

Makombe Bld., Block 1
Rhodes Avenue/Salisbury Street

Mr. D.S. Durham (Management Engineer)
Dr. Wannell (Chief Hydrological Engineer)

Mailing Address:

Ministry of Energy and Water
Resources and Development
Private BAg 7712
Causeway
Zimbabwe

Tel. 707861

Street Address:

Rhodes Avenue Complex
Block 4
Harare
Zimbabwe

Mr. Rowan Martin (Assistant Director,
Research)

Mailing Address:

Department of National Parks
and Wild Life Management
PO Box 8365
Causeway

Street Address:

North Avenue/Colquhoun Street
Harare
Zimbabwe

Dr. D.H.M. Cumming

Mailing Address

Multispecies Animal Production
Systems Project
PO Box 8437
Causeway
Zimbabwe

Tel. 728266

Mr. Enrique M. Portillo

Mailing Address:

SADCC Soil and Water Conservation
and Land Utilization Unit
PO Box 24
Maseru 100
Lesotho

Tlx. 4414 sadcc lo
Tel. 311312, 322158
Fax 310049

Harare, June 29–July 4, 1988

Dr. Liberty Mhlangwa (General Manager)

Mailing Address:

Agricultural and Rural
Development Authority
PO Box 8439
Causeway
Zimbabwe

Tlx. 2272 arda zw

Street Address:

3 McChlery Avenue
South East Lea

Dr. Henry A. Elwell

Mailing Address:

Institute of Agricultural
Engineering
PO Box BW 330
Borrowdale
Harare
Zimbabwe

A. Mpala (Executive Director)
John Santa Clara (Chief Civil
Engineer)
Glenn White

Mailing Address:

Zambezi River Authority
PO Box 630
Harare
Zimbabwe

Tlx. 4230 capco zw
Tel. 704031

Street Address:

Club Chambers
Baker Avenue/Third Street

Dr. Anduku (Director)
Mr. George Pangeti (Assistant Director of
Administration)
Dr. Colin Craig

Mailing Address:

Department of National Parks and
Wild Life Management
PO Box 8365

Causeway
Zimbabwe

Tel. 707624

Street Address:

North Avenue/Colquhoun Street

Mr. E. Dengu (Director)

Mailing Address:

Department of Agricultural
Technical and Extension Services
PO Box 8117
Causeway
Zimbabwe

Street Address:

Makombe Blvd., Block 2
Rhodes Avenue

Dr. Chris Magadza (Director)

Mailing Address:

Lake Kariba Research Station
University of Zimbabwe
PO Box MP 167
Mt. Pleasant
Harare

Tlx. 4874 zw
Cutty Sark Hotel, Kariba
Zimbabwe

ATTACHMENT 2

SADCC–IIASA Workshop on the Applications of Decision Support Systems to International River Basin Management

AGENDA

First day	0900-1000	Session 1: Opening by SADCC, IIASA, FORD Foundation, UNEP. Review of workshop objectives and programme
	1030-1200	Session 2: Introducing the participants Presentation of the Large International Rivers Project: its objectives, research activities and expected contribution to the implementation of the Zambezi River Action Plan
	1400-1530	Session 3: Country-by-country presentation of of Zambezi River Basin development and management issues. Discussion Note: Presentation and discussion may be continued during Session 4. If subject of Session 3 is exhausted then Session 4 will be:
	1600-1730	Use of models in river basin planning and management
	1900	Social event
Second day	0830-1000	Session 5: Basic concepts of decision support systems and decision problems. How decision problems can be analysed by using DSS
	1030-1200	Session 6: River basin management and associated problems of data needs and aspirations Discussion of papers presented
	1400-1530	Session 7: Review of interactive computer graphics capabilities and applications
	1600-1700	Session 8: Basic concepts of Interactive River Simulation Package IRIS. Tutorial for IRIS
Third day	0830-1000	Session 9: Water resources allocation and reservoir operation - lecture and introductory exercises on IRIS

	1030-1200	Session 10: Hydropower generation modeling using IRIS - lecture and introductory exercises
	1400-1530	Session 11: Use of spreadsheets for solving water management problems – lecture and exercises
	1600-1730	Session 12: Introduction to joint decision making and negotiation – separating option creation from option evaluation; taking advantage of similarities and differences among parties; separating issues, tradeoffs; incremental agreements, etc.
Fourth day		Field Trip: on-site study of selected issues of river basin management problems
Fifth day		All day – activities in teams: negotiation games hands-on training using IRIS – formulation of example decision problems and solving them
Sixth day		Till lunch time: continuation of previous day activities
	1400-1530	Session 13: Discussion of examples of problems and methods used to solve these problems
	1600-1730	Session 14: Discussion and evaluation of the workshop, future project activities and Zambezi related research. What should be prepared for the next workshop?
	1800-1900	Closing session