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NOTEC REGIONAL DEVELOPMENT

Proceedings of Task Force Meeting I on Notec Regional Development

M. Albegov
R. Kulikowski
Editors

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PREFACE

From the beginning of 1978, the regional research activities at the International Institute for Applied Systems Analysis began to concentrate on the elaboration of several case studies. These activities should provide insights into the ascertainment of the complexity of real problems of future regional development in reference to the workability of applied methods of systems analysis. One of the two case studies begun is the Upper Notec River Basin. A Task Force Meeting was held on May 10-11, 1978 which was an introduction to the study. The primary ideas behind this meeting were to describe all the sets of problems which exist, to formulate the main interdependencies in the regional economy, and then estimate what plan of action should be undertaken to solve the problem.

The materials of this meeting showed clearly that at least five main problems should be jointly analyzed: the development of regional irrigation systems; primarily, the growth of agriculture, then that of industry; the changes in future regional migration patterns; and the development of a system of rural and urban settlements. One optimal or a few sub-optimal solutions need to be prepared, taking into account not only the abovementioned, but also a series of other problems (rational concentration of production in agriculture, pollution, etc.).

This meeting made possible the better understanding (at least for IIASA scholars), of the Notec Region's growth problems and to start cooperative efforts with Polish scholars.

Murat Albegov

Abstract

The first Task Force Meeting on Noteć (Poland) regional development was held at IIASA, Schloss Laxenburg, Austria, May 10-11, 1978, with joint cooperation between the International Institute for Applied Systems Analysis and a group of prominent Polish scholars. The principal aim of this meeting was to clarify the main problems of this region to international scholars and to discuss the possibilities of their solution.

A broad spectrum of intraregional problems, starting from water supply touching regional agriculture and industrial development, migration processes, development of urban and rural settlement systems, was discussed.

The results of these discussions serve as a good introduction in problem understanding and promote the choice of the interdependent core problems to be solved.

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WELCOMING ADDRESS

R.E. Levien

It is my great pleasure to welcome you to IIASA, those who have come from Poland and from outside the Institute, to participate in the Notec Task Force Meeting. We are interested both in the specific example of Notec and in the more general problem of regional development as it appears in many countries. In order to give you a sense as to why the Institute has such an interest, I shall begin by briefly reviewing IIASA's history and major activities. I hope this will then set the stage for the more intense and specific deliberations about the Notec Valley.

As an Institute, IIASA is slightly more than five years old, although the proposal to establish it occurred about twelve years ago. It was at the end of 1966 when the then President of the United States, Lyndon Johnson, suggested the establishment of an institute to work on the common problems of the developed countries and thereby to serve as a bridge between East and West. He asked his national security adviser, former security adviser McGeorge Bundy, who was then President of the Ford Foundation, to travel to other countries and in particular to the Soviet Union to see whether this notion would meet with common approval. In the beginning of 1967, Bundy met with Jermen Gvishiani, the Deputy Chairman of the USSR State Committee on Science and Technology, to discuss the proposal. There was common enthusiasm for the idea and the United States and the Soviet Union became the leading initiators of multi-national negotiations which took place over the period 1967 to 1972. During this time an increasing number of nations were engaged in the deliberations, until by October 4, 1972, twelve National Member Organization (NMO) representatives met at the Royal Society in London and agreed to establish what we now know as the International Institute for Applied Systems Analysis. About nine months later the first scientist began work at the Institute. So although the Institute legally is slightly over five years of age, it will not be until next month that we celebrate the fifth anniversary of our operations here in Laxenburg. In May 1976, there was the first IIASA Conference at which we reviewed the Institute's accomplishments during its first three years of activity.

What has been the progress and the nature of work at the Institute? Let me begin by reviewing what we feel was the major heritage of our founders--the people who worked over that five-year period to establish the Institute. They gave us an Institute that is *nongovernmental*, unlike United Nations agencies that are established by inter-governmental agreement. IIASA is legally an Austrian association and our members are scientific organizations, one from each participating country. The representatives on our Council are scientists and not members of foreign ministries, so that the staff who come here from particular countries come as individuals and not formally as representatives of their national viewpoints. This makes it possible for the deliberations and discussions at IIASA to be informal and scientifically objective.

Secondly, our founders established the Institute to be dedicated to *applied systems analysis*. This phrase has a certain elegant ambiguity in that it does not have associated with it the kind of discipline and scientific community in many countries as for example physics or chemistry or economics has. Rather it is what I would prefer to call a craft--a technique for applying the knowledge of science to the problems faced by mankind. It is a craft in that much of the knowledge is passed on through experience and apprenticeship, not through the kind of disciplinary formats of journals, training programs, and textbooks that one finds in physics. So IIASA had the challenge to establish more formally on a global scale the discipline of applied systems analysis, to identify what is meant by that phrase, and to make it a useful activity.

The third decision of our charter and our founders was to locate the Institute in Austria. They accepted the offer of the Austrian Government to make this marvelous Schloss available to us. Since the founding of the Institute the Austrian Government has worked very quickly and at great expense to renovate the Schloss for our use and by the time it is finished they will have spent ten million dollars in doing so. They charge us one Austrian schilling a year rent, and we are five years behind in our payments.

The final decision of the charter and our founders that was important for IIASA was to establish a principle of equity and parity in the financing of the Institute. All members are divided into two categories - the category A members are the United States and the Soviet Union who provide the larger amount of support for the Institute. This year their contribution is some 1.7 million dollars each; the fifteen other members (scientific organizations from the fifteen other countries) paid this year some 260 thousand dollars each. Our contributions are based in some sense on equity of participation in that we expect each country, whether it is the Federal Republic of Germany, Japan, Finland, or the Netherlands, to participate equally and to pay equally. The total budget of the Institute in 1978 is on the order of seven million dollars from contributors by NMOs and one million dollars from other sources.

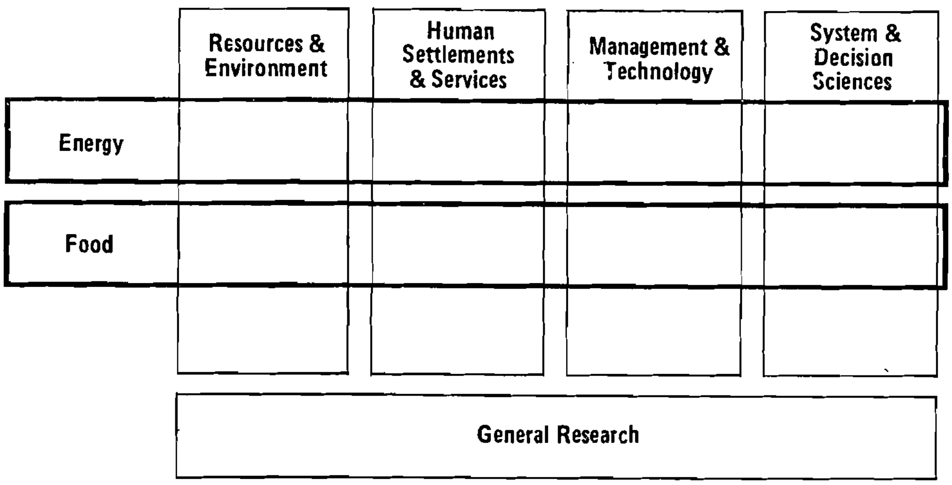
In addition to these charter provisions we have another heritage from our founders and that is a series of very high aspirations. These are threefold. The first goal we have established for ourselves is *to foster international collaboration and cooperation*--that is, to see that scientists from many nations can work together through the means of IIASA on problems of concern to all. In particular we aim to find opportunities--within the staff here, through international conferences and through collaborative ventures--to bring together scientists from the seventeen nations and particularly from nations East and West, cutting across differences in economic, social, and political backgrounds. The founders of IIASA were representatives of scientific organizations and obviously when they established a scientific institution they expected it to contribute to the advancement of science. We consider systems analysis a craft building on science but not strictly speaking a science itself so that a second goal of IIASA is *to advance the sciences contributing to its work and to advance the craft of systems analysis*.

Our third goal is *to apply our work to problems of international importance*. We distinguish two such categories of problems: the first kind we call *global*. These are problems that inherently cut across national boundaries and cannot be solved by the actions of single nations. IIASA has a role to play here because we are the only place where a scientific consideration by scientists from East and West can be given to such problems. Examples of such problems are protection of the global climate, exploitation of the oceans, or the more general problem of the global evolution--global development under the demands of a growing population. The second category of problems of international importance are *universal* problems. These lie within single nations but are shared by all nations. Obviously the problem that we are discussing at this meeting--regional development--is one that is universal in character. Almost every nation faces problems in this area: How to develop a new region that has new resources or that is lacking in economic development for other reasons? What are the major strategies or alternatives? IIASA has a role to play in exchanging experience and methodology among nations, all of whom have had to face such problems under different contexts and with different tools. By bringing together those contexts, tools, and approaches, we can also learn something of value.

Now let us return to the idea of systems analysis. What does that mean in practice? For us it means two things: first, a concern with problems of *real importance*, particularly those faced by decisionmakers. IIASA is not here to study the problems strictly in a scientific sense, but to address our results to those who make decisions concerning such problems. The second aspect that concerns us is that when doing a system study one must adopt a *comprehensive approach*. For example, when looking at a global energy problem one must study it not just as the engineer might study energy problems, or not just as the Ministry of Energy might study them, but in a way that incorporates within the boundaries of the problem the major aspects affecting the problem such as the resource constraints, impacts on health of alternative policies, how one manages future energy strategies, what techniques can be used for analysis.

Let me give you an example of how IIASA adopts a comprehensive approach when studying problems of international importance. I mentioned two categories of problems--global and universal. One major concern of a global character is global development. How will the world evolve as the population doubles over the next sixty or seventy years? How will we meet the needs for that population for energy, food, water, a clean environment, housing and so on? There have been studies that address this in a comprehensive way--the global models in the Club of Rome studies for example. However, IIASA decided that at this stage in the evolution of methodology it is more appropriate for the Institute to study single sectors within the global perspectives in depth, to do each of those sector studies in a systems way but not to draw them together yet. We have currently underway a major global study on energy futures and one on food futures; subsequently we may undertake studies of these other sectors. In the long term we hope to bring them all together in a comprehensive approach. Regional development with which this meeting is concerned is a universal problem that has been deeply studied on an individual sectoral basis. The energy development of regions, the agricultural development of regions, the water development of regions, and the environmental problems of regions have been studied separately. The Institute seeks to develop an integrated approach to regional development that would bring together these efforts and draw the boundary around the many sectors that contribute to regional development. It is this quest that we shall discuss at this meeting.

With this background let me explain the organization of the Institute's research. We have what we call a matrix organization that is two dimensional. The vertical columns are research areas that represent pools of skills needed for systems studies. We believe that to carry out a broad and comprehensive study, one must draw together skilled people with specific talents and then put them into an interdisciplinary team with a cross-cutting leadership. So we have four research areas: Resources and Environment, led by Oleg Vasiliev who is at this meeting, concerned with the natural endowments of the earch, with water resources, with environmental questions, climatological questions, etc. Secondly, there is the Human Settlements and Services Area, led by Andrei Rogers, that is concerned with human resources--the number of people on the globe, how they are distributed and the services they need. The third Area, Management and Technology, led by Rolf Tomlinson, has specialists in engineering, operational research, management and organization concerned with the man-made contributions to the global endowment, to organizations and technologies. And the System and Decision Sciences Area is concerned with the mathematical and computational tools for studying complex systems. There are also major research tasks that are done jointly with other areas. For example, the Resources and Environment Area is working on regional water development, on water quality, and on regional environmental management. These tasks provide the contacts with the scientific communities on a global scale that keep us up to date and help us to contribute to the advancement of knowledge in each field.



RESEARCH PLAN MATRIX

The second dimension of our matrix is represented by two cross-cutting rows which are our major programs of a global dimension. The first is our Energy Systems Program which is concerned with the future development of the global energy system from 15 to 50 years from now and in particular with strategies for the transition from an energy systems based on oil and gas to one based on relatively inexhaustible sources of energy, nuclear, solar and coal. And our second cross-cutting study--Food and Agriculture--is concerned with the development over the next 10 to 15 years of national agricultural food policies and their interaction through the international market place. What national policies, what international policies will help to satisfy mankind's need for food and a higher level of nutrition?

We have a residual category, as all good organizations must, that we call General Research. Here we hold the seeds of future programs as well as other cross-cutting activities that do not fit into the structure as shown on the matrix. An important seed lying within General Research is our work on regional development, led by Murat Albegov. The activity there is intended to develop our approach to regional development progams as well as to integrate ongoing work in the existing areas, focussed on a regional level through the application to case studies such as the Notec Case Study in Poland, the Silistra Case Study in Bulgaria and possible case studies in Sweden and Italy.

That is the overall structure of the Institute's research program. There are roughly seventy scientists whose salaries are paid for by NMO contributions, and the usual resources in computing and library. But these internal resources are really only the core of IIASA's activity. If we had to approach the wide range of problems we are concerned with using only these limited resources, we would have little hope of success. What is important for IIASA is its use of this core to mobilize and link activities in other countries and elsewhere outside of the Institute. In addition to those seventy scientist we have each year some ten guest scholars whose salaries are paid by their home institutions. Another fifteen or so scientists are working at IIASA supported by external funds such as grants from foundations, UN agencies, and from individual governments. But that is still only some ninety-five scientists. The real extension of IIASA's work occurs through collaborative research, through joint activities carried out with other Institutions. I hope that the Notec Valley Case Study will be another example of collaboration where the core group of activity at IIASA can serve as a fruitful means for linking activities of other institutions. This year some 150 institutions in 25 countries are actively collaborating with the Institute. For example, we are studying the coal option as a major energy option. IIASA's work done as part of our Energy Systems Program is part of a major effort underway at the British National Coal Board, at Ruhr Coal in the FRG, and elsewhere. It is this sort of joint work that makes it possible for IIASA to aspire to the high goals of its founders with some reasonable hope of success.

The next level of integration, of drawing on external resources, is work that is catalyzed because of IIASA's effort. These are activities undertaken in other research institutes, not in close collaboration with IIASA, but stimulated by our concern for a particular problem.

And finally there is the activity of *information exchange*, of which this meeting is one example, and of which there are some 30 meetings of various kinds at the Institute each year, many publications, and an *International Series on Applied Systems Analysis*. All are intended to facilitate the exchange of information between scientists working on similar problems in many countries.

This brief introduction to the Institute perhaps gives you a clearer sense of why we are interested in working together with the Polish scientific community and with the decisionmaking community on the Notec Case Study, and how that fits into our larger concern for regional development and for problems of international importance. We hope that collaborative efforts involving scientists at IIASA, from Poland, and those working on similar problems in other countries such as Bulgaria, Italy, and Sweden will make major advances beyond those that any of these groups working together or alone might achieve.

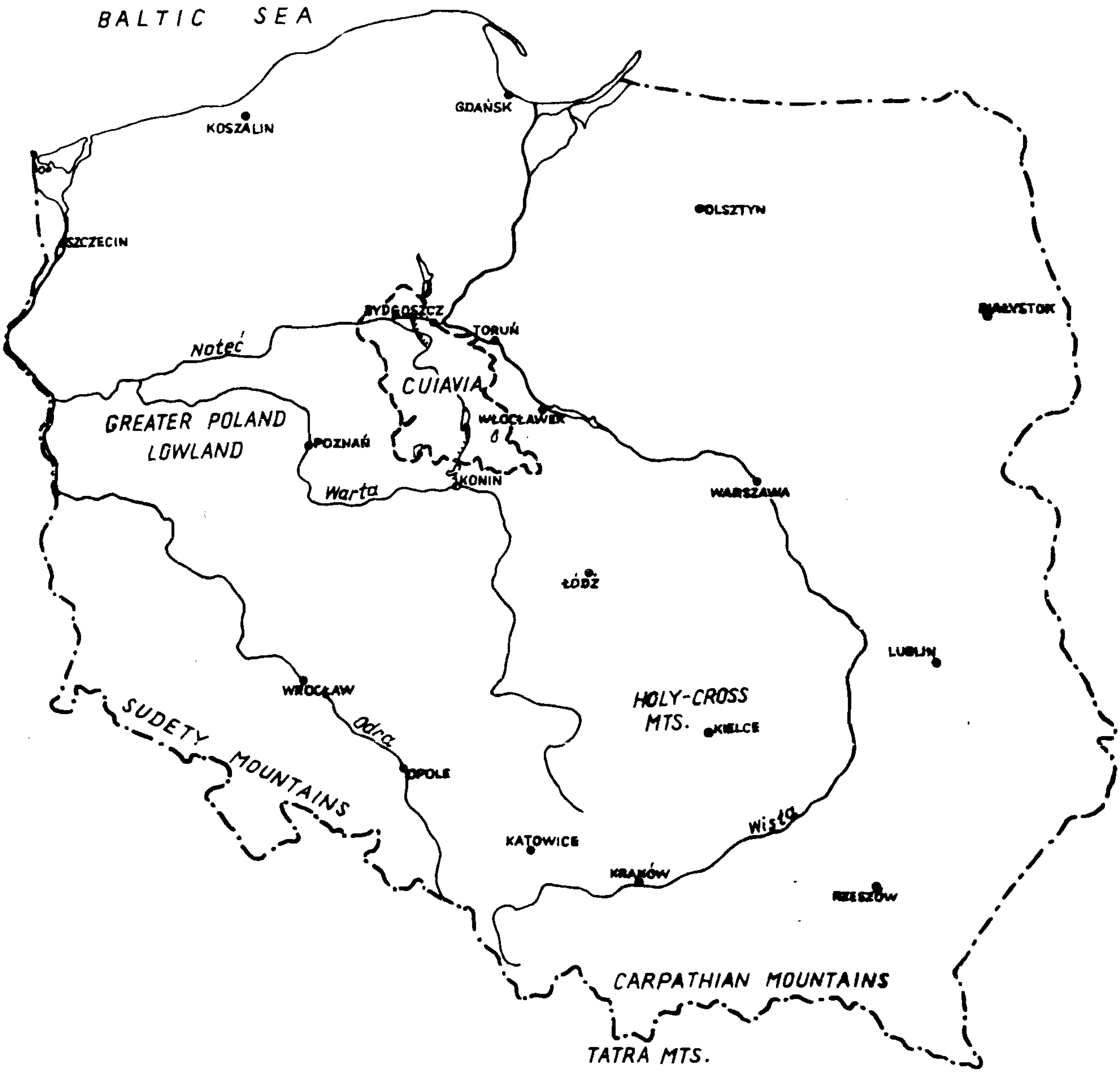
Again, welcome to IIASA. I wish you success in your deliberations and look forward to a long and stimulating partnership between IIASA and the Polish scientific and decisionmaking community.

SHORT DESCRIPTION OF THE NOTEC DEVELOPMENT PROJECT

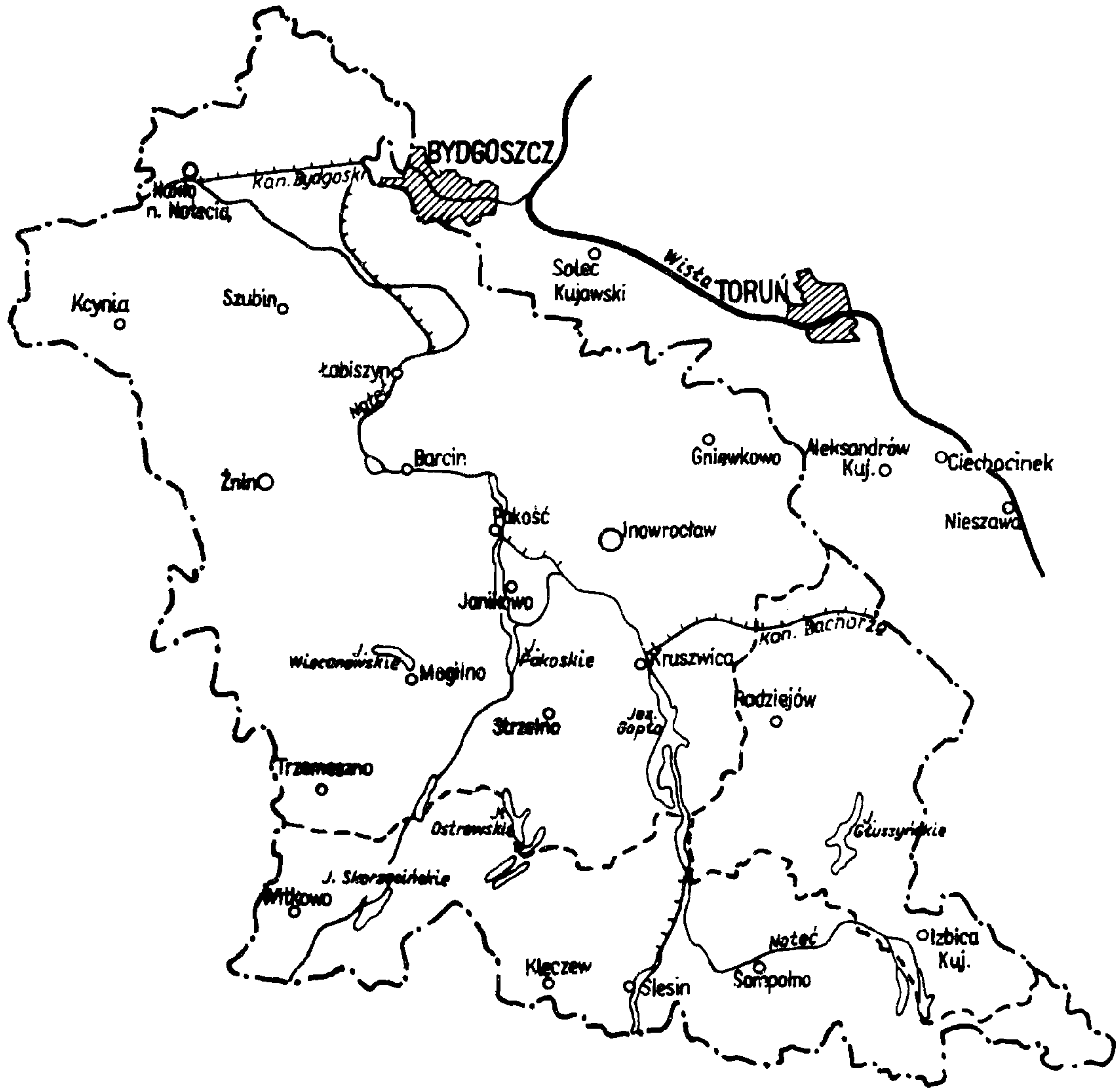
R. Kulikowski
IIASA

1. Characteristics of the Noteć Region

The Upper Noteć region is located in central-nothern Poland /see Map 1/, adjacent to Vistula river, although it belongs to Odra watershed. It overlaps with traditional historical regions of Kujawy /Cuiavia/ and Wielkopolska /Greater Poland/. The region is named after the basin of the upper part of the river Noteć. The upper part of the Noteć river consists of two creeks called West and East Noteć respectively. The West Noteć flows out of the Skorzęcin Lake, passes a number of lakes and joins the East Noteć creek. Then the river passes again a number of lakes, becoming transportable up to the Odra river. The total region's area is 6194 km^2 with a population of 476,900 people /see Map 2/. As such the region is comparable with an average non-urban voivodship /49 voivodships make the higher level in two-tier local administration system in Poland, with "gmina" units at the lower level/. Since 61,0% of the total population is rural, the region is mainly agricultural. Inowrocław has 50,000 inhabitants; two towns, around 15,000 and the rest of the towns less than 10,000 inhabitants; 67,2% of the total region area belongs to the Bydgoszcz Voivodship, 20,2% to Konin and 12,6% to Włocławek Voivodship; Bydgoszcz-Toruń agglomeration, above half a million inhabitants /see Map 2/ would have an obvious influence on the region; 24,8% of arable land is owned by large state farms and the rest by private farmers divided into comparatively small farms.



Map 1. Location of the Upper Noteć watershed region /its boundaries denoted by ---- / in Poland. The watershed muchly overlaps with the traditional Cuiavia region.



Map 2. The Upper Noteć watershed region

-·-·-·- the watershed region Boundary

- - - - - - the voivodship boundaries.

The region's specialization is grain production /51,8%/; potatoes and sugar beet constitute 22,1% of the land cultivated. The soil in the region is fertile and there exist all the conditions for intensification of agriculture production. However, the precipitation is rather low /i.e. 450-500 mm/year/ as compared with the rest of the country. The water shortages during the vegetation period limit agriculture production /especially in the production of sugar beets/.

The increasing demand for water by urban population, industry and water transport and resulting shortages of water supply for agriculture create misgivings that the future regional growth may significantly be slowed down. It is believed that the large regional water development projects should be launched soon in order to prevent the expected losses in regional economy and firstly in regional agriculture. The project should be based on the complex analysis of the impact of water demand and supply on the integrated reglional growth.

Most of the research conducted in that area so far is financed by the Government Program connected with the development and utilization of water resources.

2. Government Program and Research Organization

The governmental program on the development and utilization of water resources for 1975-1980 has been created in 1974 under the general coordination of the Institute of Meteorology and Water Economy /IMGW/.* The main objective of the program is the development of basic scientific technical and organizational methodology, for the realization of water resources management

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*The detailed information on the program are given in the paper by J.Zieliński, "Wiadomości Meteorologii i Gospodarki Wodnej", T.II /XXIII/ No. 4 /1975/.

in industrial-urban agglomerations and in agriculture. Within the program special attention is being paid to the pilot project dealing with the development of the Noteć region under the general coordination of the Institute of Agricultural Hydrology and Grassland Economy/IMUZ/. This institute is supposed to supervise the irrigation construction project for Noteć, which is developed by the constructing Agency BIPROMEL. The estimated Noteć irrigation area is 50,000 hectares = 500 sq km by 1985 and will increase after 1985 up to 100,000 hectares = 1000 sq km. The project expects the production value per ha to increase from $/22-27/ \cdot 10^3$ Zl to $/50-55/ \cdot 10^3$ Zl.

In order to solve the problem in computerized form BIPROMEL has signed an agreement with the System Research Institute /I.B.S./ of the Polish Academy of Sciences. In particular, IBS will develop the programs for optimization of water system development and control and allocation of water resources during the vegetation period. A special agreement deals with the development of the computerized data bank for the Noteć region. After signing the agreements it became obvious that the successful solution of irrigation problems requires modelling of the complex socio-economic regional processes. Research in that area is being conducted in the Institute of Systems Research and is financed by the Polish Academy of Sciences. As far as the general regional methodology is concerned, IBS cooperates closely with the Institute of Geography and Spatial Organization /IGPZ/ of the Academy of Sciences and with the Agriculture Academy.

In 1977 IBS signed an agreement with IIASA in which both parties agree to establish close cooperative research with IBS carrying out the specific Polish analysis and IIASA providing consultative support.

The Noteć project cooperation structure is given in Figure 1.

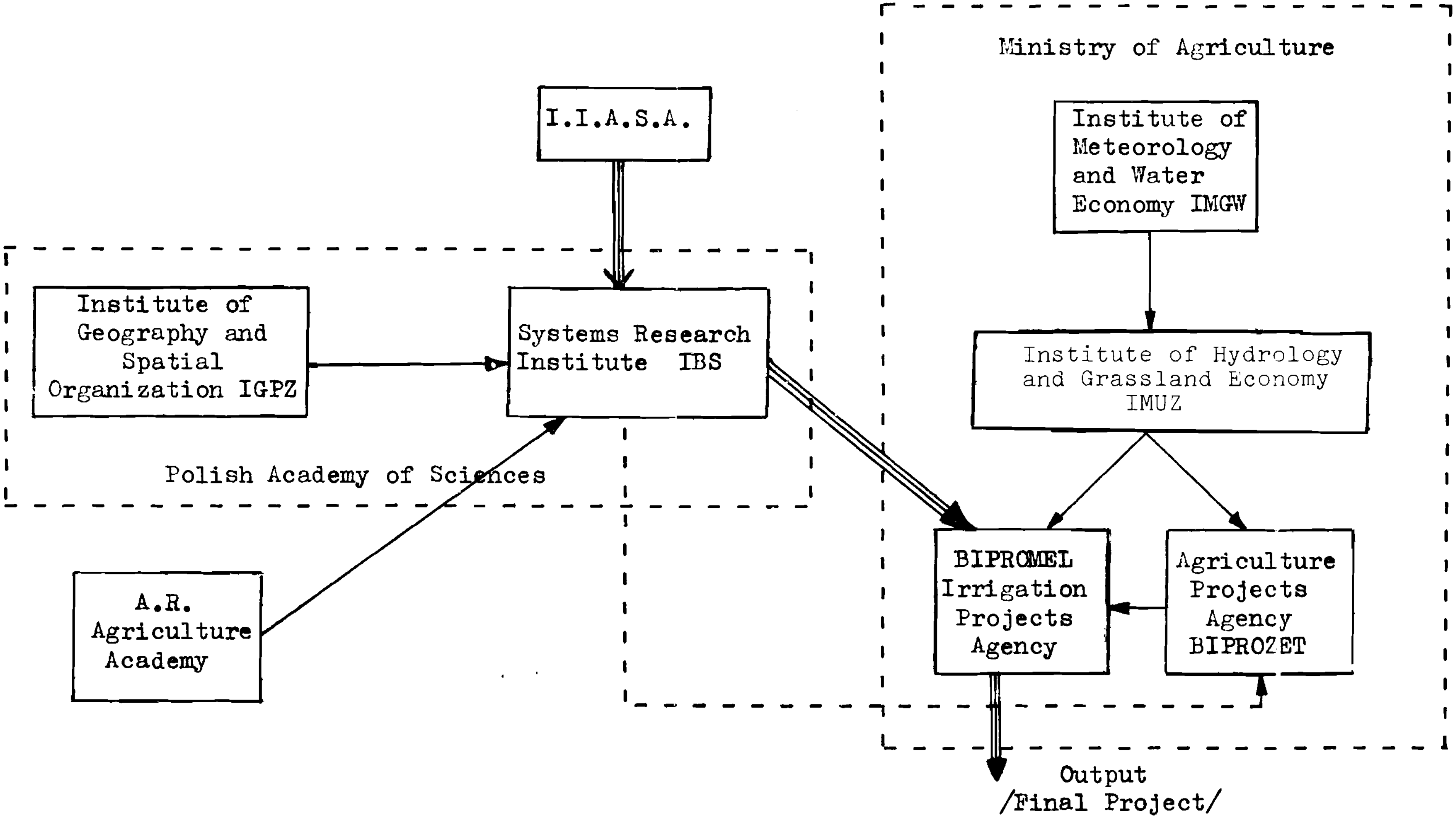

Figure 1. Main Cooperating Institutes at Noteć Development Project

3. Assessment of the Research Problems

Many of the existing large-scale irrigation projects, contrary to expectations, did not prove to stimulate significantly the regional economic growth. Examples of such projects are given in the survey by C.W. Howe: "The Effects of Water Resource Development on Regional Growth," WP-76-22, IIASA, Laxenburg, July 1975.

Due to the high investment cost there are usually misgivings expressed prior to any decision taken in water systems. There is, however, no other way of minimization of the risk involved as the detailed and thoroughfull economic analysis of all the benefits and costs involved. That approach has already been adopted in the Notec project and a complex system of research institutes, shown in Figure 2, has been engaged in the project. That system will work efficiently if the exchange of information and the coordination of individual efforts be possible. The system analysis, which uses an integrating approach and computerized models, seems to be very useful in the Notec Project development.

The project's main objective is to evaluate the economic benefits resulting from investments in a water irrigation system. However, the estimation of costs and benefits cannot be done within the agriculture sector alone.

The increasing yearly shortages of water supply result not so much from the extension of agriculture production but rather from the increasing use of water by industry and the urban population. Among the sectors which compete for water, agriculture is a losing partner. Since a similar situation occurs in many regions of the country, the optimum development of the water system and water allocation methodology is an urgent research task. The development of a water system is highly capital consuming while the total water investment, which represents a fraction of the agriculture investment, is limited each year. Therefore it is necessary to find by a cost-benefit analysis, the optimum magnitude of water investments for each year of the planning interval. In particular, it is necessary to find the location and size of the main water reservoirs and the construction schedule. In addition, the economic efficiency of water transfer from the Vistula Basin should be investigated. A combination of Fulkerson's "out of kilter" and "bound and branch" algorithms can be used for that purpose.

The size of irrigation projects depends to a great extent on the cost-benefit analysis carried out at the agriculture farm level. On the benefit side, it is necessary to investigate the agriculture production functions which depend on land, capital, labor, fertilizers and evapotranspiration (water consumptive use). The production functions should be constructed for all the crops which are cultivated in the region. Then the problem of aggregation of different crop functions should be solved. The resulting production (benefit) function should be compared with the irrigation system cost function in order to find the optimum size of the irrigation project at each particular farm or sub-region. That problem should be solved under the condition that the investment magnitude is limited. Besides the constraints which follow from the operation of a water system (i.e. the admissible water levels and water flows at each water reach) should be taken into account. Then a model concerned with an optimum allocation of the water over space and time subintervals can also be constructed.

The elaboration of the system of models in such a way enables one to determine the possible agriculture production increases as a function of the water system investments. The next important step is to check whether the other production factors (in particular labor and capital) will be correlated with increased water supply. Since we are interested in a rather long time horizon it is not possible to avoid the question of the so called forward markets in output products and production factors. As far as the agricultural labor is concerned it is necessary to observe that 71% of land in the Notec region belongs to private small farms (2-15 ha) which are characterized by low labor efficiency. Due to the considerable rural-urban migration rate and aging of farm owners the government has started a retirement program for farmers under the condition that they agree to give up the land. As a result of this program **the state farms, or younger and productive farmers can increase the farm acreages by buying the land surplusses. The increase** of farm sizes which follows results in an economy of scale effect and a change of farming technology ensues. The process of technological and structural changes has a considerable effect on the agriculture efficiency in general and on water efficiency use as well. In order to find out how much the agriculture in the Notec region will benefit from structural and technological change, a model of an agricultural economy of scale should be constructed. In order to estimate the region's comparative advantages with respect to the rest of the country, the so called marginal production costs should also be compared for specific farm sizes. The problem of the optimum size of an average farm should also be investigated. This is especially important for large agro-industrial complexes which are being organized within the state farms sector.

The question of agriculture labor efficiency cannot be investigated properly without modelling the employment sector, which in turn requires that the demographic and migration submodels are also being constructed. Since migration depends on the employment and standard of living at different regions it is necessary to construct a model in which the personal and aggregate (social) consumption impact on the migration rate is taken into account.

In other words, it is necessary to construct a model in which the strategy in allocation of capital, labor, water, etc., is correlated with the socio-economic policy regarding private and aggregate consumption, migration and demography in such a way that the given regional utility attains a maximum value.

It is obvious that the successful solution of the Notec project requires an integrated, complex approach in which the specialists in water engineering, agriculture, regional sciences, and systems analysis cooperate, in order to construct a system of cooperating submodels. The most difficult part of the project is connected with the modelling of socio-economic subsystems.

The model requires that a number of variables be exogenous. In particular it is essential to know the annual amount of investment for agriculture and water system development. For this purpose the country-wide model MRI, constructed at the Institute of Systems Research, can be used.

A possible structure of the regional model which can be used for the Noteć Project development is given in the figure 2. The economic part of this model consists of two sectors: agriculture, and the rest of the economy. The outputs (X_1, X_2) of these sectors create the gross regional product (GRP) which is allocated by the regional decision center (cooperating with the national decision center) on investments (I_1, I_2, I_w) in sectors and water development system. Part of the GRP is spent on consumption ($Y\nu$) in such a way that utilities (U_1, U_2) of urban and rural residents are maximized. The rural-urban migration and settlements resulting from the U_1/U_2 level together with natural demographic growth determine the employment (L_1, L_2). The structural and technological changes (C) affect the economical and employment subsystems. The environment quality affects the consumers' utility and migration and settlement patterns. The natural resources model is linked with environmental quality. Several subsystems of the model of the figure have already been developed but the general linkage and model adaptation for the Noteć region case study still remain to be done.

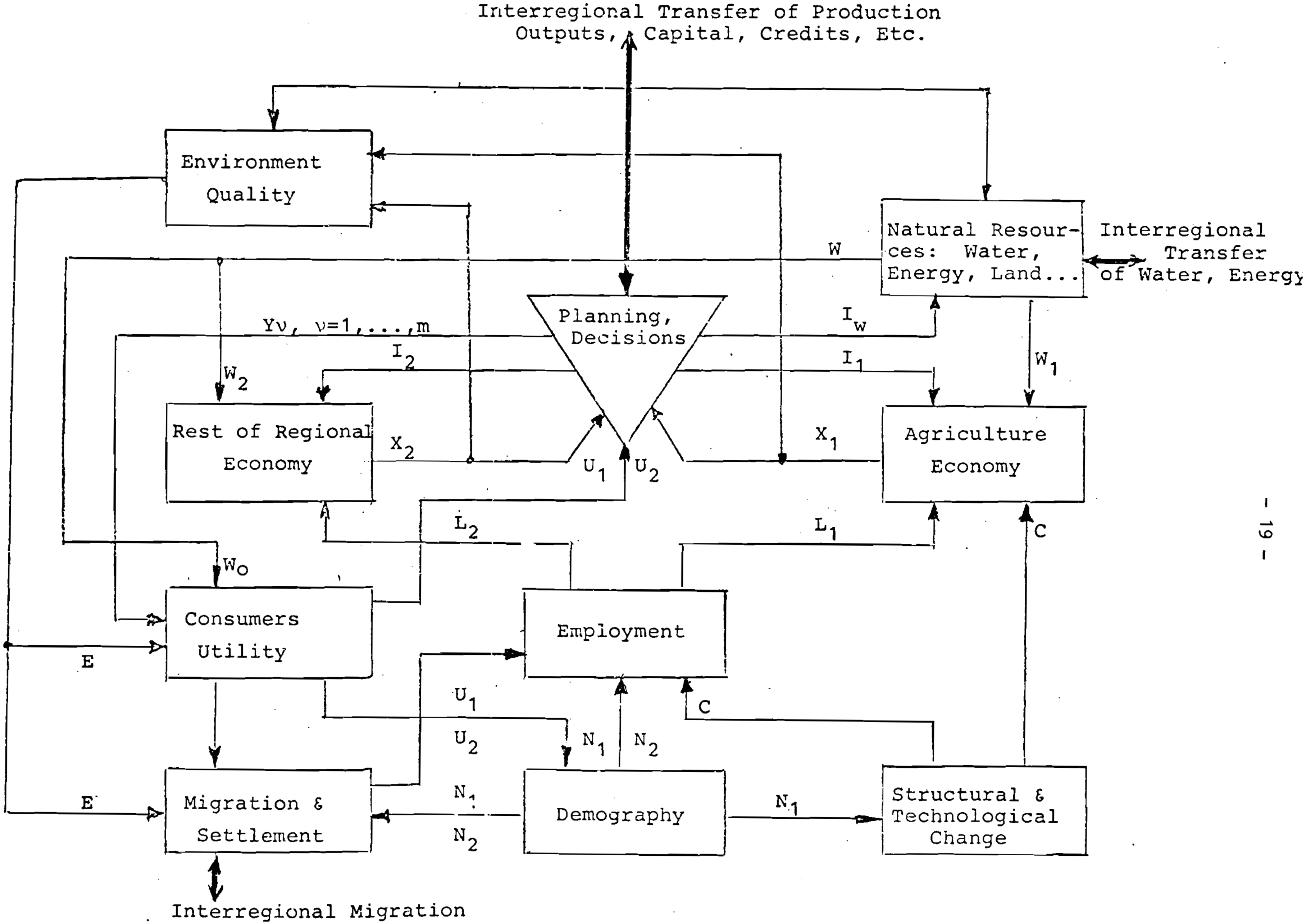

Figure 2. Typical System of Models for Studying Regional Growth in Poland

Contemporary Conditions and Development Problems of the Upper Noteć Region

Ryszard Domański

Academy of Economics, Poznań, Poland

Paper presented at the International Institute for Applied Systems Analysis, Regional Development Task, Laxenburg, May 10-11.

1. Description of the region

Most of the drainage-basin of the Upper Noteć River covers the area of two geographical regions: the Glacial Valley of the Noteć River and the Gniezno Lake District. Two historical-ethnic regions /Kujawy and Pałuki/ have developed in this area. The differences between these regions have gradually vanished, and it is now preserved only in folklore, museums and skansens. Within the boundaries determined for the planning purposes, the Upper Noteć Region covers an area of 6.195 square kilometres. It constitutes a part of the middle-western macroregion[1].

Within the Upper Noteć Region there are rich deposits of rock-salt /at Inowrocław, Góra, Mogilno/ as well as limestone and Jurassic marl /at Barcin, Piechcin, Bielawy/. Both minerals are extracted here in large quantities. Saline waters are used for therapeutic purposes. Brown coal deposits, which have not been exploited yet, occur in some places.

The Noteć River is the hydrographical axis of the region. It is connected to the Vistula through the Bydgoszcz Canal. The Bydgoszcz Canal, the Noteć and the Lower Vistula form a waterway running in an east-west direction and connecting the Vistula to the Odra River. The second waterway runs in the meridian direction from the Warta through Gopło Lake and the upper Noteć towards the Bydgoszcz Canal. There are many lakes in the drainage-basin of the Noteć, including

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[1] Data come from research carried out by order of the Technological-Design Bureau of "Biprozet".

the Gopło and Pakość. Flows of waters are not evenly distributed in time. They are the highest in the period of the lowest demand for water. Thus, a lot of water flows uselessly. A better utilization of water requires that it be stored in retention reservoirs. Dammend lakes may perform the function of such reservoirs.

A small amount of precipitation is the characteristic feature of the region. The average annual total precipitation amounts to 450-550 mm. However, it often drops below 450 mm. Such quantities are not sufficient for agriculture. They cannot provide for the needs of many cultivated plants, especially sugar-beets and green forage. In addition to this there are fluctuations in precipitation in particular years. On the average, there is a serious insufficiency of precipitation every second year. Under these conditions there appeared some changes in the flora. They testify to the process of acquiring the characteristics of a steppe. This process is most clearly seen in Kujawy, the most fertile part of the region.

Because of the strong differentiation of the mother - rock and sculpture of the earth's surface, and especially because of water conditions, a mosaic structure of soil cover has been formed within the region. The suitability of soil for agriculture is also strongly differentiated. However, average and good soils prevail. Soils of classes III and IV constitute 68,1% of arable lands. In Kujawy, in the vicinity of Inowrocław and Radziejów, there are black soils belonging to the highest classes. Soils of classes I and II constitute

5,5% of arable land in the region.

In the structure of land used for farming purposes arable lands, which cover 86,7% of its area, prevail. Permanent grasslands and orchards cover 11,9% and 1,4% respectively. The largest part of permanent grasslands is located in the northern and western part of the region.

In 1975 the number of people inhabiting the Upper Noteć Region amounted to 487 thousand, 38% living in towns and 62% in rural districts. Population density equaled 77 persons per square kilometer. Half of the population is professionally active. The professionally - active proportion of the population is higher in rural districts than in towns and amounts to 51% and 47%, respectively. This difference results from the higher level of professional activity within individual farmers' families. The level of rural population exceeds the demand for manpower determined on the basis of norms in the rural environment. The excess quantity lies in individual farms. It is gradually reduced because of migration of the population from villages to towns or by taking up different jobs outside the rural environment.

Inowrocław /60 thousand of inhabitants in 1975/ is the main city of the region. Other towns like Janikowo, Kruszwica, Gniewkowo and Pakość developed in its neighbourhood. This subregion, where urbanization processes are relatively the most advanced, is at the same time the area of the highest land productivity. Therefore, it is the logical area for the development of intensive agricultural production. Apart from fertile soils and well-developed agriculture, rich deposits of rock-salt have contributed to the development of towns in this subregion.

The characteristic feature of the Upper Noteć Region is the fact that it is within the zones of influence of larger cities located just outside its boundaries, e.g. Bydgoszcz, Toruń, Włocławek, Konin, Gniezno. Urbanization processes based on forces outside the region developed in the hinterlands of these cities. They are the strongest within the zone of influence of the Bydgoszcz-Toruń agglomeration /Nakło, Solec Kujawski/.

Districts located in the southern part of the region are the leaste urbanized. Here the levels of industrialization and cultivation of the soil are relatively low. Population density and the proportion of non-agricultural population are both low. The splitting up of farm units tends to be high.

Among the consequences of urbanization for agriculture /the main branch of the regional economy/, two deserve special attention: the growth of the "double-profession" group of the population /peasant-workers/ and the ageing of rural population. Both phenomena are especially strong within the zone of influence of big and medium size cities. The share of "double-profession" people in the total professionally-active agricultural population amounts to 25%. In the most intensive zones of urbanization it even reaches 50%. In Inowrocław's zone of influence the share of the population over 60 years of age amounts to 18-25% of the total rural population, and in Bydgoszcz's zone of influence it reaches 10-20%.

The rural settlement is characterized by a high degree of dispersion or scattering. There are 868 village districts in the region. The average number of citizens inhabiting a district is 347. Almost one third of the total number of such areas has less than 200 citizens. Larger areas, having a thousand or more inhabitants, constitute only 2%. The state of dwelling-houses and farm buildings does not generally fulfill modern standards of living and requirements of intensive agricultural production.

About 25% of farmlands belong to the socialized sector. 71% belong to individual farms. The rest of the grounds belongs to the State Land Fund. The average size of individual farms is 6,5 ha. Rural economy is most intensively developed in the middle and in the north-western part of the region. The occurrence and interaction of three factors: good soils, advanced methods of cultivation and the development of agricultural-processing industry have been the basis for the region's development. It is one of the most productive agricultural areas in Poland. Highly valued crops /wheat, sugar-beets, rape and fodder crops/ are grown here in large quantities. Yields per hectare and the number of farm animals per hectare are high.

The agricultural-processing industry is represented by 242 plants located quite evenly throughout the region. Sugar refining, grain-milling, meat-processing, dairying, fat producing as well as fruit and vegetable-processing industry have the greatest shares in the total output. When compared with the local supply of agricultural raw materials, sugar refining, fat producing and dairying show surplus of processing capacity, while the meat-processing industry shows a deficiency. The capacity of grain storage is also insufficient in comparision with the level of purchased grain. In addition to the agricultural-processing industry, the chemical industry and the building-materials industry have been developed on the basis of local minerals.

Within the areas especially suitable for agriculture, this branch of economy is preferred in the division of scarce resources. In connection with this the development of conflicting activities, especially an industry requiring a lot of space, large quantities of water and releasing harmful sewerage, is limited.

Networks of supply and sales as well as of technical service form the sector which serves agriculture. Local plants purchasing farm produce, plants selling machines, tools and production materials, as well as service workshops are the component elements of these networks. The locational objective of these elements is to get nearer to the market /demand/, i.e. individual farms. The organization of services for state-owned farms is different. They have direct contacts with the agricultural-processing industry as well as with the wholesale and industry supplying agriculture with machines, tools and production materials. The level of development of the services sector is correlated with the intensity and scale of agricultural production.

The skeleton of the transportation network is railways of nation-wide importance /to Upper Silesia, Baltic ports and Poznań-Toruń/ as well as roads for vehicles/ Bydgoszcz-Szubin-Gniezno, Bydgoszcz-Inowrocław-Konin, and Toruń-Inowrocław-Gniezno/. Inowrocław is the main transportation junction.

An important railway thoroughfare and the Warsaw - Poznań arterial road both run on the southern side of the region. This basic arrangement is supplemented by regional railways, narrow-gauge railways, regional and local roads for vehicles as well as waterways. The density of roads for vehicles is higher than the national average. However, the surface of many local roads is not of an all-weather standard, and this makes transport operations difficult especially in the period of autumn transportation of farm produce.

The spatial concurrence of many socio-economic features in particular parts of the region makes it possible to differentiate several "synthetic" subregions. These are: 1/ Kujawy agricultural district, 2/ Pałuki agricultural district, 3/ western-Kujawy industrial district, 4/ the zone of influence of the Bydgoszcz-Toruń agglomeration, 5/ tourist areas around the lakes.

In 1918 the territory of the region was crossed by the border between the German and the Russian areas of partitioned Poland. This border has left permanent traces in the economic landscape. The areas on both sides differ with respect to the size of farms, the state of dwelling-houses and farm buildings, the state of railways and roads for vehicles, the level of agricultural-processing industry, etc.

As regards administration, the area of the Upper Noteć Region belongs to three voivodeships: Bydgoszcz, Włocławek and Konin. Such administrative division requires the supra-regional coordination of activities within the territory of the region, starting from planning activities and ending with the management of newly-created objects.

The position of the Upper Noteć Region in the country is highlighted by its socio-economic characteristics, relative to these characteristics within the nation as a whole. The region takes up 1,98% of the national area and its inhabitants constitute 1,42% of the national population. Agriculture, the agricultural-processing industry and the network of roads are, on the average, better developed than in the rest of the country. Other branches of industry and urbanization processes are less developed.

Apart from the migration of population, the connections of the region with the rest of the country manifest themselves, among other ways in the import of sugar-beets, oil - plant seeds, tools and materials for agricultural production, building materials, as well as in the export of sugar, fats, grain and grain products, slaughtered animals, and products of both chemical and mineral industry.

2. Problems of development

The economic goal of the development of the Upper Noteć Region is to increase agricultural production. The basic means for achieving this goal is the improved development of water resources which will require large investments. The social aim is to accelerate the growth in the standard of living of the rural population and to bring it closer to that of the urban population which will also be improving. The means for achieving this goal lies in both the development and modernization of rural settlement and the service sector.

Problems of water - resource economics and agriculture are the subject of special detailed studies. The aim of this paper is to present the impact of the development of water - resources and agriculture for the remaining branches of socio-economic life. In my opinion a useful way of achieving this aim is to present these impacts as a part of the general development of the region and its spatial organization.

In regional planning, there exists the tradition of the unified approach to problems of resource exploitation. This is also true for the analysis of production, social, environmental and spatial problems. Assuming that solutions to water and agricultural problems are possible, let us try to identify the problems concerning the rest of the regional system.

1. Intensification of agricultural production will require the retention of an adequate amount of labour in the villages of the region. What level for the labour force will be adequate? A tentative answer may be obtained with the help of employment standards per 100 hectares of arable land. These standards must be differentiated according to labour consumption in agricultural production as well as local conditions. The answer may be corrected by treating the "indispensable" employment in agriculture as a function of many variables characteristic of an intensive rural economy.

2. The process of regional development will bring about changes in the structure of employment. The share of workers employed in the sector serving agricultural production and rural population will be considerably increased. The growth of employment in the agricultural-processing industry will probably be moderate, and smaller than the increase in the

supply of agricultural raw materials. This will be possible, thanks to the modernization of agricultural-processing plants existing in the region as well as to the processing of regional agricultural raw materials in plants located in the neighbourhood. Only then it will be possible to determine how large are the changes in employment structure. According to experts, in the optimal structure of employment in rural environment, each 1000 of workers employed in agricultural production should include 50 workers employed in agricultural - processing industry/sector II/ and 110 workers employed in the sector of services /sector III/.

3. In future population migration will still occur in the region and will be of a rural - to - urban nature. However, the intensification of agricultural production will require new, qualified personnel. The acquiring qualified people will be accomplished through the education of local workers as well as by the of employees from outside. Demographic forecasts, the programme of socio-economic development of the region, as well as the attractiveness of cities and other regions will form the basis for evaluating migration levels. Simulation models of migration and models of migration control may prove useful in the evaluation process.

4. Intensification of agricultural production and acceleration of the development of the standard of living of the rural population will require modernization and development of the rural settlement network. The scale of development must be additionally increased in order to compensate for the loss of decapitalized dwelling-houses and farm buildings and to substitute for buildings whose standards do not suit

modern agriculture and needs of the population. The following factors will shape the size, number, and arrangement of rural settlements: a/ socio-economic changes within the country which manifest themselves in the structure of land possession; b/ organization of agricultural production in both the individual and socialized sectors; c/ non-agricultural functions performed in the rural environment; d/ the already existing size, number and spatial distribution of rural settlements; e/ administrative division /areas subject to village administrators, commune territories, towns/ and its relation to economic divisions /localization and spatial range of service workshops, building enterprises, supply and sales locations, agricultural-processing plants/; f/ accepted assumptions in comparision with the scale, composition and spatial range of service centres of different orders.

At present the year 1990 is regarded as the time horizon for realization of the perspective plan of socio-economic development of the region. The assumed development will manifest itself in the following changes:

4a. The share of the private sector in the structure of land possession will be gradually decreased; however, it will not drop below 50% of the cultivated land. This will result in the increase of the share of socialized sector which, at the same time, will gain more economic power. The average area of private or individual farms will increase because resilient farms will take up the land handed over by old farmers without successors. Intuitive hypotheses concerning the rate of socializing the rural economy, as well as results of individual farms' increased areas, can only be accepted with a rather low degree of confidence. This could be increased if predictions were made with the help of different types of prediction models, including simulation models.

4b. The individual farm will be the basic form of organization of production in the non-socialized sector. The team of farmers will be an additional form. Higher forms of collective economy - co-operative farms - will also be developed. The basic form of organization of production in the state - owned sector will be a combine. Apart from crop and animal production such a combine will include technical service workshops, building plants, fodder producing plants and agricultural processing plants. These different forms of organizing agricultural production will determine the forms of rural settlement. The future development of rural settlement will be an improved continuation of the following two forms: 1/ villages where individual farms prevail, 2/ settlemnts connected with large-scale agriculture /up to now, mainly state farms/. Determination of the optimal spatial organization of both types of settlement remains a problem which must be solved. As a rule, theoretical models of such organization do not take into consideration the variety of local conditions /morphological, hydrographical, soil, etc./. Therefore, it is necessary to elaborate a flexible method which would allow us to deduce the optimal spatial organization of settlements under different local conditions.

4c. Apart from agricultural production and the processing of farm produce which is connected with it, the region fulfills a series of other functions. Two of them will exert an especially strong influence on the forms of rural settlement.

These are: an industrial function and tourist-recreation function. The proximity of industry influences the differentiation of agricultural production, splitting up farm units and forming the double-profession group of the population /peasant - workers/. Apart from their basic function, rural settlements must fulfill one more function for the people employed in industry, namely, they must provide certain residential functions. The double function is also fulfilled by rural settlements located in the area with tourist-recreation values. Thus there arises the problem of determinig the range of additional functions of rural settlements. The solution should determine these function in such a way that they would not inhibit the development of agricultural production. It must also include the question of their spatial organization.

4d. The scattering of rural settlements, as well as the existence of substandard and decapitalized buildings result in the fact that not all settlements have favourable prospects for development. A lot of small villages where the standard of buildings is low do not justify expensive investments for infrastructural and productive purposes. Therefore, it is necessary to select villages with good conditions for development and to concentrate future investments there. Works on rural planning refer to them as basic villages. The selection should be made with regard to the future model of the rural settlement network which will be accepted as the optimal model.

4e. The administrative status of settlements determines their remaining functions to a large extent. Within agricultural territories the basic role will be played by settlements which are the seats of commune authorities. An opinion has been formed that commune centres should have, apart from fundamental services, a wide range of supra-fundamental services for agricultural production and rural population. Commune centres should be relatively evenly provided with services. Agricultural-processing plants are also located in many commune centres. The value of the already existing investments and durability of individual farms are the reasons why the second, lower level of rural settlement will be represented by willages. This, however, will include only selected villages, i.e. basic villages, which should be equipped in the full range of fundamental services. Therefore the future hierarchic structure of rural settlement within the region will be based on two main levels: commune centres and basic villages. In the course of approaching this structure there will also exist the level of dissappearing villages.

4f. The general model of rural settlement should be the means coordinating specific conceptions and activities within this range. This model should be derived from accepted and tested assumptions concerning the scale, composition, and spatial range of service centers of different levels. Apart from the general model one should also elaborate its several versions adjusted to the types of economy prevailing in particular subregions. This would bring model constructions closer to reality.

4g. There is still one more problem concerning spatial organization of rural settlement created by the co-existence /in some villages/ of three sectors of griculture/ individual farms, farming co-operatives, and state farms/ as well as the evolution of the structure of land possession orientated towards the growth of socialized sector. The problem consists in finding out such spatial organization which will most favourably fulfill the requirements of three different forms of agricultural production organization. Spatial organization should also be adaptive, i.e. it should be easily adjusted to the new organization of production which will be created in the course of increasing the socialized sector. When the problem is formulated in this way, it comprises many specific problems concerning localization, architecture, engineering, economy and society. In terms of mathematics, these are the problems of dynamic optimalization with a multicriterion objective function.

5. The intensification of agricultural production as well as socio-economic changes of the country will also exercise an influence on urban settlements. This influence will manifest itself in migration of the population to towns, in the development of agricultural-processing industry as well as in the development of the sector providing services for agriculture and rural population /services of the higher-order/. Its further impact will be the development of scientific research stations working for agriculture and agricultural - processing industry. Urban settlement will develop also under the influence of non-agricultural and endogenious functions /chemical and mineral industry, trade, education, health protection, etc./. A reversed influence of towns on their hinterlands will be shown in the differention of agricultural production, in the renovation of "double-profession"

groups of population /peasant - workers/, in spreading the urban type of building - up and urban style of living. In literature these phenomena are known under the name of spread effect and urbanization.

6. The main transportation problem stressed by the development of agriculture is to improve the surface of local roads. More and more heavy agricultural machinery is driven along these roads and a constantly increasing quantity of farm produce is transported there, especially in the autumn. Soaked ground roads create a lot of transportation difficulties. When selecting the routes for surface improvement, apart from the requirements of agricultural production and sales of farm produce, one should take into consideration the spatial distribution of rural settlements, their administrative status and their hierarchic structure. Between the elements of a regional system, the development problems of which have been presented in items 1 - 6, there occur complex interrelations. Some of them are shown in Fig.8.

7. Changes in land use will be the synthetic manifestation of the socio-economic development of the region. Basic changes will be determined by the administrative decisions. Among other things there will be introduced restrictions in the localization of housing for the population not related to the country and agriculture. Their aim will be to protect agricultural potential of high productivity. However, a wide margin will be left for individual decisions which will influence the changes of land use. Prediction of these changes is an interesting problem to be investigated. Another problem may be formulated in the following way: Will the changes in

land use, after their generalization, provide a substantially modified picture of the division of the region into subregions?

8. Both water investments as well as production and social goals are of long-range character. Therefore, an essential problem is the proper distribution of activities in time. In matemathical terms it is the problem of finding out the optimum trajectory for the region and its component parts. It has already been established that the development of services for agriculture and rural population should be concentrated in commune centres and basic villages. Localization of new production facilities should also be selective. In the remaining villages the investment activities should be restricted /as regards their scale/ and carried out by means of cheaper methods. However, it will be necessary to invest in renovation or partial supplement of the already existing fixed assets in order to prevent rapid decrease of agricultural infrastructure and, in consequence, agricultural production.

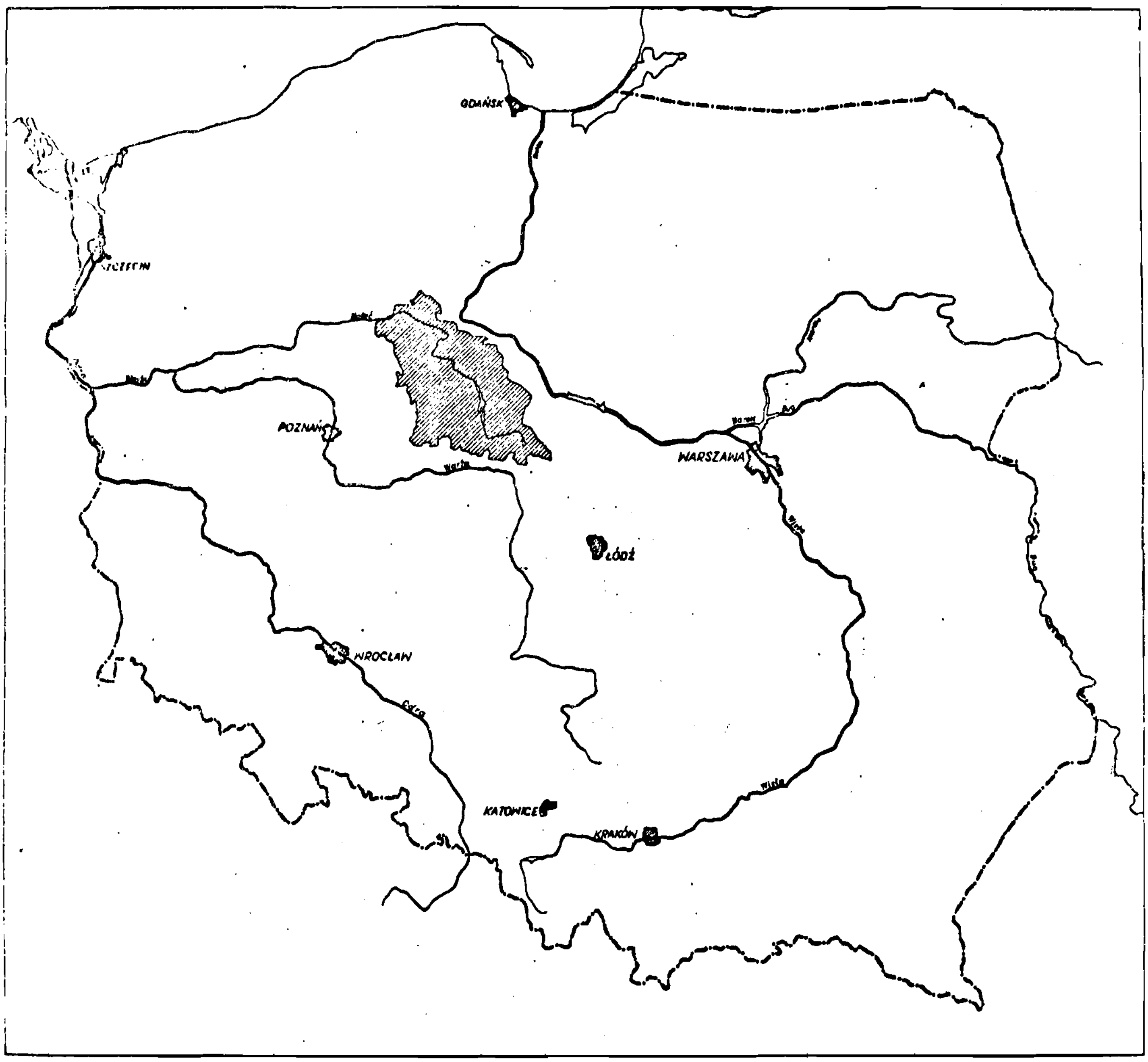


Fig. 1. Drainage - basin of the Upper Noteć River against the background of Poland's territory

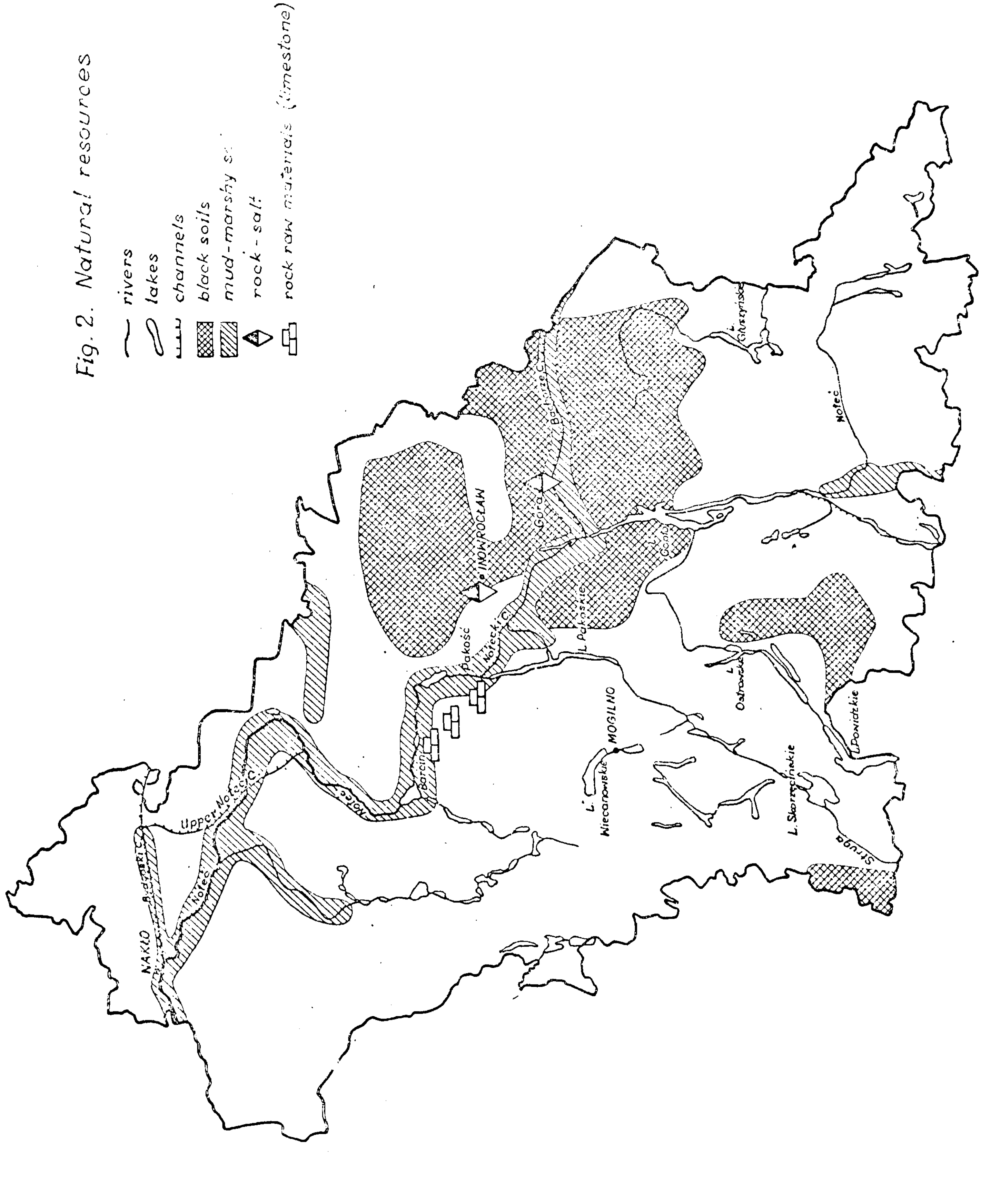
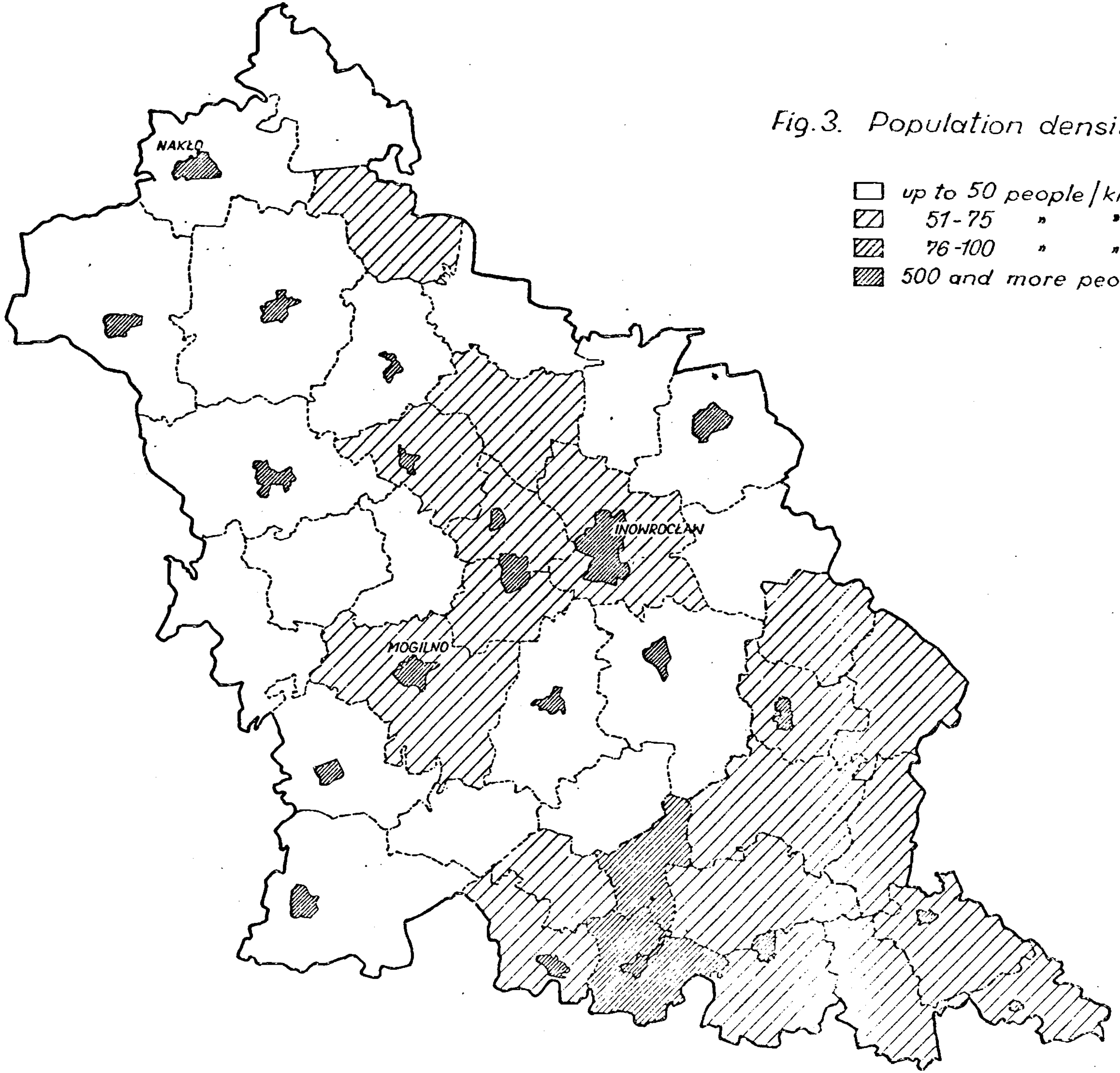


Fig. 2. Natural resources

Fig.3. Population density in 1975



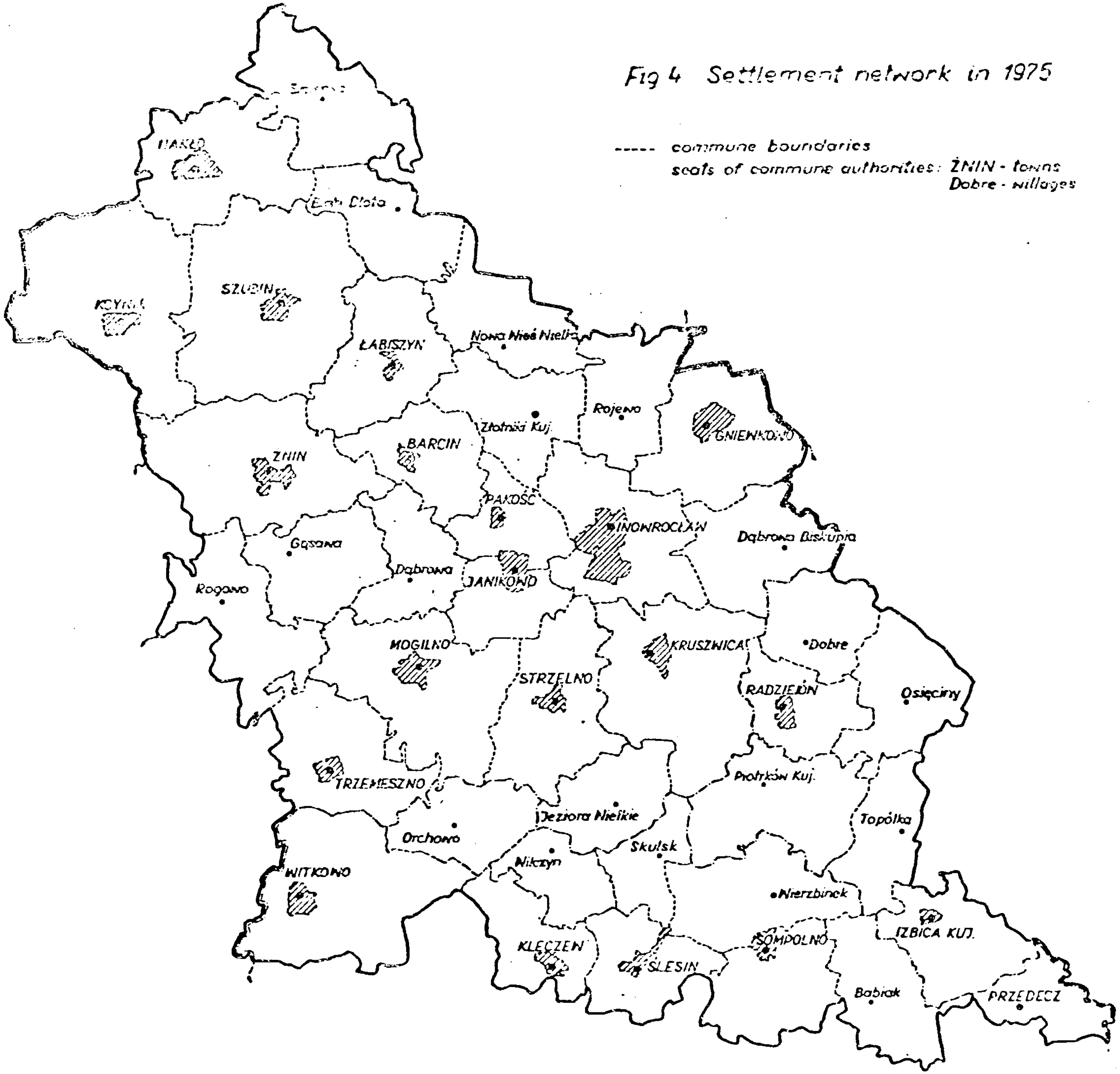


Fig 4 Settlement network in 1975

Fig.5 Agricultural processing industry in 1975

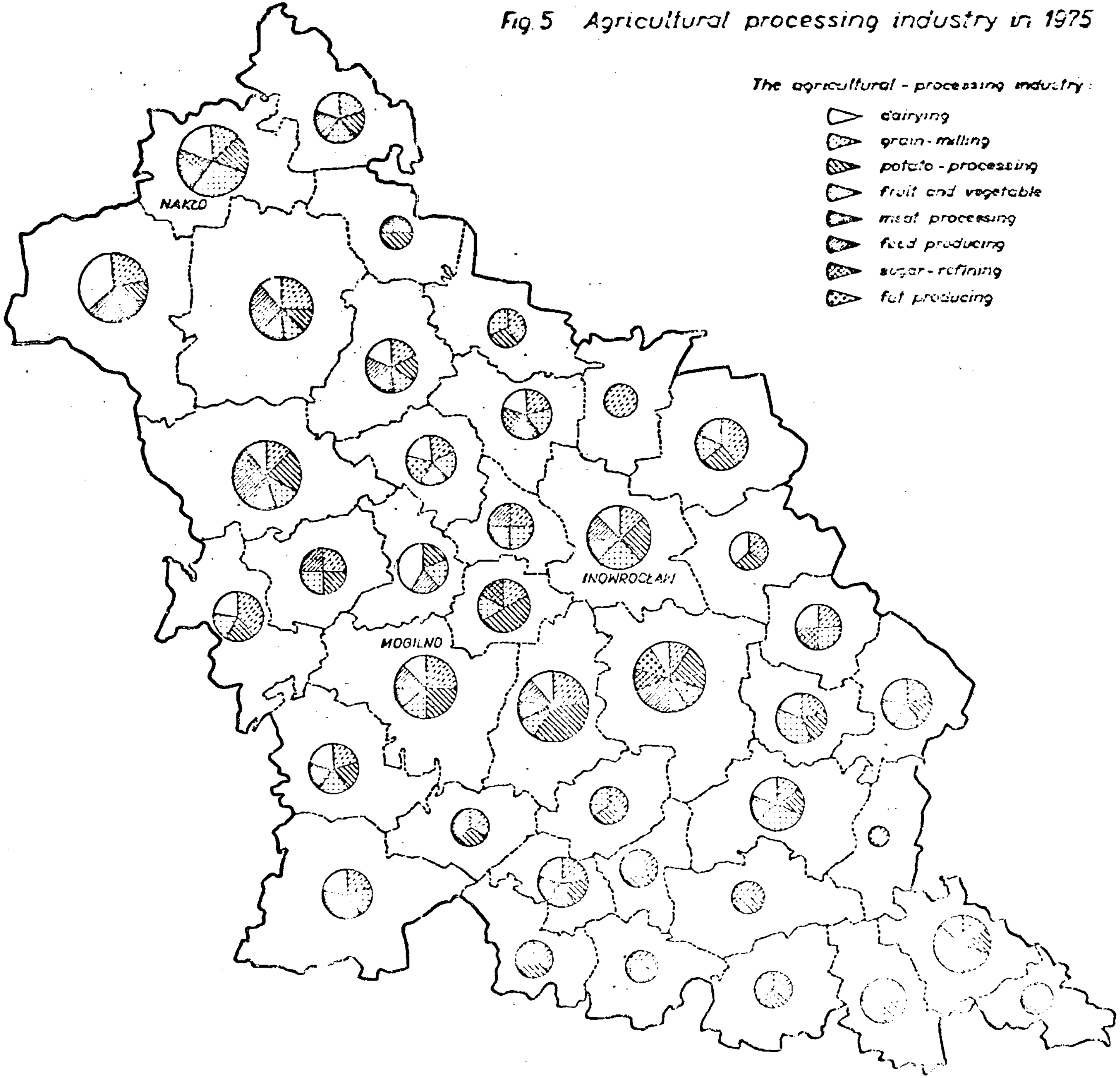


Fig. 6. Network of technical and trade services for agriculture in 1975

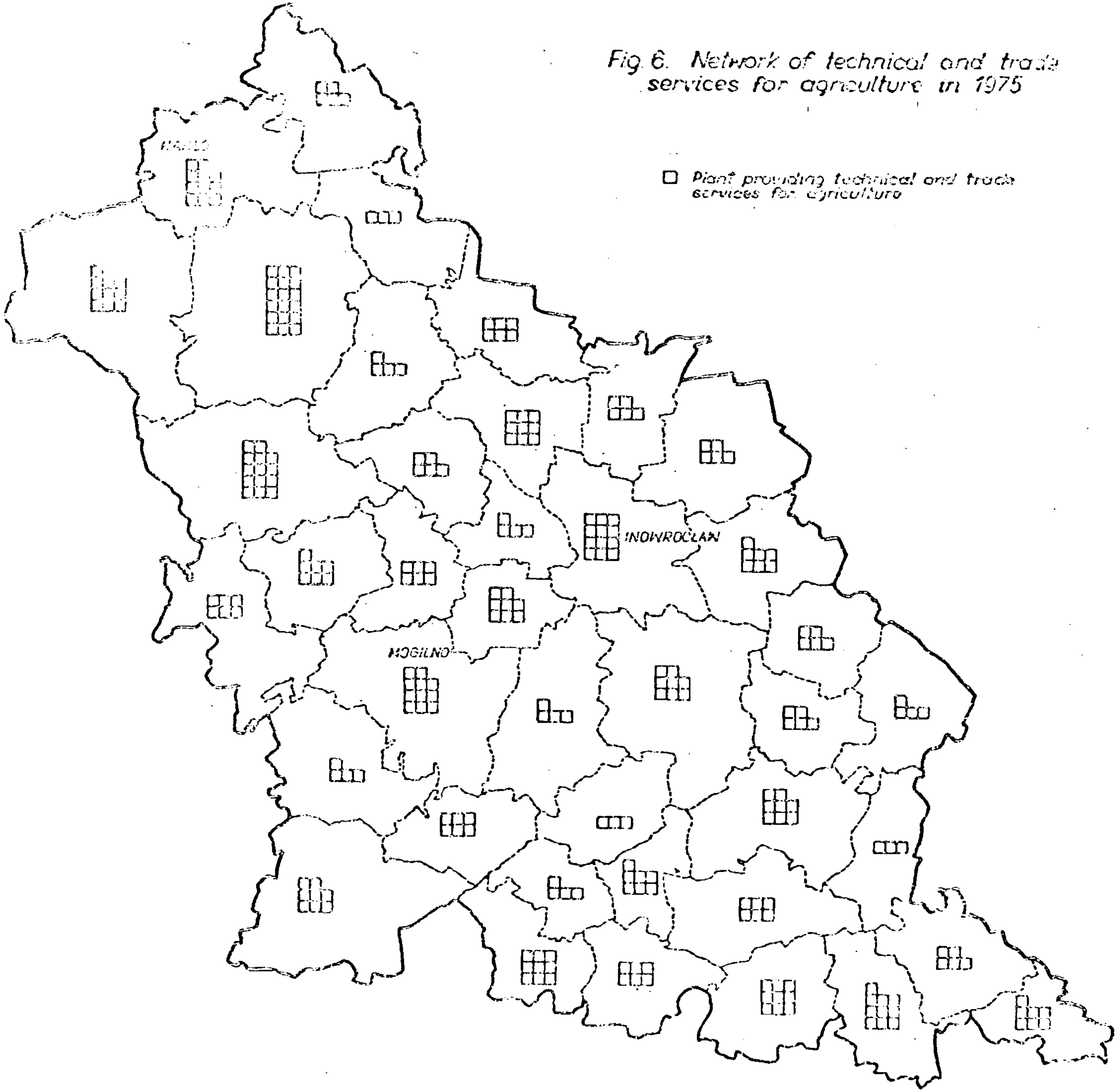
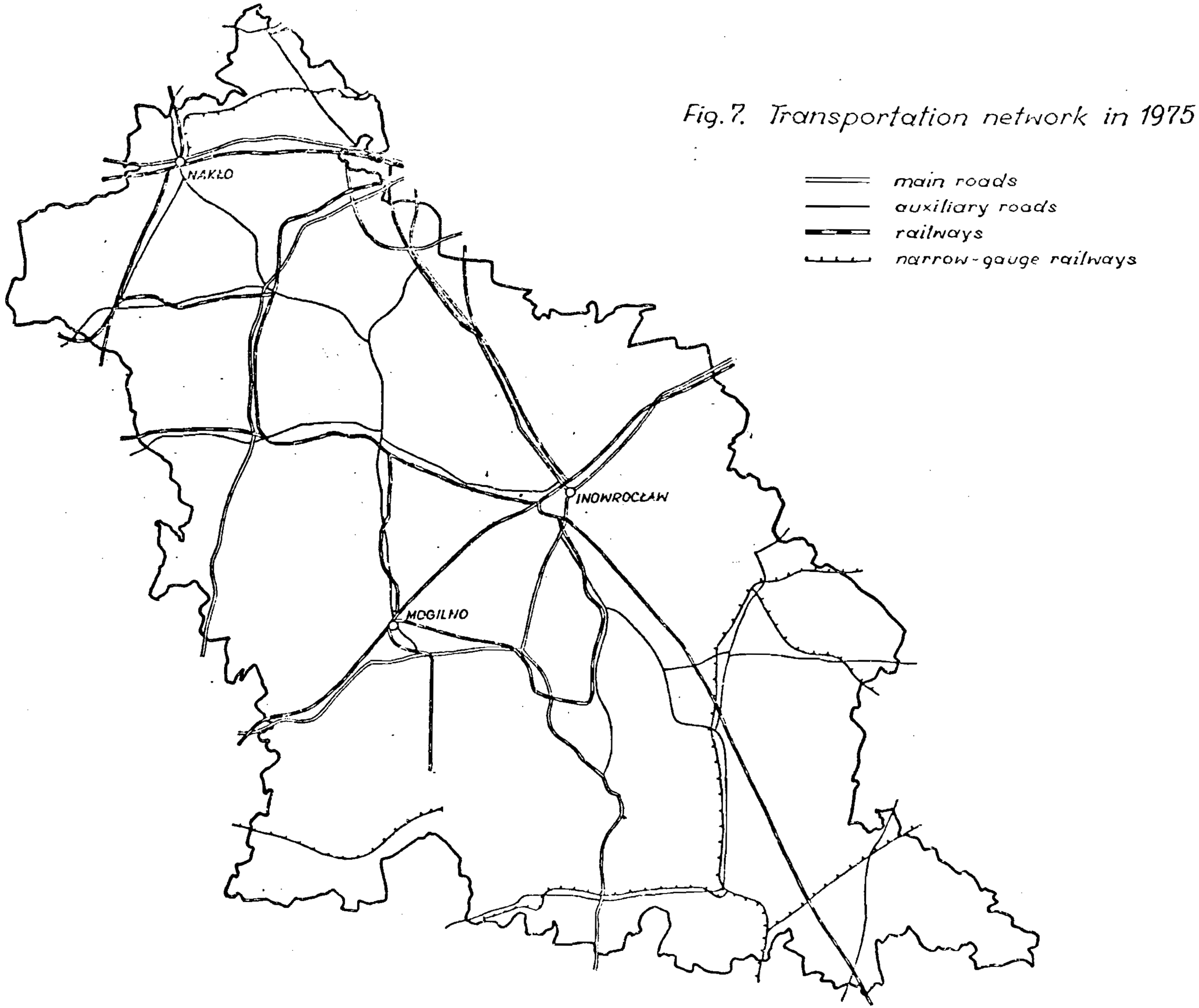


Fig. 7. Transportation network in 1975



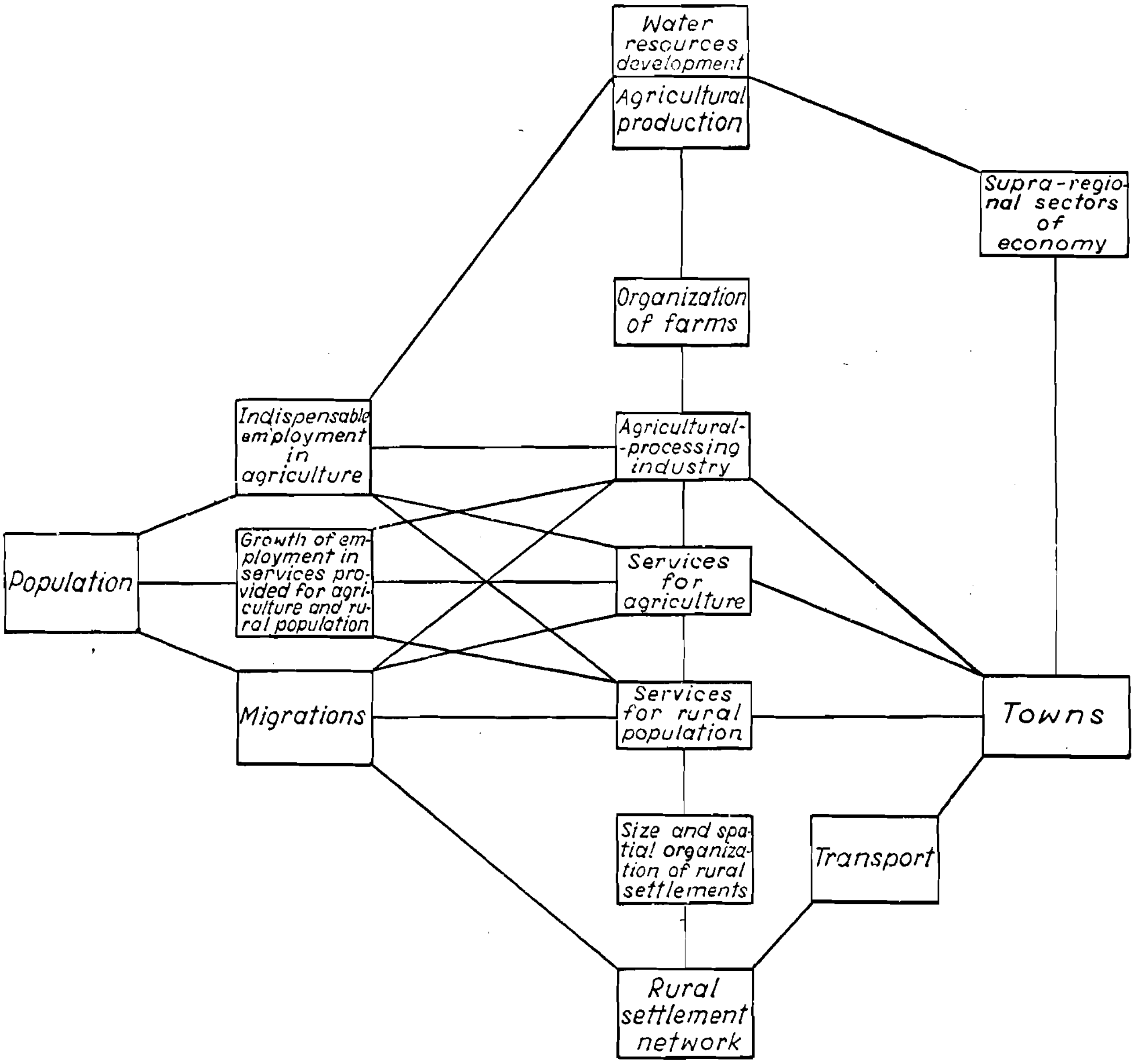


Fig. 8. Network of interrelations between the elements of regional system

INTRODUCTION to AGRICULTURE of the UPPER NOTEĆ RIVER BASIN

Prof. Jerzy Kostrowicki

Institute of Geography and Spatial Organization
Polish Academy of Sciences

The Upper Noteć Basin is situated in the middle of central Polish lowlands, forming the easternmost part of the lowland of Greater Poland (Wielkopolska lowland). As most of the Polish territory the Basin is covered with glacial deposits, mostly with those of the older stages of the last, Baltic (Würm) glaciation (see Fig. 1). The Basin is situated between two great proglacial (ice marginal) valleys (pradolinas): the Noteć (or Toruń-Eberswalde) valley on the north and the Warta (Warsaw-Berlin) valley on the south. Much narrower, relatively shallow, the valley of Upper Noteć divides roughly the Basin into two parts: the eastern - the Cuiavian (Kujawy) plain, almost flat is covered with ground morainic (mostly clayey) deposits, the western one - the heights of Gniezno is formed of end morainic hills intermingled with some fluvioglacial sediments (Fig. 2). All those glacial deposits cover thick layers of tertiary sediments out of which the so-called Poznań clays are of value as a building material.

The important geological feature of this area is a great Cuiavian-Pomeranian anticlinorium (Fig. 2) extending from the Holy Cross Mountains on the south-east to the Pomeranian coast and the Island of Rügen (Rugia) on the North-West, that under-lies most of the Basin. With this anticlinorium Permian (Zechstein) deposits are connected with huge salt beds from which a number of salt domes (diapirs) are stretching out, reaching almost a surface, exploited by several mines, as well as saline waters used by health resorts, some traces of petrol and natural gas as well as Jurassic limestones exploited for various purposes (8, 14, 15).

The glaciation was also responsible for the formation of numerous lakes of various size and type. Most of them have disappeared already leaving numerous hollows filled with peat and with various lake deposits. The most characteristic for the area under study are the ranges of long and narrow channel (or finger) lakes often connected with each other by streams. The largest of them is Gopło Lake which together with some smaller lakes forms a channel about 70 km long, originally connected with Warta river. In the past it had certain importance as a waterway (28).

Like the whole Polish lowlands the climate of the Upper Noteć Basin is characterized by a constant struggle of the influences of maritime climate of Western Europe with those of the continental climate of Eastern Europe. This results in frequent changes in the direction of winds, in temperatures and in a weather as a whole. Within the Basin itself the climate is little diversified. In average only 35 days are of a mean temperature below freezing point. Heavy frosts are rare and do not last long but with little snow cover strong winds might damage winter crops. More perilous might be light frosts during a growing season which are quite common in April, occur in average 4-5 times in May and appear sometimes even in June, particularly in the eastern, flatter part of the area. Also light frosts in a fall are there the earliest. The average length of the growing season for the Basin is 215 days (13).

The most distinct climatic feature of the area under study is its relative dryness, as the Upper Noteć Valley is situated in a very centre of the dry belt (Fig. 4) extending between middle Odra and middle Vistula rivers. This belt is characterized by mean annual precipitation below 500 mm which drops in the centre of the area under study (Kruszwica) to below 450 mm, out of which only slightly over 300 mm falls in the growing season.

At the same time the distribution of precipitation between the years is highly uneven. Practically every second year is dry in terms that an amount of precipitation in a growing season, particularly in April and May does not meet the requirements of most cultivated plants. Unfavorable are also frequent changes in temperature and strong south-eastern winds in a springtime that lead to further drying of soils (13).

Differences in the character of glacial deposits together with differences in the original vegetation cover contributed largely to the differentiation of soils (Fig. 5) of the Upper Noteć Basin. While on the western and south-western parts of the area various podzolic soils formed from boulder clay dominate, intermingled with some lighter, more sandy soils formed on fluvioglacial deposits, and on the northern and north-eastern margins, alluvial sands are the most common, the characteristic features of the central part are the so-called Cuiavian black earths - ones of the most fertile soils in Poland (29). They have been formed during centuries from original marshy soils which because of a high content of calcium carbonate, with growing dryness of climate had eventually been transformed into alkali or neutral soils with a deep, often up to 40 cm, humus layer with 2-5 per cent content of organic matter (32).

Fertile soils covered with sparse broad-leaf forests, easy to cultivate were probably responsible for very early settlement of this area (33, 43). According to archaeological findings already in the 5th century BC agriculture was fairly well developed there. After certain decline, probably due to the great migration of nations, about 6th century AC certain revival was spotted in that area, which eventually became one of the cradles of the Polish statehood. The Bavarian geographer in the 9th century AC mentioned already about a tribal state of Goplani that occupied this area with its centre in Cuiavia, which later on, together with other tribes, is supposed to form a larger state of Polani comprising the present day Greater Poland. That were Polani rulers who eventually unified the other Polish tribes into the historical Polish state (43).

In the Middle Ages Cuiavia with its centre in Kruszwica on the Gopło Lake - Mare Polonorum of that time - was one of the best developed and most densely populated parts of Poland. It declined with the subdivision of the Piast monarchy and frequent inroads of the Teutonic knights. After the reunification of the Polish State and particularly after the reopening of the outlet to the Baltic Sea through Gdańsk, resulting from the victory over the Teutonic Order, Cuiavia developed again as one of the most important grain producing areas in Poland exporting its products by Vistula to Gdańsk and then to

Western Europe. Swedish wars of the 17-18th centuries and internal disorders contributed greatly to the further decline of the country as a whole. At the end of the 18th century in result of the partitions of Poland most of the Upper Noteć river Basin was incorporated to Prussia, with the exception of its south-eastern part which after 1815 became a part of the autonomous Polish Kingdom under a sceptre of the Russian tsars. That division had a far reaching consequences on the economic development of this area.

Early settlement of the area under study as well as its intensive land utilization resulted in the considerable transformations of its natural conditions (22, 27, 33). Early deforestation of this area, particularly rapid between the 14th and 18th centuries and conversion of forests into fields, contributed greatly to further dessication of soils by south-eastern winds no longer hampered by trees. In the 18th and 19th centuries, in order to extend the surface of agricultural land, water level of numerous lakes was artificially lowered. Many lakes shrunk, the other disappeared altogether. In 1873-1887 the level of Gopło lake was lowered by 1.38 m what resulted in its dwindling to the present size and lowering of the water table of the connected lakes (30). The reclamation of meadows and pastures by drainage, without any attempt to keep water balance, further accentuated this process. After few years of good yields, in result of over-drying, most of those reclaimed grasslands had turned into waste land. The ground water table of the fields had been lowered as well (15, 22, 27).

The problem of the so-called "steppization" of Cuiavia (5, 25, 26, 34, 40) was widely discussed both in the inter-war period and after World War II. According to some biologists (7, 39 etc.) the whole process is marked by the growing appearance of plants characteristic for the steppes of south-eastern Europe such as needle grasses (Stipa capillata and S. Joannis), adonis (Adonis vernalis), Siberian bell-flower (Campanula sibirica) etc., as well as animals such as hamster (Cricetus cricetus), vole (Microtus arvalis), bustard (Otis tarda), numerous molluscs, etc. at the detriment of species characteristic for surrounding forest sites. They explained this process as a result of transformation of the environment by Man, while the other challenged that view (49).

The problem to what extent this process is resulting from natural changes of climate or has been caused by the activity of Man is debatable. It seems that while the Cuiavian Plain might have certain natural predispositions that facilitated this process, the deforestation, the reclamation works and degradation of soils resulting from long lasting cultivation without sufficient manuring have certainly contributed to the acceleration of the process.

New situation emerged with the intensification of agriculture after World War II, and particularly during the last 15 years. AS intensive use of chemical fertilizers and higher crop productivity demands more and more water, it has recently been observed that due to the insufficient moisture growing inputs of chemical fertilizers not only increase less and less the yields of some crops, but in some cases they bring about even their decline. It looks like certain ceiling of crop productivity under present day water conditions has been reached, that would bar any further development of agriculture unless more water is artificially introduced. This is a general and very important problem with which agriculture of the whole of the central Polish lowland is to be faced in its growing intensification. The problem appeared earliest just in the Upper Noteć river Basin.

Irrigation of fields has no tradition in Poland. Only recently it has been introduced either in some State farms or else in the small-scale intensive market gardening of the suburban zones. As the Upper Noteć Basin is concerned while water is very scarce on place it could easily be drawn from the nearby Vistula and Warta rivers.

In spite that the existing water resources are abundant they should consciously be divided between industry, urban settlements and agriculture, and could be used for irrigation under the condition that water is sufficiently clean.

It seems that the whole problem is not so much of natural or technical but rather of economic character. Irrigation is a costly business which would rise greatly the costs of agricultural production. To what extent in the Polish conditions field irrigation can be economical and if so in which natural conditions (landforms, soils), in which form of agriculture and for what crops, the problem demands a thorough-going investigation. The possible solutions are ranging from a zero growth of agriculture upwards that ceiling through partial to total crop irrigation.

As forms of agriculture are concerned two different types of agriculture coexist side by side in Poland:

1. small-scale, individual (private) agriculture that cover at

present about 80 per cent of agricultural land and 2. large-scale socialized whether state or collective agriculture that cover 17.7 and 2.1 per cent of agricultural land respectively. These proportions vary greatly from place to place. While regional differences between socialized farms are not very great as far as their level of development is concerned, individual agriculture in Poland is much more diversified. In general it is just passing from semi-subsistence through semi-commercial to commercial agriculture. Those stages of development of agriculture in individual parts of the country differ greatly not so much because of natural conditions but more for historical reasons. The same is true for the area of the Upper Noteć Basin.

Present differences in the level and character of agriculture in this area result from both differences of natural conditions and those caused by the differences in economic development in the past, particularly between the greater north-western part of the area which at the end of the 18th century was incorporated into Prussia and the smaller south-eastern part that became a part of the Tsarist Russia.

In spite that the situation of Polish farmers in the Prussian part was difficult from the political point of view, particularly since the Bismarck time, because of a strong policy of germanization, including a pressure on taking over as much as possible of land from the Polish great landowners and peasants for which a special "Colonization Commission" was established, the economic situation in the Prussian part was much better.

First of all land ownership was granted to peasants already in 1823, while in the Russian part of Poland peasants had to wait until 1864. Then in result of a rapid industrialization and urbanization that followed the unification of Germany in 1870, an absorptive market for agricultural products developed that created good economic conditions for agricultural development also on the former Polish territories.

To rise agricultural production it became both feasible and economical to increase capital inputs and to introduce modern agricultural systems. The development of transportation network and the establishmebt of a number of plants processing agricultural goods and in result the development of the local market facilitated agricultural development. At the same time an outlet for labout surpluses of manpower both in nearby urban centres and the industrial districts of Western Germany enabled to maintain and even to increase the size of farms. In result land and labour productivity of agriculture and its commercialization greatly increased, both in the large landed estates, that in 1907 in the area under study owned about a half of total agricultural land, and in smaller farms most of which were held by middle sized or big peasant holders.

The situation in the south-eastern part that in 1815 was incorporated to Russia was different. Delayed land reform, lack of outlet for labour surpluses due to very slow pace of industrialization and urbanization, poor transportation network, and low prices for agricultural goods resulting from both the weak local market and the competition of grain and meat produced by extensive methods on the southern steppe gubernias of the Russian Empire made the development of agriculture difficult. It was true both for the landed estates that covered less agricultural area and were usually smaller that on the west and particularly **for** the largely semi-subsistent peasant holdings that because of the growing surpluses of man power were compelled to subdivide their land every generation.

After the reunification of Polish state in 1918 some land reserves of the former Commision of Colonization as well as land taken over from some Polish and those German landowners that left Poland was subdivided among peasants. This however did not eliminate the differences between the two parts of the Upper Noteć Basin.

After World War II all landed estates in Poland were either subdivided among peasants or converted into state farms. As however peasant holdings in the south-eastern part of the area were smaller and the density of agricultural population higher, most of that land was used there to increase peasant farms and not much was left for state farms. On the contrary, in the north-western part of the area, where landed estates covered more land and small farmers were few, less land was given to peasants, and much more state farms were organized.

In result the differences in the agrarian structure between north-western and south-eastern parts of the area remained considerable. While on the north-west socialized (mostly state) farms cover about 20 per cent or more of agricultural land, in the south-eastern part about 4 per cent only (Fig. 6). At the same time while on the east medium sized farms (5-10 ha) dominate, covering about 47 per cent of individual agricultural land, over 15 per cent falls to the smaller (below 5 ha) farms and only about 38 per cent to larger farms (over 10 ha), on the north-west larger farms (Fig. 7) cover usually over 61 per cent of agricultural land, medium-sized farms (Fig. 8) over 30 per cent and the smallest 9 per cent of agricultural land of individual farmers (37, 38).

In result of those differences also density of agricultural population (Fig. 9) in the south-eastern part is higher (over 60 or even over 70 persons per 100 hectares of agricultural land), and lower on the north-west (below 50 or even below 40 persons) (27). Differences in the size of farms and labour reserves result in the differentiation of agricultural mechanization and machinization. Here however greater differences could be observed between socialized and individual farms, lesser in the use of chemical fertilizers, as private farms, particularly larger ones on the west in this respect do not lag much behind socialized farms. Also crop rotation systems (37) are different in the socialized farms. With that respect in the individual farms considerable differences occur between larger farms of the north-west where they are more varied (usually 4-5 years long) and smaller farms of the south-east where they are much more uniform (usually 3 or 4 years long).

Because of limited area and low productivity of permanent grasslands and a very little importance of perennial crops (orchards) arable lands are the principal basis of agricultural production in the Upper Noteć Basin.

While in individual agriculture, on better soild intensive crops such as sugar beet and potatoes occupy together over 30-35 per cent of arable land, extractive (or exacting) crops (mostly wheat and barley) - 50-55 per cent and structure-forming crops (mostly clover and lucerne) - less than 15 per cent, on poorer soils the proportions are different. Intensive crops (almost exclusively potatoes) usually do not exceed 30 per cent, exacting crops (mostly rye) - 60-70 per cent and structure-forming crops (mostly clover and serradella) - 10-15 per cent of arable land. Irrespective of soils a ratio of sugar beets, barley and lucerne is usually higher on the north-western and that of legumes as a whole on the south-eastern parts of the area (37).

The proportions between various crops could best be presented by means of crop combinations (or orientations in the utilization of arable land).[2)]

As the most common crop combinations in individual farming (Fig. 10) of the area under study the following could be listed (37):

$E_4r + I_1p + S_1c$ - extensive, rye, secondarily with potatoes and clover, on poorer soils of the south-east.

$F_3r + I_2p + S_1l$, $E_3 + I_2p + S_1s/c$ or $E_3r + I_2p + S_1c$ - medium intensive, rye with potatoes, secondarily with lupine, serradella or clover on poorer soils of the south-east.

$E_3r + I_2bp + S_1c$ - medium intensive, rye, with potatoes and sugar beets, secondarily with clover, on better soils mostly on the south-east.

$E_4 + I_2p$ - medium intensive, rye with potatoes - the most common. They can be found either on medium quality soils on the south-east or on poor quality soils on the north-west.

$E_4hr + I_2p$ - medium intensive, barley-rye with potatoes - on medium quality soils on the north-west.

$E_4hr + I_2pb$ - medium intensive, barley-rye with potatoes and sugar beets in the north-western part of the area.

$E_3r + I_3p$ - intensive, rye-potatoes orientation on medium quality soils both in the eastern and western parts of the area.

$E_3rh + I_3pb$ - intensive rye-barley-potatoes-sugar beets, on good soils, exclusively on the north-west.

The analysis of correlation between quality of soils, size of farms and crop combinations (Fig. 6) revealed the following concentrations (Fig. 11) (37):

I. With larger farms and good soils the intensive (E_3I_3) crop combinations with cereals, mainly wheat-barley, or barley and sugar beets are correlated; less often medium intensive ones (E_4I_2) with less sugar beets - mostly on the north-west.

II. With larger farms and slightly poorer soils similar, most often, medium intensive (E_4I_2) but sometimes also intensive (E_3I_3) crop combinations are correlated - mainly on the north-west.

III. With larger farms but poorer soils, medium intensive (E_4I_2) rye or rye-wheat with potatoes combinations are correlated in the western part of the area, while medium intensive ($E_3I_2S_1$), mostly rye or rye-barley with potatoes, secondarily with clover, in the eastern part of the area.

IV. With larger or medium-sized farms but still poorer soils - medium intensive crop combinations ($E_3I_2S_1$) are correlated, exclusively rye with potatoes, secondarily with clover or serradella on the south-east.

V. With larger farms and similar soils on the east but the poorest soils on the north-west only, extensive crop combinations ($E_4I_1S_1$), mainly rye, secondarily with potatoes, serradella or lupine, are correlated.

VI. With small farms and poor soils, medium intensive or even intensive (in case of urban territories) crop combinations are correlated. As on the area under study small farms seldom dominate except urban areas, these correlations seem to be not very conclusive.

It is interesting that crop combinations in medium-sized farms do not reveal closer correlations with soil conditions. In general however on good soils intensive ($E_2I_3S_1$ or E_3I_3) crop combinations prevail while on medium quality soils - medium intensive ones ($E_3I_2S_1$ or E_4I_2). With poorer soils medium intensive ($E_3I_2S_1$) crop combinations often correlate. Most of the units with a dominance of medium-sized farms are characteristic for the south-east.

In general as one can see from the above the distribution of crop combinations in individual farming is correlated in a high degree with both quality of soils and the size of farms. Additional factors that may distort that picture are differences in labour reserves, location in relation to industrial or market centres, and a general level of agricultural development.

In individual farms the highest yields of cereals are obtained in the central part of the area under study, the highest yields of potatoes on the extreme north of the area.

The differentiation of crop combinations in the socialized farming (Fig. 12) is much greater being much less related to quality of soils and particularly to the size of holdings. It is more connected with a planned production orientation of farming and to some extent with labour reserves.

In general crop combinations in state farming are less intensive than in individual farming. The proportion of intensive crops (sugar beets, rapeseed, much less potatoes) usually do not exceed 25 per cent and often falls below 20 per cent of arable land, the proportion of extractive crops (more wheat and barley, much less rye) is also lower - 40-50 per cent and often less than 40 per cent of arables, while that of structure forming crops (clover, lucerne, mixed fodder crops) usually exceeds 30 per cent or even 35 per cent of arable land.

The most common are various extensive crop combinations $E_3I_1S_2$) usually rye, rye-wheat, wheat-barley or wheat with various legumes such as clover, lucerne, mixed fodders (mashlum) and secondarily with potatoes, sugar beets or maize (grown mainly for silage).

The second are various medium intensive crop combinations ($E_3I_2S_1$), usually rye, rye-barley, and wheat-barley with potatoes or/and sugar beets and secondarily with clover or/and lucerne.

In few state farms highly extensive (E_2S_4 or E_5S_1) crop combinations were found, while intensive crop combinations were discerned in some state farms of the north-east where state farms are few.

Crop combinations in collective farms are usually less intensive than in individual farms but more intensive than in state farms. Two groups of crop combinations prevail:

1. $E_3I_1S_2$ - Extensive rye, rye-barley or barley-wheat, with mixed fodders (mashlum) or clover and secondarily with sug ar beets.

2. $E_3I_2S_1$ - Medium intensive rye, rye-barley, wheat-barley or wheat, with potatoes, sugar beets, rapeseed, secondarily with mixed fodders or other.

More intensive (E_3I_3) crop combinations are characteristic for few collective farms of the south-eastern part of the area.

As livestock breeding (42) is concerned the density of cattle is not much differentiated on the Upper Noteć Basin, varying between 50 to 55 heads per 100 hectares of agricultural land, in which 60-70 per cent are cows. It is higher in the centre, lowering towards both the north-west and south-east.

Differences in the distribution of pig population are much higher, ranging from 90-100 heads per 100 hectares of agricultural land on the south-east, where smaller farms dominate, and 70-80 heads on the north-west, being the lowest (60-70 heads) in a very centre of the area.

Sheep breeding is less developed. Its density is the highest in central part of the area (30-40 heads), lower on the north-west (20-30 heads) and the lowest on the south-east (15-20 heads).

Poultry breeding does not play any important role. Its density varies between 350-450 hens per 100 hectares of agricultural land on the east, below 350 heads on the west and much less than 300 heads in the south-west.

In total the density of livestock population in conventional (large) animal units varies from below 65 in the central and northern part of the region to over 80 units mostly on the South-East (Fig. 13).

As a whole orientations of livestock breeding are simple and little diversified. Most common is that of cattle breeding - with pigs (C_4P_2). In the central part of the area the dominance of cattle is increasing (C_5P_1), while on the south-east is decreasing (C_3P_3).

In the socialized farming livestock population per unit area is smaller, particularly as pigs are concerned. The ratio of cows to total cattle is lower (40-60 per cent) that reflect mixed, dual purpose or beef orientation of cattle breeding.

Taking gross agricultural production of individual farms as a whole the following orientations have been identified (23, 24, 35) on the area under study.

In the central part of that area mixed orientations (V_3A_3) wheat-potatoes-milk with pork prevail, while toward the south-east and north-east they are changing into crop orientations with livestock products (V_4A_2) - potatoes with sugar beets, wheat, pork and milk and towards north-west to crop, potatoes with wheat, rye, pork and milk. In the former district of Żnin different mixed orientations: rye-milk with potatoes and pork were observed.

Land productivity in terms of gross agricultural production per unit area is in individual farming rather high in both parts of the area under study (18.600-20.000 zlotys per 1 hectare of agricultural land), lowering to the north (16.000-18.000 zlotys) as the quality of soils decreases. Labour productivity in terms of gross agricultural production per one person employed in agriculture is the highest (80-90.000 zl) in the western part of the area, lowering to the east and to the north, and particularly to the south-east (50-60.000 zl) where smaller farms using more labour dominate (23, 24, 35).

The degree of commercialization (35, 36) is the highest (over 55 per cent of gross production) in the central part of the area, i.e. where sugar beets, rapeseed and some other cash crops make a high percentage of agricultural production and where fairly high part of milk, beef and pork is also commercialized. It is lower both toward the north and on the south (below 40 per cent).

According to Falkowski (9) the following types of agriculture [3] could be identified in the Upper Noteć Basin (Fig. 14):

1. Intensive, highly productive (70-90 conventional grain units per hectare of agricultural land) and commercial agriculture (55-65 per cent of agricultural production) resulting from relatively high inputs of chemical fertilizers (over 200 kg in pure content NPK per 1 hectare of agricultural land), relatively high mechanization (30-40 hectares per 1 tractor), with medium intensity of livestock breeding (80-90 large animal units per 100 hectares of agricultural land). In gross production crop orientations (V_4A_2), wheat-sugar beets-fodder crops with dual purpose (milk and beef) cattle and with pig breeding dominate.

Animal products prevail in commercial production (A_4V_2), beef-milk-pork with wheat, barley, sugar beets and sometimes with rye and potatoes.

This type has developed in the best natural conditions, on the heavy soils (black earths, clayey podzolic soils etc.) of the Cuiavian plain and the Gniezno heights as well as on Krajna heights on the extreme north of the Basin.

2. Intensive, productive (50-70 grains units) and commercial (50-55 per cent) agriculture with slightly lower high chemical fertilization (150-200 kg NPK), lower mechanization (40-45 hectares per 1 tractor), but higher density of livestock

(100-120 large animal units). Crop production dominates in gross production (V_4A_2). Wheat-sugar beets with beef, pork and milk (on the north-west) or wheat-rye-potatoes with pork and milk orientations (on the south-east) dominate. Commercial production orientations are mixed (A_3V_3) pork-beef-milk-sugar beets-potatoes. This type has developed on the areas with good or medium quality soils in the eastern part of the Cuiavian plain as well as on the clayey soils of the Gniezno heights.

3. Medium intensive, medium productive (about 50 grain units) and, medium commercial (45-50 per cent) agriculture, with lower chemical fertilization (below 150 kg NPK per 1 hectare of agricultural land) and mechanization (40-50 hectares per 1 tractor); inputs of labour are higher (30-40 employed per 100 hectares of agricultural land). In gross production crop with livestock orientations (V_4A_2) - rye-wheat-potatoes with pork and milk dominate. In commercial production - mixed orientations (V_3A_3): rye-potatoes, pork and milk. This type has developed mainly in the south-eastern part of the area.

The type 4 is occurring in two variants:

4a. Intensive, productive and commercial agriculture with higher inputs of labour (over 30 active in agriculture per 100 hectares of agricultural land), high proportion of part-time farmers (70-80 per cent) have developed irrespectively of natural conditions in the suburban zones of certain towns (Inowrocław, Nakło etc.). In gross production crop orientations (V_4A_2), with livestock, rye-potatoes-fodders with cattle and pigs dominate, in commercial production livestock with crops (V_2A_4): dairy cattle-pigs with potatoes, vegetables and rye.

4b. This variant is similar to 4a but because of the greater distance from urban centres and poor soils it is less intensive, less productive and less commercial. It has been identified on the north, west and south-east of the area under study.

5. Relatively extensive, low productive (about 40 grain units) and low commercial (about 30 per cent) agriculture with lower capital inputs (below 100 kg of fertilizers in pure content per 1 hectare, 60-100 hectares per one tractor). Crops prevail in gross production (V_4A_2). Rye-potatoes-fodder crops with pigs and cattle orientations. Commercial orientations are mixed (V_3A_3) rye-potatoes-pigs-cattle. This type has been identified on the poor soils of the north-eastern part of the area.

The dominance, co-dominance or co-existence of particular types of agriculture has served the same author as a basis for subdividing the area into agricultural regions and subregions. The larger north-western part of the area under study with more advanced agriculture, more socialized farms, larger individual farms, higher capital inputs, lower labour inputs, higher labour productivity and commercialization has been included to the IV Greater Poland-East Pomeranian region described before (17).

Within the area under study this region has been subdivided into the following subregions:

IV.3. Krajna (on the extreme north) with high proportion of the type 1 and lower of the types 2 and 3.

IV.4. Bydgoszcz-Toruń on the north-east with types 4a and 5.

IV.5. Kujawy (Cuiavia) in the centre - with about 80 per cent share of the type 1 and smaller proportions of the types 2, 4a, 4b and 5.

IV.6. Wągrowiec - on the west with types 4b and 5.

The much smaller south-eastern part with less advanced agriculture, less socialized farms, smaller individual farms, lower capital but higher labour inputs, lower labour productivity and commercialization has been identified as a part of the larger V Central (Warsaw-Łódź) Region, in which type 3 prevails with types 5 and 1 of less importance.

The introduction presented above has been based on the material collected from various studies, compiled for various basic units, and various periods, dealing mainly with individual farming, made either for the whole country (23, 24, 35, 36) or covering only a part of the area under study (9, 37, 38).

The study to be made specially for the programme should cover both individual and socialized agriculture, using smaller and more comparable units (communes or villages for individual farming, enterprises or particular farms for socialized farming).

The data ought to be calculated either as averages for several years or compiled for one year proved to be a typical for the multi-year trend of agricultural development. To serve best the purpose it should be based on modern quantitative methods in both analytic and synthetic parts of the study. Only on such data a proper modelling of future desirable types of agriculture could be possible.

Such a study together with a profound analysis of natural conditions of agriculture would be essential for both a general development planning of the Upper Notec river Basin and for the calculations of the feasibility and economics of agricultural development in general and irrigation problems in particular.

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41. Województwo Bydgoskie. Krajobraz, dzieje, kultura, gospodarka (Bydgoszcz voivodship. Landscape, history, culture, economy) Poznań 1967.

42. Załuska J. Przemiany w strukturze przestrzennej chowu zwierząt w Polsce 1950-1969. (Changes in the spatial structure of livestock breeding in Poland 1950-1969), 1978 (Doctoral dissertation, manuscript).

43. Żurowski K. Pradzieje (Prehistory) (in:) Województwo Bydgoskie ... pp. 79-93.

Footnotes

1) All the figures taken from the study by W. Tyszkiewicz refer to this part of the Upper Noteć region that belonged to the historical province of Kujawy /Cuiavia/.

2) There are many methods of identifying crop combinations (The discussion cf. (2 and 31)).

The method developed by Polish agricultural geographers consists of grouping crops into three main groups of similar agronomic character, namely the intensive crops - (mainly root and industrial crops), the extractive or exacting crops - (mainly cereals), and the structure-forming crops - (mainly legumes). Then by means of a successive quotients technique dividing an area covered by each group of crops by 1, 2, 3 up to 4 or 6, according to the detailness of a given study -

their relative ranks are established. The number of quotients granted to each group is then divided in the same way by individuals crops. The result is presented in a kind of formula or a code.

The same technique has been applied to establish the combinations (or orientations) of livestock breeding as well as to the identification of gross production orientations and orientations of commercial production, granting first a definite number of quotients to crop and livestock products and then to given crop or livestock products (16, 17) etc.

The following symbols are used in the present paper: I - intensive crops; E - extractive crops; S - structure-forming crops; w - wheat; r - rye; h - barley; p - potatoes;

b - sugar beets; c - clover; l - lucerne; s - serradella; V - vegetal, crops; A - animal, livestock; C - cattle; P - pigs, pork; S - sheep.

3) The study has been based on the principles and methods of agricultural typology as established by the Commision on Agricultural Typology of the International Geographical Union (18, 19) and partly also on the techniques proposed by the Commision for identification of agricultural types.

FIGURES

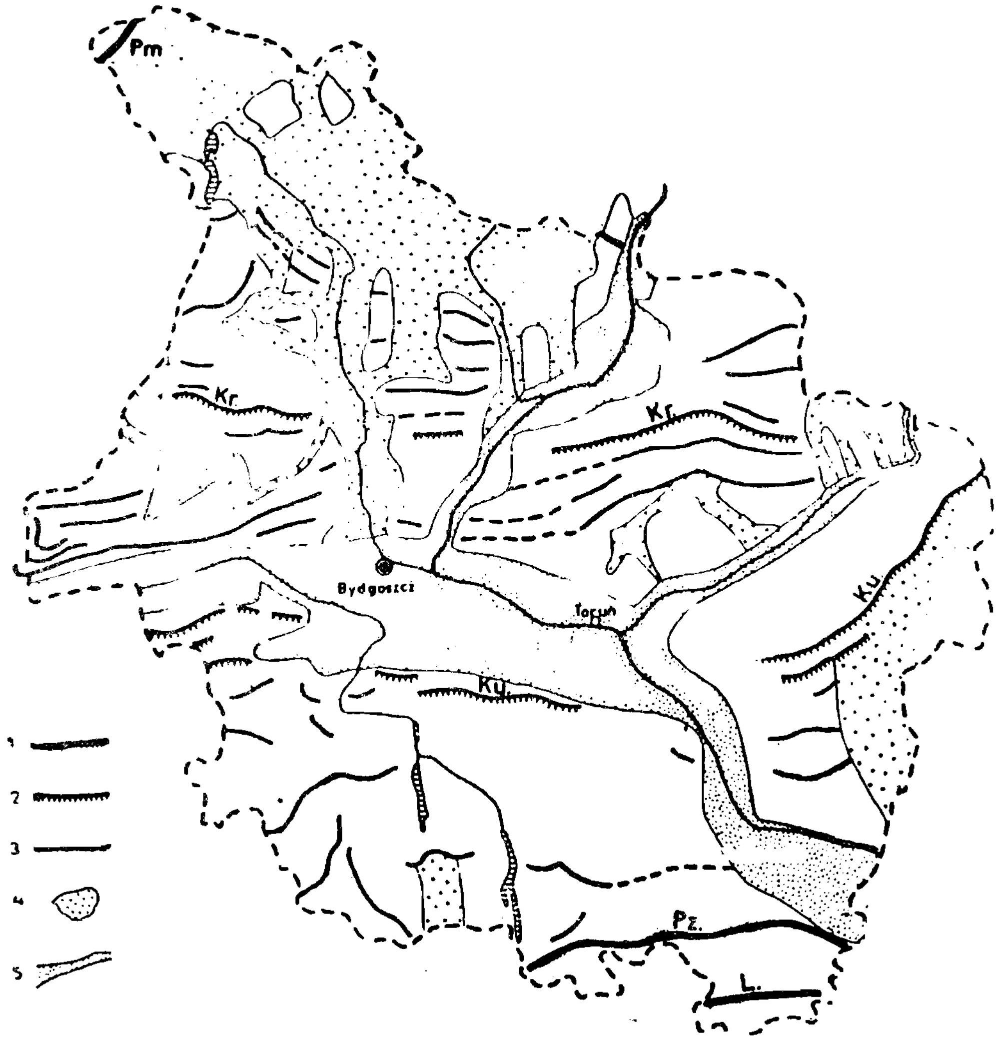

Figure 1

Bydgoszcz voivodship: Glaciation stages

After L. Roszko (40, p. 20)

1. End moraines belts of various stages of the Baltic (Würm) Glaciation

   L. Leszno stage, Pz - Poznań stage, Pm - Pomeranian stage.

2. Substages

   Ku - Cuiavian substage, Kr - Krajna substage

3. Smaller recession belts

4. Outwash plains (sanders)

5. Ice marginal (pradolinas) valleys and valleys.

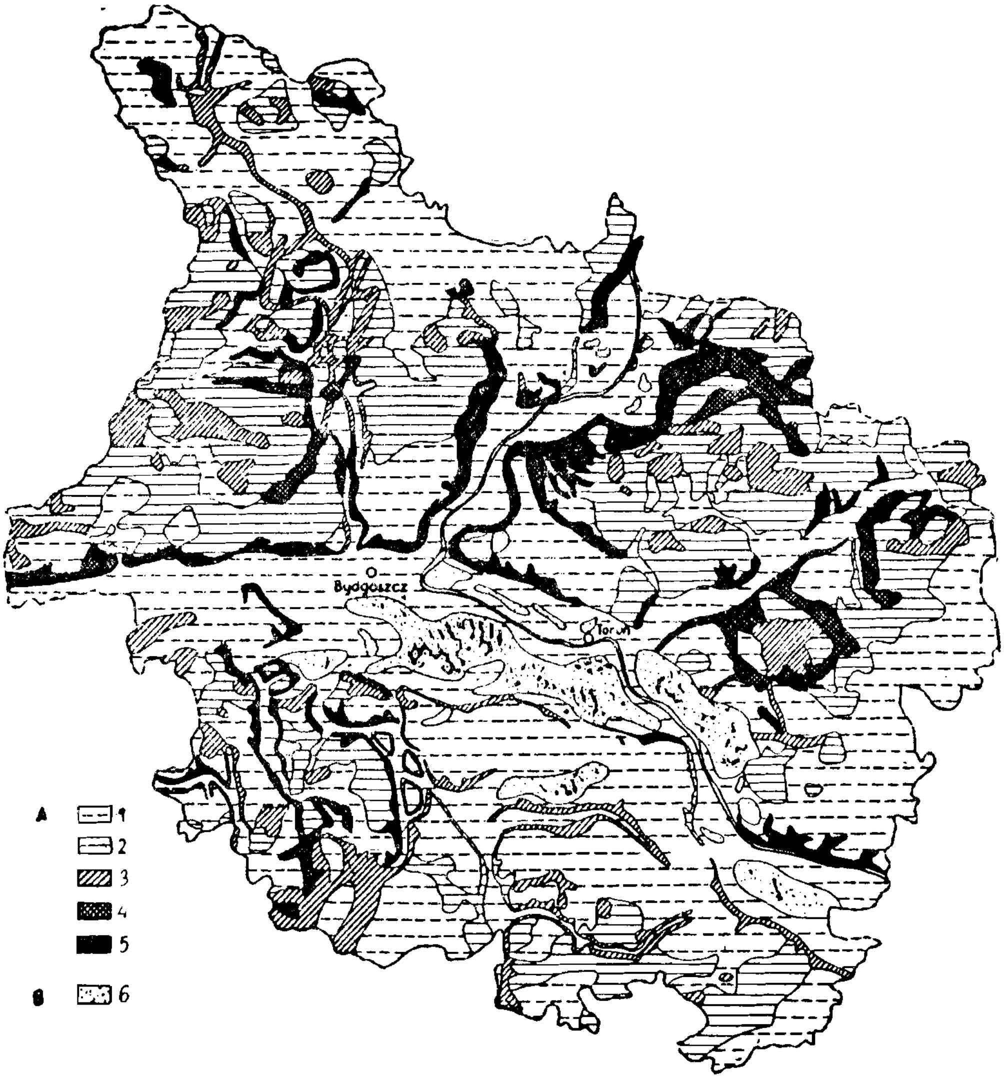

Figure 2

Bydgoszcz voivodship, Erosion processes

After L. Roszko (40, p. 22)

A. Areas threatened by water erosion

1. None or negligible (plains), 2. low, 3. moderate,

4. strong, 5. intensive (heights, escarpments)

B. Areas threatened by eolian erosion (sand dunes)

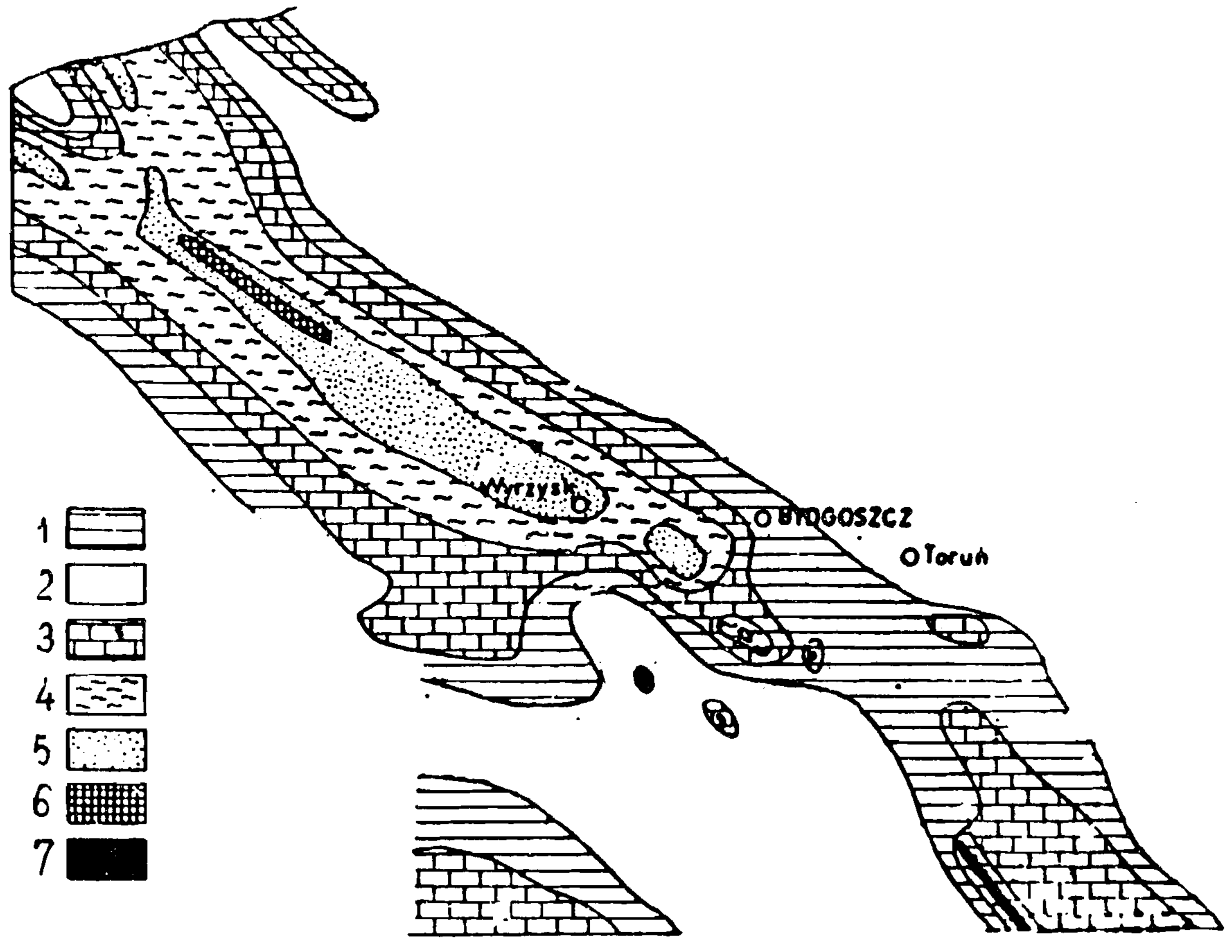

Figure 3

Cuiavian - Pomeranian anticlinorium

After R. Galon (40, p. 11)

Geological map without tertiary and quaternary deposits.

1. Upper Cretaceous, 2. Lower Cretaceous, 3. Upper Jurassic, 4. Middle Jurassic, 5. Lower Jurassic, 6. Triassic, 7. Permian deposits.

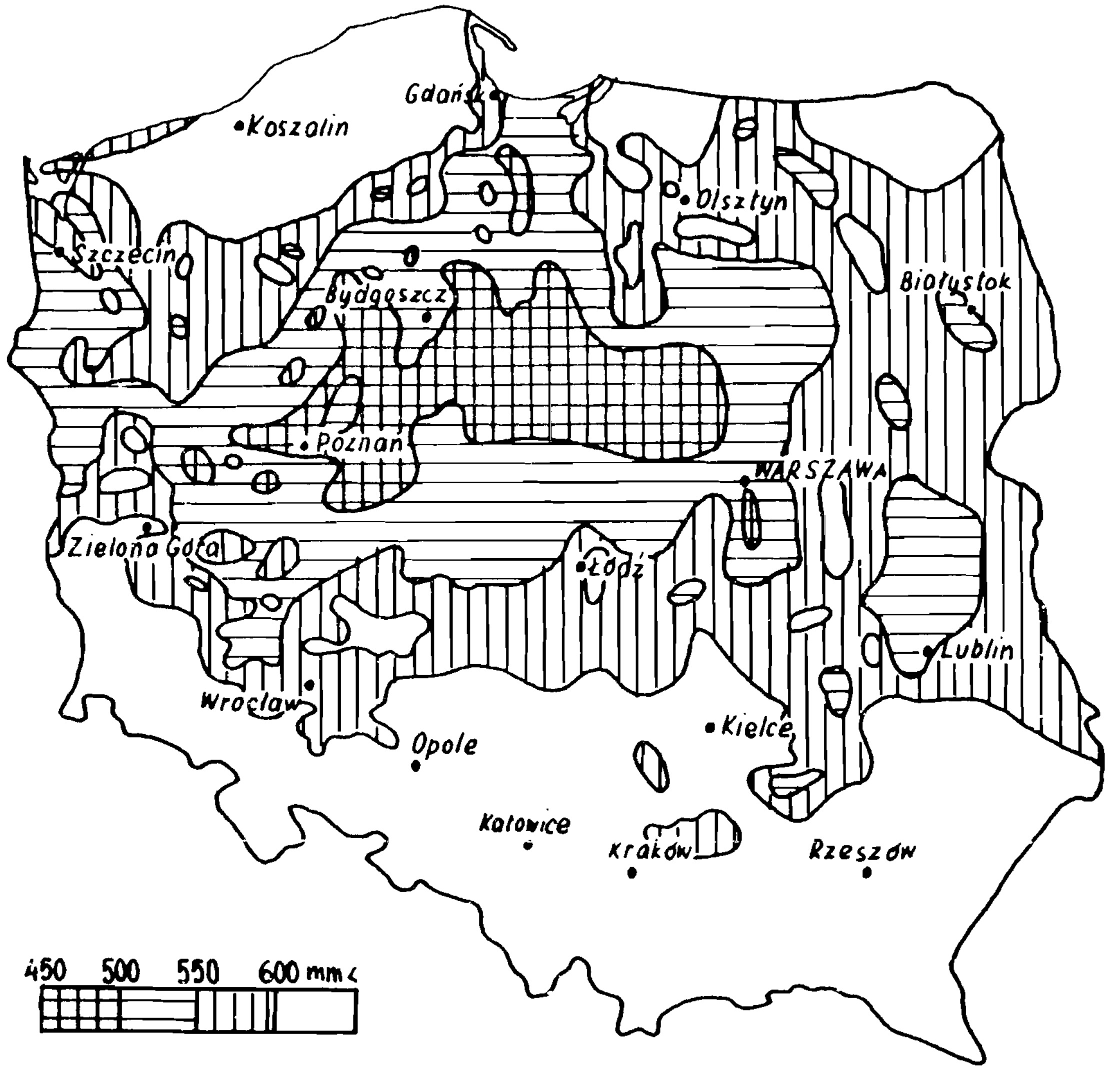

Figure 4

Poland. Mean annual rainfall after J. Lambor (25, p. 52).

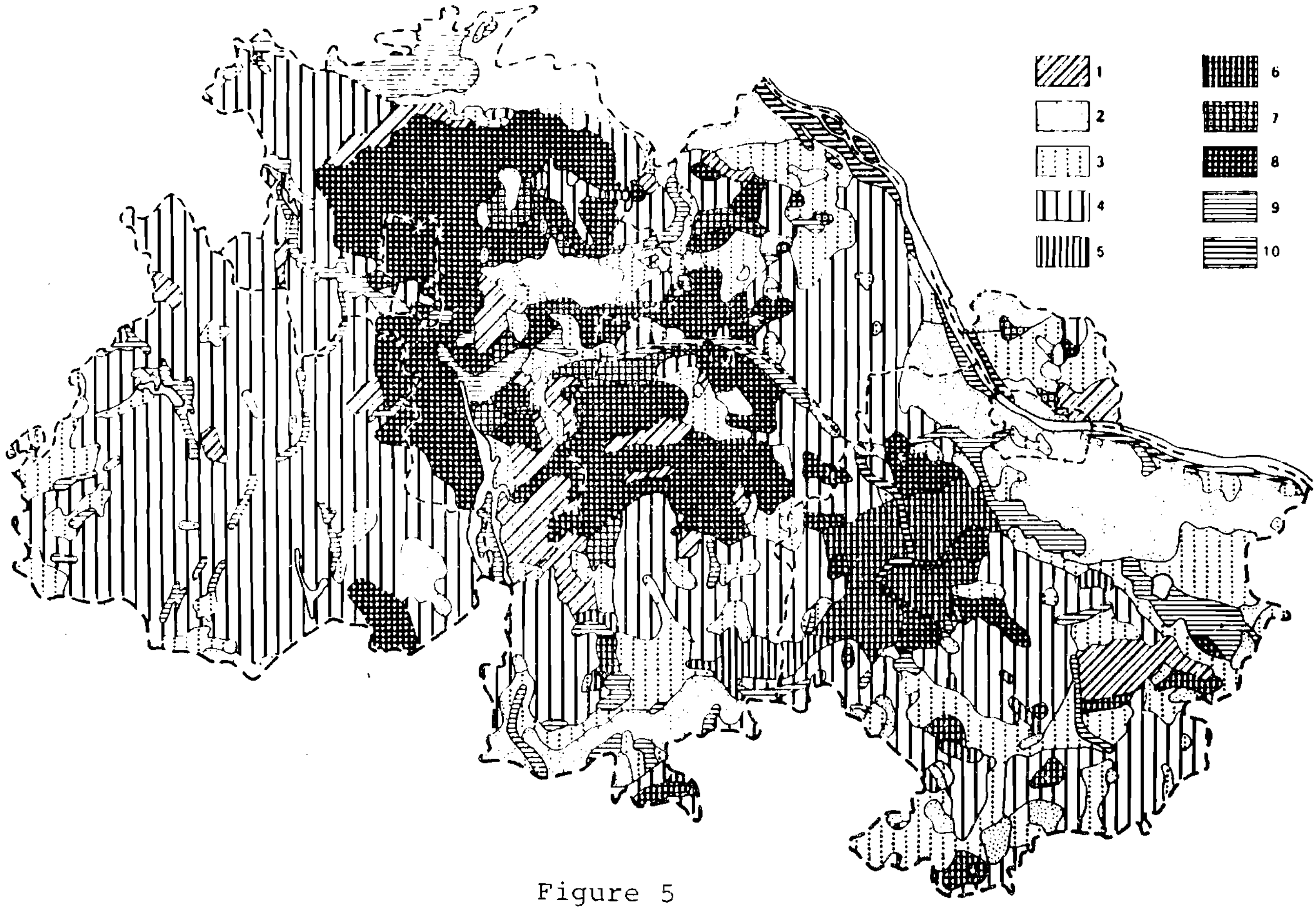

Figure 5

Cuiavia. Soils

After W. Tyszkiewicz /38, p. 400/ based on IUNG

Broen forest soils developed from boulder clay and from sands on clay or on loam: 1- light, medium or heavy soils as well as developed from silts deposited by water. Podzolic soils developed from sands: 2- loose, 3- with clay content and clayey, complex with clay content and clayey soils. Soils developed from boulder clay and from sands on clay and on loam: 4- light and medium, 5- heavy, 6- developed from silts deposited by water. Black earths: 7- developed from sands /light/, 8- developed from clays and loams of various origin. Marshy soils: 9- slime-bog soils, peaty soils developed from peats of low vallej bogs, mursh soils. Alluvial soils: 10- sandy alluvial soils and river sands, light, medium and heavy alluvial soils.

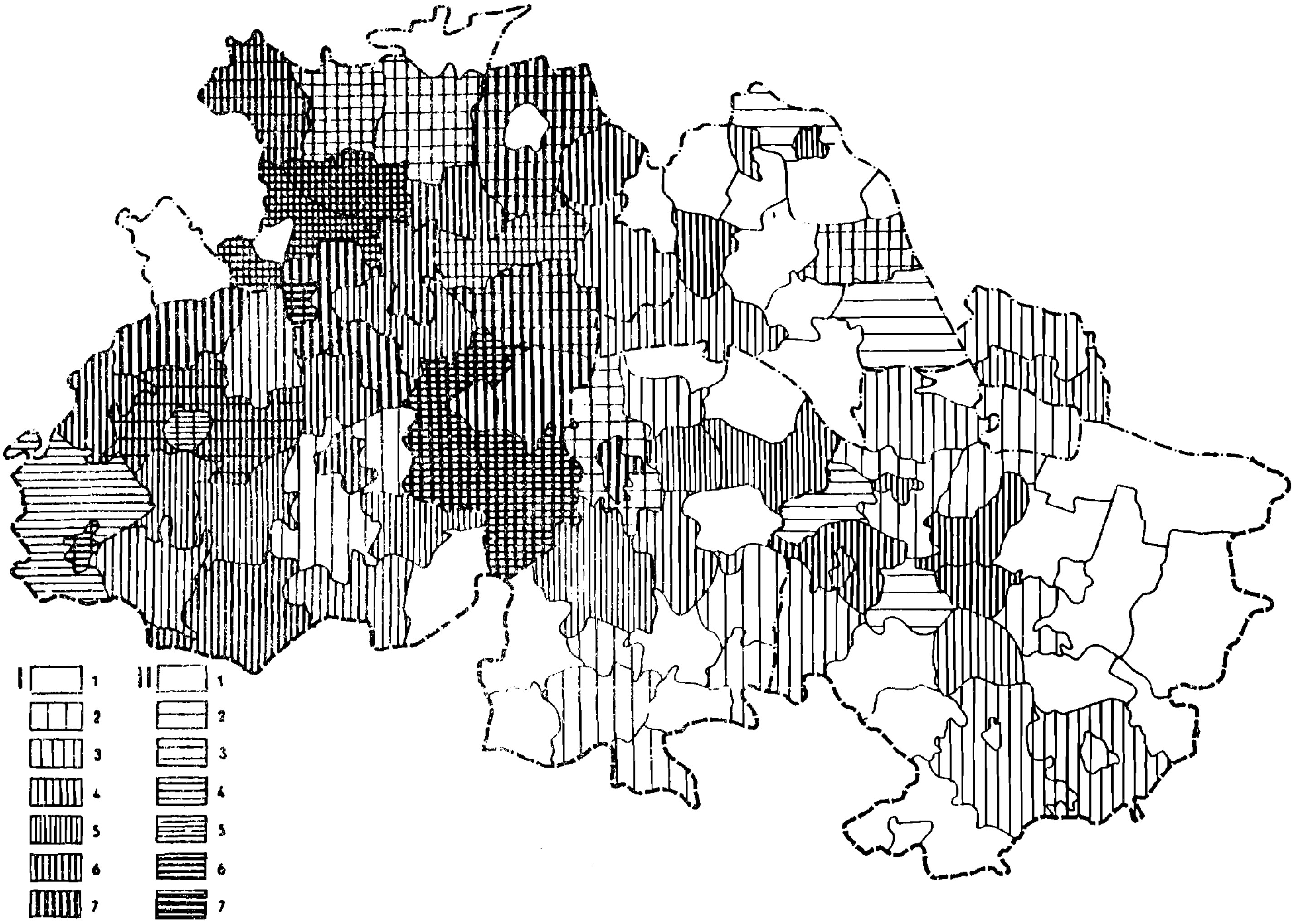

Figure 6

Cuiavia. Socialized farming

After W. Tyszkiewicz (37, p. 32)

I State farms. II Collective farms as a percentage of agricultural land 1. do not occur; 2. up to 3 per cent; 3. 3-6; 4 - 6-10; 5. 10-15; 6. 15,20; 7. 20 and over.

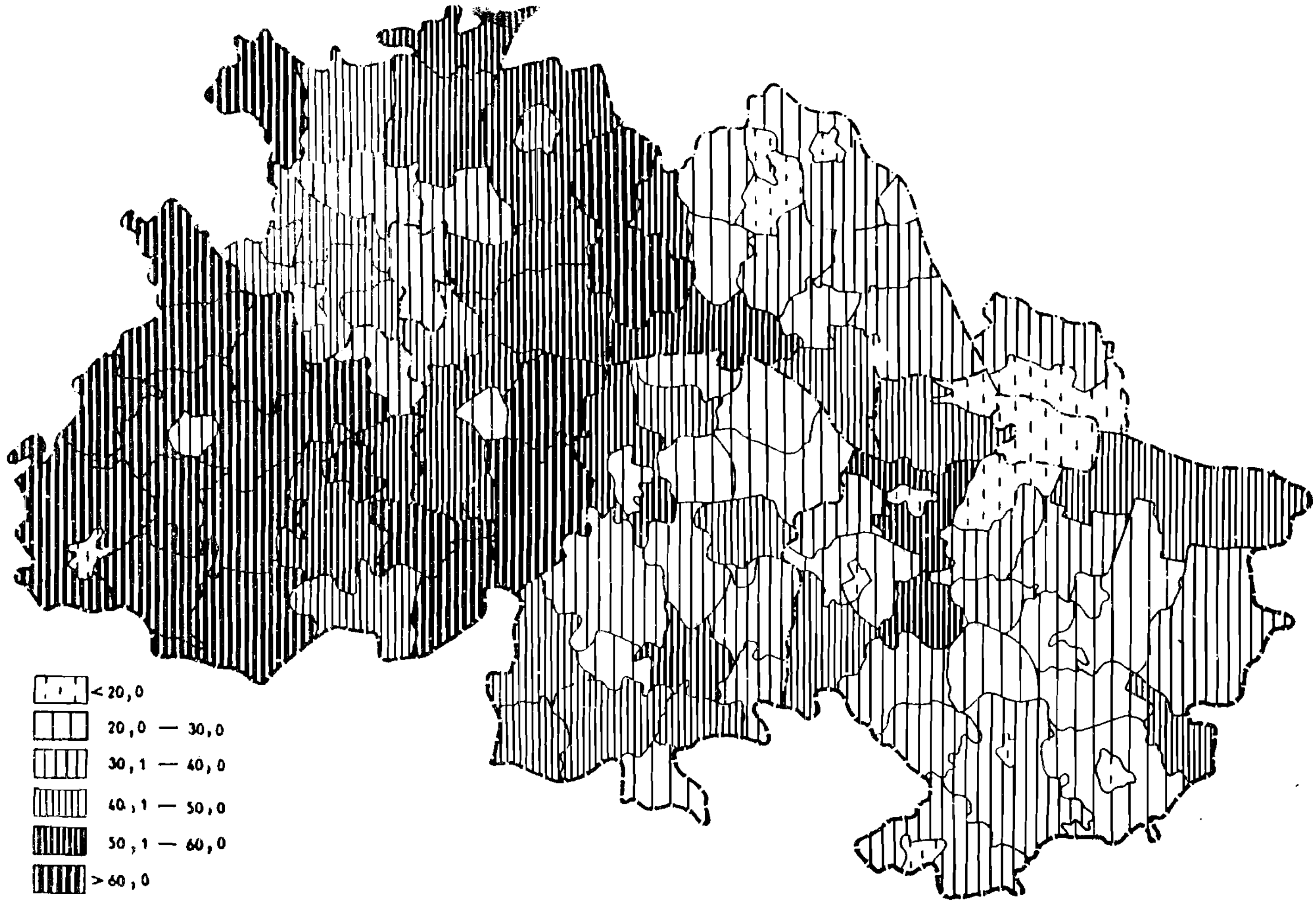

Figure 7

Cuiavia. Individual holdings

After W. Tyszkiewicz (37, p. 38)

Holdings over 10 hectares as a percentage of land under individual farming.

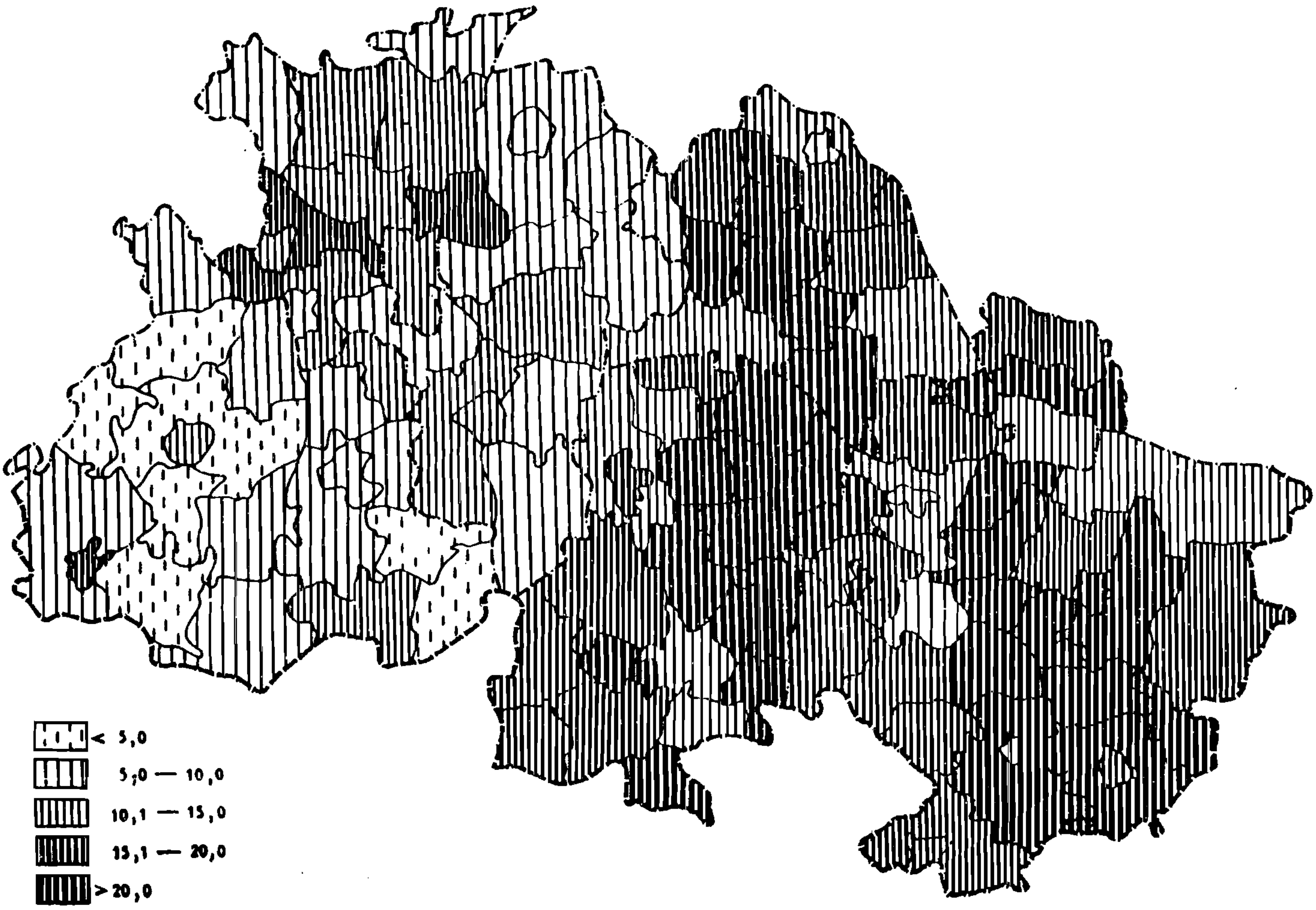

Figure 8

Cuiavia. Individual holdings

After W. Tyszkiewicz (37, p. 37)

Holdings between 5-7 hectares as a percentage of land under individual farming.

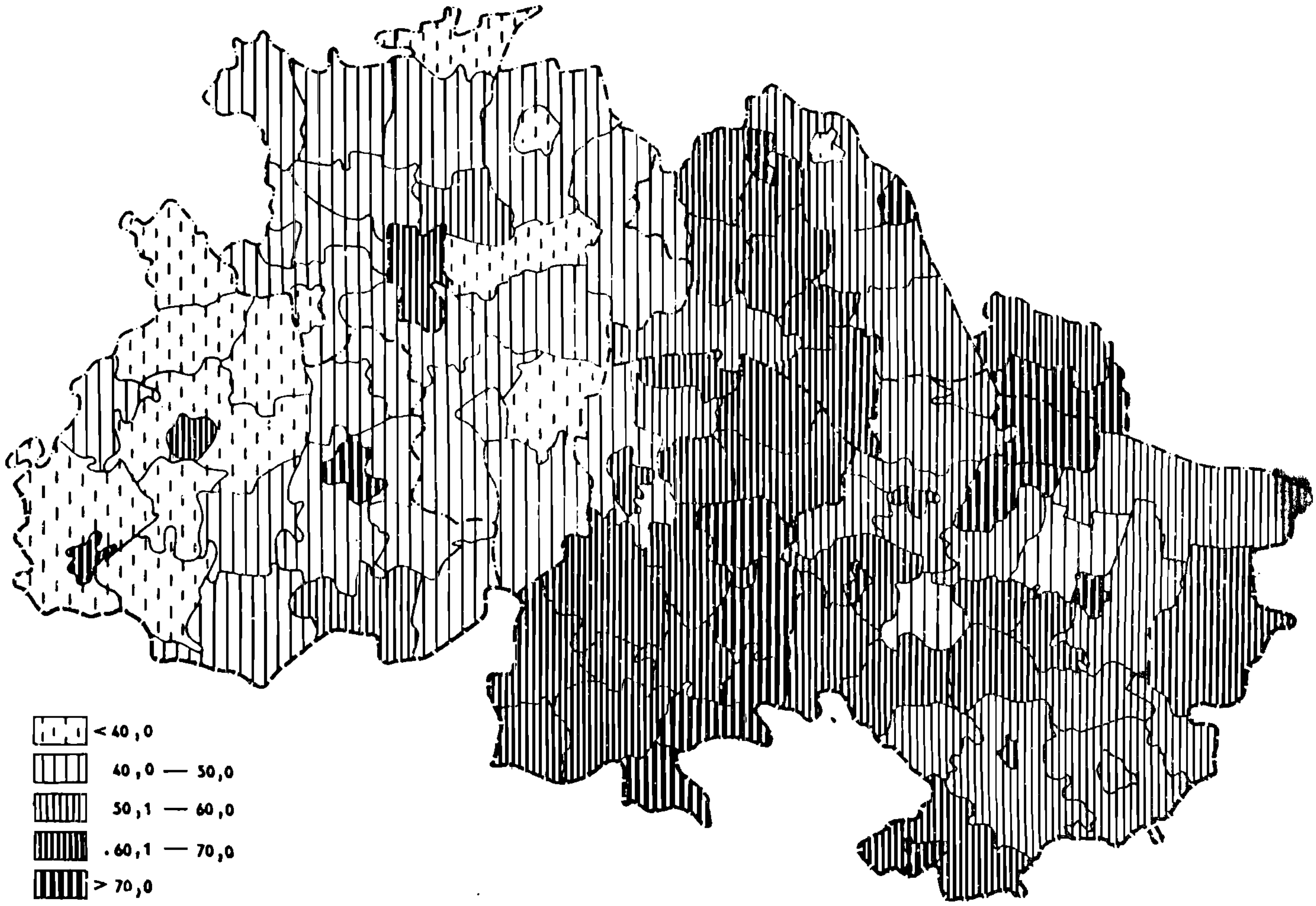

Figure 9

Cuiavia. Agricultural population

After W. Tyszkiewicz (37, p. 44)

Density of agricultural population per 100 hectares of agricultural land.

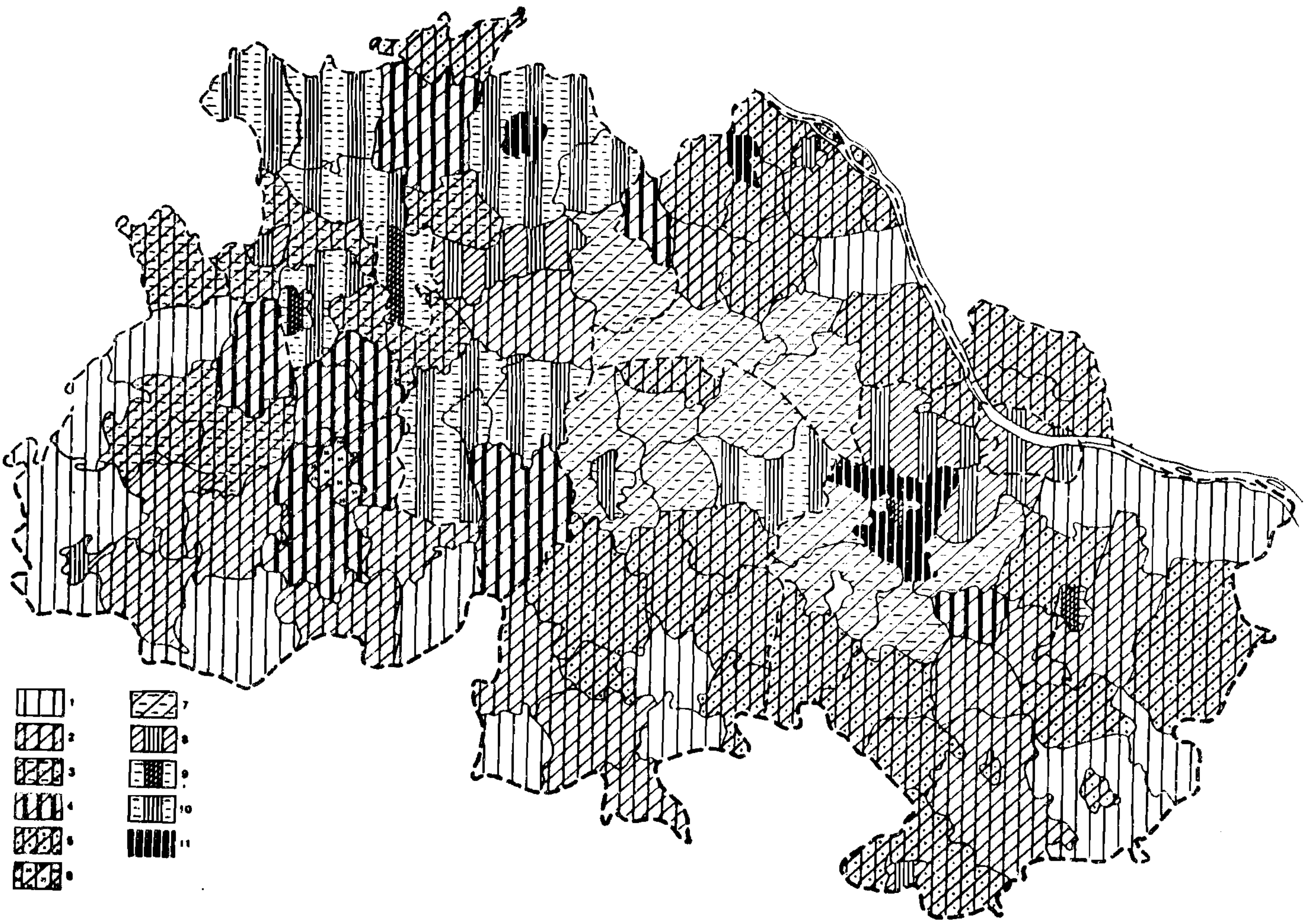

Figure 10

Cuiavia. Crop combinations in individual farming

After W. Tyszkiewicz (38, p. 412)

1 - rye with potatoes and fodder crops, 2 - rye with potatoes, 3 - rye-barley with potatoes, 4 - rye with potatoes and sugar beet, 5 - rye with potatoes and a share of clover or clover and seradella, 6 - rye with potatoes and sugar beet and a share of clover, 7 - barley with potatoes and a share of clover, 8 - rye-potato, 9 - rye-barley-potato, 10 - rye-barley or rye-wheat-potato-sugar beet, 11 - potato with rye and barley and a share of fodder crops (lucerne, clover or serradella).

Figure 11

Cuiavia. Concentrations of correlations between soil conditions, size of individual holdings and crop combinations. After W. Tyszkiewicz (37, p.103)

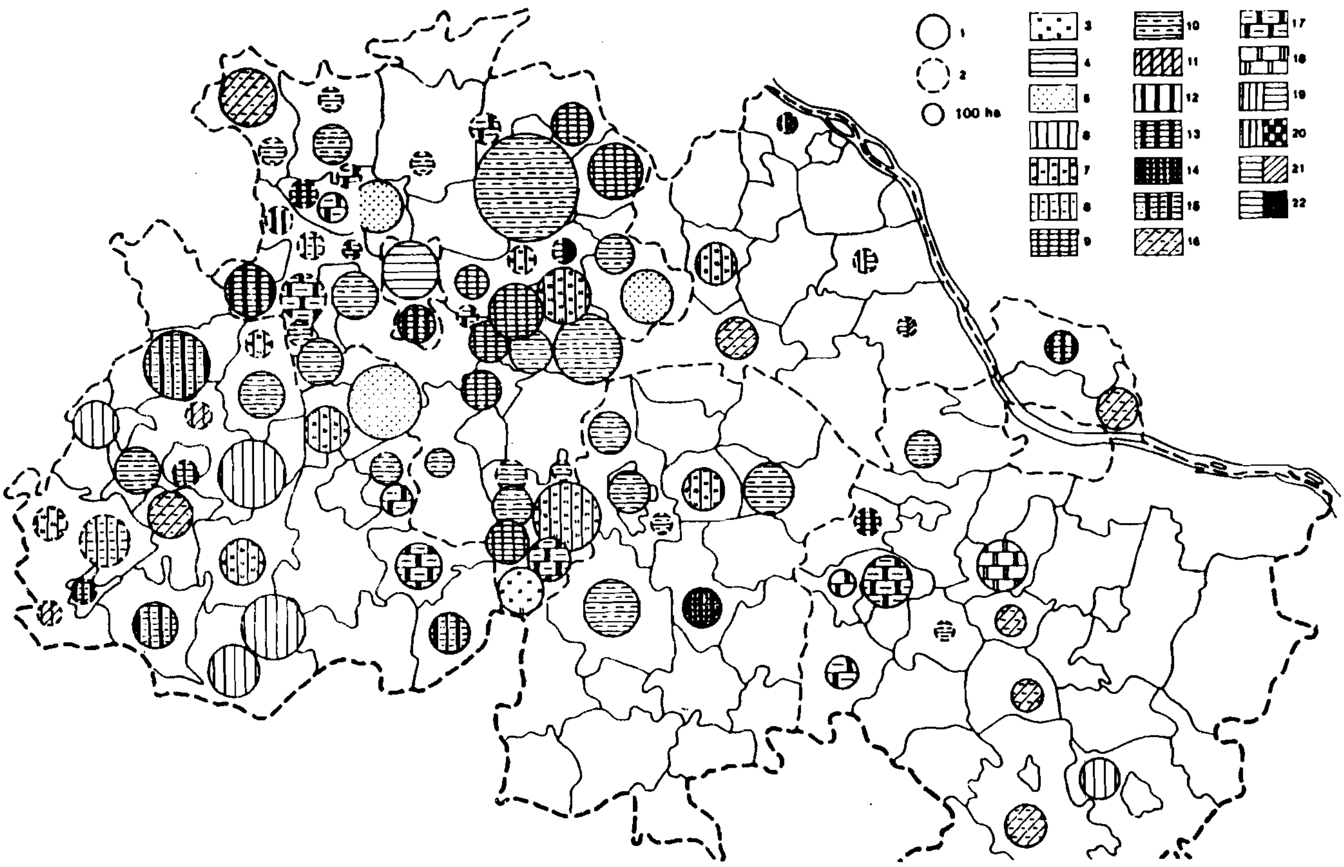

Figure 12

Cuiavia. Crop combinations in socialized farming.

After W. Tyszkiewicz (38, p. 413).

1 - state farm, 2 - collective farm, 3 - clover with wheat and barley, 4 - wheat with a share of clover and mixed fodder crops, 5 - lucerne with wheat and barley and a share of sugar beet, 6 - rye with fodder crops and a share of potatoes, 7 - rye with clover and lucerne and a share of sugar beet and potatoes, 8 - rye-barley with mixed fodder crops and a share of sugar beet and potatoes, 9 - wheat-rye with clover and lucerne and a share of sugar beet and maize, 10 - wheat-barley or wheat with clover and lucerne and a share sugar beet and potatoes, 11 - rye with a share of potatoes and field pea, 12 - barley-rye with a share of sugar beet and field pea, 13 - wheat-barley-sugar beet-rape seed fodder, 14 - oats-wheat-sugar beet-potato-clover, 15 - rye with potatoes and sugar beet and with fodder crops, 16 - barley-rye or wheat-rye with potatoes or potatoes and sugar beet and a share of clover or lucerne, 17 - wheat-barley or wheat with sugar beet and potatoes and a share of clover, 18 - wheat with sugar beet and maize, 19 - rye-wheat-potato-sugar beet, 20 - rye-wheat-sugar beet-vegetable, 21 - wheat-potato, 22 - wheat-flax.

Figure 13

Cuiavia. Livestock breeding

After W. Tyszkiewicz (38, p. 410)

Density of total animal population in large animal units per 100 hectares of agricultural land.

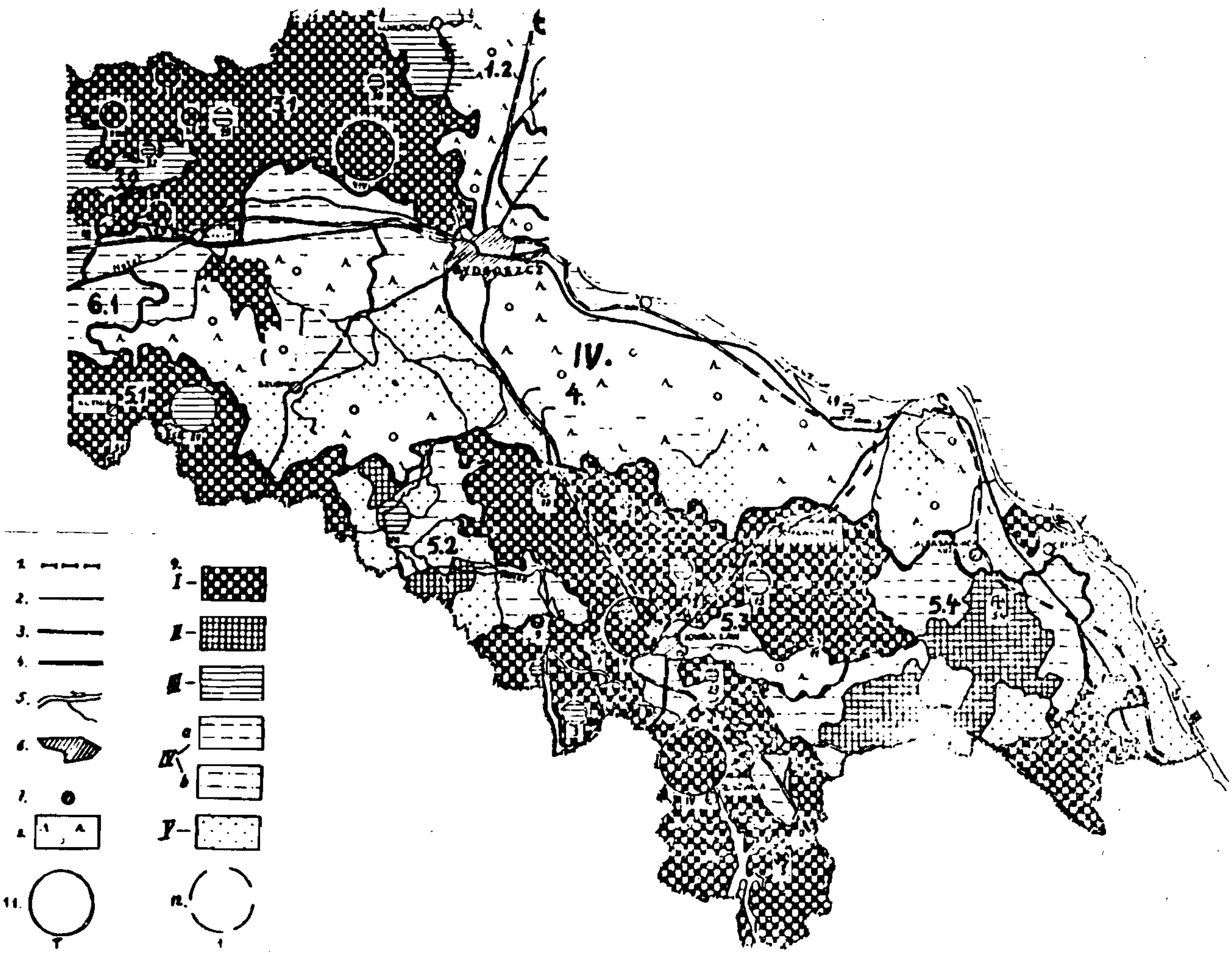

Figure 14

Bydgoszcz and Toruń Agglomeration. Agricultural types and regions.

After J. Falkowski (9)

1 - the boundary of the agglomeration, 2 - division lines between the seperate types of agriculture, 3 - roads, 4 - rail-way lines, 5 - rivers, 6 - the areas of the built-up area in Bydgoszcz, Inowrocław and Toruń, and other towns, 7 - forests, 8 - state farms, 9 - collective farms.

Explanations see the text.

PROBLEMS of WATER RESOURCES in the UPPER NOTEC AGRICULTURAL REGION

Cz. Somorowski
Director, Institute of Agricultural Hydrology and Grassland Economy

1. Introduction

The pilot-prototype system unifying water resources and more general economic aspects of an agricultural region will be located in the Upper Noteć river watershed, where by Upper Noteć this portion of the river is understood which begins with sources and ends with the Bydgoszcz Channel. The area of the watershed thus understood is approximately 4000 sq km. This area has been increased up to about 6000 sq km by inclusion of most of these administrative units which are partly covered by the watershed.

Administratively the region belongs to three voivodships: Bydgoszcz /68% of the area/, Konin /20%/ and Włocławek /12%/. Main types of land use are: arable land /74%/, including grasslands /9%/, forests /16%/, inland waters /3%/ and others - settlements, roads etc. /8%/.

Main agglomerations in the region are Inowrocław, Żnin, Mogilno, Nakło, Szubin, Barcin, Kruszwica, Strzelno, Trzemeszno and Janikowo /see Map 2 in the Introduction/, but they do not constitute any essential factor in shaping of the regional profile. Chemical, construction materials, machine and food processing are the leading industries of the region. These industries are centred in Inowrocław, Janikowo, Kruszwica, Barcin, Nakło and Trzemeszno.

The general objective in implementation of the pilot water-resource-and-economic system is to create within the framework of natural and socio-economic conditions adequate possibilities for integrated development of the region, and especially of the regional agriculture.

The area to be covered by the pilot system is characterized by:

- relatively high water needs in crop production, resulting from meagre precipitation,
- relatively high level of agricultural knowledge and cultivation techniques,
- important possibilities of providing disposable resources within the same watershed by storage of water.

The water resource factor, considered from the viewpoint of comprehensive satisfaction of needs and demands expressed by various users will therefore play an essential role in the planned system's development.

2. Location, morphology, soils

The Upper Noteć watershed is located in eastern part of the Greater Poland - Cuiavian Lowland, comprising partly such subregions of the Lowland as Gniezno and Cuiavia Lake districts. Geomorphologically the watershed territory lies within the area of end-moraine hills formed in the last glaciation stage /the southern border/ and the lowlands of ground moraines /rolling on the west and flat on the east/.

The landscape of the watershed, shaped by consecutive glaciation stages has as its characteristic feature numerous, especially gully- or finger-form lakes, of the north-south orientation resulting from directions of the glacier's movement and of the subsequent water outflow. These lakes form typical chain-like groupings /Gopło lake cluster, Pakość cluster, Żnin cluster etc./.

Water divide between rivers Warta and Noteć is not very distinctly defined in this area, there are several cuts in it and in one of these cuts the Warta-Gopło channel is located.

Under the post-glaciation sediments /not very deeply - 50 m or sporadically deeper/ there is the older base formed of so called

Poznań loams, being the lake sediments of the pliocene period.

From the north-west to the south-east of the watershed the Cuiavian-Pomeranian ridge stretches which, however, does not come up on the surface. This anticlinorian ridge is formed of cretaceous, jurassic and even triassic and permian rocks. It has an economic importance because of presence of extractible permian salts. The salts have been pushed upwards to form gigantic columns/diapirs/ covered with gypsum. The latter constitutes also an object of mining activities.

The Greater Poland-Cuiavian lowland is the region of the oldest in Poland tradition of rational agricultural economy. Areas of good soils located higher, to a large extent drained, and the small portion of worse soils create advantageous conditions for development of agricultural production. Valley areas, located lower, were subject to intensive drainage activities which made arable additional land, but also influenad the hydrological relations. This especially concerns works connected with creation of the Bydgoszcz Channel and drainage activities around the Gopło lake.

More detailed data on soils of the Upper Noteć region are presented in the table below:

Agricultural soil value categories	Type of soil categories	Main soils	% in total of arable land
1,2	D, AB, B	light clays	25
3,4,5	AB	clayey sands and sandy clays	41
6,7	AB, A	weakly-clayey sands, loose sands	27
8,9,10	F	variably granulated	7

Pseudo-podzolic and brown forest soils /AB/ occupy approx. 74% of the surface, brown soils /B/ - 1%, black earths /D/ - 18% and finally alluvial soils and others - approx. 7%.

The average index of soil quality for arable land in the region is 1.79.

More detailed structure of land use in the region is presented in the table below :

No.	Type of use	Area	
		hectares	%
I.	Agricultural use	455 600	73,5
I1.	Arable land	393 072	63,5
I2.	Orchards	6 351	1,0
I3.	Meadows	37 857	6,1
I4.	Pastures	18 140	2,9
II.	Forests	97 644	15,8
III.	Waters	16 709	2,7
IV.	Other	49 494	8,0
	Total	619 447	100,0

3. Climatic conditions

Precipitation, defining the input side of hydrological balance, is the highly discriminating characteristic for the region in relation to the whole of Poland. Annual and seasonal /summer-winter/ precipitation volumes are the lowest here, the annual sum is below 500 mm, and for the period 1951-1975 the hydrological station in Pakość has established the level of only 414 mm. Precipitation in the region is also the lowest when compared to neighbouring areas of the Great European Lowland. Characteristically the summer precipitation constitutes an important portion of the annual precipitation volume /about 0,65/. Consequently, there is a clear deficit of water in growing season. This results not only from higher evaporation of water during summer when more precipitation occurs and from meagre amounts of water left by winter snows by and large insufficient for summer period needs, but also from the temporal precipitation distribution - only 150 days with precipitation over 0.1 mm. These observations gave rise to hypotheses of "steppization" of the area considered, which, however, have eventually not found conclusive positive evidence. It should be emphasized that simultaneously with its low level the precipitation of the region is characterized by its great variability on per annum basis - from 65% to 130% of the average for extremal cases. In conjunction with other conditions /temperature, soils etc./ this leads to instability of hydrological balance, so that not only atmospheric and soil droughts occur, but also, sporadically a surplus of water may temporarily exist in the system.

The average annual air temperature in the region is slightly below 8 degrees centigrade. The amplitude of monthly averages in Inowrocław has for 1951-1975 period been 20.8 degrees centigrade and the absolute maximum amplitude for Bydgoszcz was 67.8 degrees.

Average annual air moisture deficiency for Inowrocław is 3.3 hPa and for growing season /April - September/ - 5.3 hPa.

Precipitation and temperature conditions shape the evaporation capacity of the atmosphere which, characterized by e.g. notion of potential evaporation can serve to define the irrigation needs. According to classification actually in force the Upper Noteć region belongs to the 1st range of areas with irrigation needs.

4. Hydrological conditions

The basic streams in the water system of Upper Noteć river are Eastern Noteć, Western Noteć and Gąsawka /see Map 2 in the

Introduction/. All these streams flow out of lakes in the south of the region towards north and then connect also a number of subsequent lakes. Eastern Noteć in its upper stream within the area of Gopło Lakes gully joins the Warta-Gopło channel. Below Kruszwica the Bachorze channel joins Gopło lake, constituting probably an outflow for some portion of Gopło waters to Vistula. In the vicinity of Pakość Eastern Noteć joins Western Noteć and at this point the watershed covers 2187 sq. km. Further on below Łabiszyn the Upper-noteć channel begins which then goes along the Vistula-Odra water divide and supplies with water the highest point of Bydgoszcz Channel. An important confluent further downstream is Gąsawka with 552 sq. kms of watershed. Noteć enters then the Toruń-Eberswalde valley /"pradolina"/ and joins the Bydgoszcz Channel. This channel, connecting Vistula with Odra, has been constructed in 1772-1774 and after a reconstruction in 1905-1915 constitutes a waterway for barges up to 500 tons.

In the Upper Noteć water system the lakes are the second important landscape and economic element. Altogether 253 lakes /of surface above 1 hectare/ are located in the region covering the overall surface of 115 sq km, i.e. approx. 3.2% of the watershed. Density of lakes is relatively high, with lakes above 1 sq. km summing up to more than 70% of their overall surface. The lakes are exclusively of post-glaciation origin and for the most part are gully or finger-form. This creates advantageous conditions for damming them up for surface water retention.

Specific low precipitation of the region shapes unit runoffs of medium waters at the level of about 2 litres /sec.•sq.km, and of medium-low waters at the level of about 0.2 litres /sec.•sq.km. With the runoff-to-precipitation rate $\alpha = 0.13$ these runoffs are the lowest observed for the broader geographical region to which the Upper Noteć watershed belongs. Independantly of the fact that there are small amounts of water in the streams their disposability is also constrained by pollution of rivers, channels and lakes -

mainly of industrial origin.

Ground waters, because of specific geological conditions, occur on varions depths. Within the quaternary formations there are certain reservoirs of medium volume in the Izbica trough and in Cuiavian Lowland, which can be utilized as potable and for industrial purposes after initial processing. Locally in the vicinities of Inowrocław and Szubin in the quaternary formations saline waters can be found.

5. Drainage and irrigation installations

The Noteć watershed region has for a long time been subject to activities aiming at improvement of water conditions. Some early works were oriented at ensuring appropriate navigation conditions and they led to lowering of the Gopło lake level and to reshapements in the Noteć valley after its canalization and after construction of the Bydgoszcz Channel. Besides that, beginning with late XVIIIth century drainage activities were conducted in marshy areas ultimately resulting in important additions to arable land on the one hand, and in changes of the soil conditions observable up till now, on the other hand. Simultaneously, beginning with the middle of XIXth century, especially in areas under Prussian administration, large portions of already arable land were subject to drainage. From about the same period dates the Łabiszyn-Noteć Water Association, local organizational form grouping users of the drained fields.

One of the goals in the design of the pilot system is creation of the water-melioration subsystem ensuring optimal shaping of hydrological conditions in drained or irrigated areas, and centralized control of water resources - both in their quantity and quality - so that they can be optimally utilized by all users /agriculture-and-food-processing sector, industry, urban and rural services, navigation/, with due account to environmental features of the area. Optimal shaping of hydrological conditions in areas considered would consist in successive removal of water surplus or deficit barriers to deployment of production capacities:

- countermeasures for periodical or constant water surpluses in the soil,
- countermeasures for periodical water deficits in drought periods.

In the first case the - drainage - activities must concern all areas in the region requiring this type of intervention. As to the second case the activities would have a limited scope, consecutively covering needs of predefined land portions and of other entities, qualified as liable to irrigation.

According to a survey of water installations on the area of the pilot system there is a need for ensuring adequate control over at last 44% of the basic water stream network of total length of 867 km. As far as the arable land drainage is concerned more than 35% of existing installations requires reconstruction and modernization, and for the grasslands the analogous number is 20%. This situation certainly increases the volume of necessary investments.

Initial estimation of needs in irrigation and drainage works /including reconstruction and modernization/ has yielded following results:

- for arable land :	approx. 1500 sq.km
including rain-type irrigation :	approx. 1200 sq.km
- for grasslands :	approx. 400 sq.km
including peat land reclamation :	approx. 150 sq.km
- erosion prevention	approx. 7 sq.km

Importantly broad irrigation program coupled with necessity of satisfying water demands of non-agricultural users sum up to requirement of providing significant water volumes, which cannot be taken out of natural streams in current situation. It has been concluded in initial assessments, taking into account ecological, technical and economic criteria, that approximately $200\text{-}250 \cdot 10^6$ cubic meters of water can be stored in artificial and lake reservoirs. Thus, for complete coverage of the water deficit of about $350 \cdot 10^6$ cubic m it is necessary to transfer additionally from Vistula or Warta about $90 \cdot 10^6$ cu m of water per annum.

It is imperative that the optimization of water resource system and its management, involving shaping of hydrological soil conditions through irrigation-drainage activities, with inclusion of large land area irrigations covering 30-40% of arable land, be coupled with adequate measures aiming at synergy of factors stimulating agricultural and more generally socio-economic development in the region.

MIGRATIONS IN THE UPPER NOTEC BASIN

Kazimierz Dziewonski
and
Piotr Korcelli

INTRODUCTION

The paper deals with population structure and migrations in the Upper Notec Basin. Purposely, it avoids the use of the term "region". Although historically the area formed a separate region--some consider it to be the cradle of the whole Polish State--practically all major urban centers which developed later (from the 14th century onward) are located either on its periphery or completely outside. The only exception is Inowroclaw, an industrial city (in 1977 of 62.3 thousand inhabitants), smaller than the neighboring Bydgoszcz (339.2), Torun (164.1) and Wloclawek (95.0) which in addition are all seats of regional governments (Voivodships). In the South the adjacent cities are smaller: Konin (60.2) and Gniezno (59.2). The nearest largest cities such as Lodz (818.4), Poznan (534.4) and the three cities of the Gdansk Bay (with combined population of 738.1) are too distant to have a greater impact on the population structure and migrations in the area. However, some influence of Poznan may be discerned in the most southerly communes, due to the vicinity of the main transportation lines connecting Poznan with Warsaw. As a result, if the concept of daily urban systems is taken as the basis of present day regionalization, the whole area may be divided between several such systems with a large part of these located outside the area.

From 1815 (Congress of Vienna) till 1918, the area was cut into two parts between Prussia and the Tzarist Russia. This division has left some, still existing, differences mainly in the technical equipment and services, but also in the field of regional and local economies, as well as in social habits and behavior. The survival of this division till the present may be explained at least partly by the fact that devastations of the two world wars in the area have not been very great when compared to other regions.

The latest changes in structures are connected with the growth in dominance of Bydgoszcz in the North, and of a new industrial and administrative center of Konin in the South.

On the whole, the area is characterized by intensive (for Polish conditions) agriculture, fairly strong industrialization and, when considered together with the adjacent cities, a balanced but advanced urbanization.

POPULATION STRUCTURES

Table 1 presents basic population data for the area in comparison to Polish averages and the data for three Voivodships in which the Upper Notec Basin is included.

All these data are a little higher than the national averages which may be explained by the fact that the whole area is well developed both in agriculture and in industry but at the same time it is located far from the most industrialized core of the country and fairly far from large urban agglomerations, Bydgoszcz being the only exception. Neither does it possess large population surpluses nor is it underpopulated. The net outflow of migrants is so far within the limits of its not very high manpower reserves and it is only slightly higher than the size of natural increase in the rural areas. It is significant that the net result of the rural to rural movements is almost nil but at the same time the figure for the rural to urban movements is a little higher than the annual natural increase of rural population.

The Voivodship of Bydgoszcz (to which the major part of the area belongs) is characterized by high general mobility of population, although the net result at the interregional level is low. It is comparatively closed so far as migrations are concerned. Its outflow from rural areas is comparatively high, its influx into urban areas also high, although lower in intensity than the outflow from rural areas.

Table 1. Basic Population Characteristics - 1974

	Number of Inhabitants	Births		Deaths		Natural Increase		Net Migrations	
		persons	°/oo	persons	°/oo	persons	°/oo	persons	°/oo
Total Population									
Poland	33,691,008	621,080	18.4	227,085	8.2	343,995	10.2	-10,991	- 0.3
Voivodship of Bydgoszcz	997,093	18,356	18.8	7,936	8.1	10,420	10.7	+ 450	+ 0.4
of Wloclawek	402,046	8,187	20.4	3,554	8.9	4,633	11.5	-2,387	- 6.0
of Konin	423,714	8,681	20.6	3,718	8.8	4,963	11.8	-1,491	- 3.5
Upper Notec Basin	477,090	8,830	18.5	3,653	7.7	5,177	10.9	-2,853	- 6.0
Urban Population									
Poland	18,605,514	301,639	18.4	142,428	7.7	159,211	8.7	+175,014	+ 9.4
Voivodship of Bydgoszcz	576,365	9,380	16.4	4,606	8.1	4,774	8.3	+ 5,165	+ 9.0
of Wloclawek	152,641	2,704	17.9	1,357	9.0	1,347	8.9	+ 1,393	+ 9.0
of Konin	131,097	2,172	16.8	828	6.4	1,344	10.4	+ 2,557	+19.7
Upper Notec Basin	148,548	2,512	16.9	1,329	8.9	1,183	8.0	+ 1,289	+ 8.7
Rural Population									
Poland	15,239,915	319,441	20.9	134,657	8.8	184,784	12.1	-185,505	-12.2
Voivodship of Bydgoszcz	406,005	8,976	22.9	3,330	8.8	5,646	14.1	- 4,715	-11.6
of Wloclawek	249,405	5,483	22.1	2,197	9.7	3,286	12.4	- 3,780	-15.1
of Konin	292,617	6,509	22.2	2,890	9.9	3,619	12.3	- 4,048	-13.8
Upper Notec Basin	328,540	6,318	19.2	2,324	7.1	3,994	12.1	- 4,142	-12.6

MIGRATION FLOWS*

The Upper Notec Basin has been characterized over the past years by a negative migration balance which may be attributed to its predominantly rural structure. The size of net outmigration, however, has been small amounting to approximately 0.5% of total population per year, as compared to the natural increase of 1.1%. For example, in 1974 of the total of 19,150 moves, 8,055 were to destinations outside the Basin, 5,202 originated at places located outside the area, while the remainder, i.e. 5,893 moves were contained within the area. When these figures are decomposed into their rural and urban components, it turns out that urban places within the Basin experienced a net loss of 789 migrants with respect to urban places located outside the Basin, and that the corresponding figure for rural areas was a negligible net gain of 13 persons. When accounting for rural-urban and urban-rural flows, however, urban places within the Basin show a net gain of 1,289 migrants, and the rural areas a loss of 4,142 migrants. In fact all the rural communes, as well as one third of urban places within the area have experienced net migration loss (but not a great loss in the number of inhabitants) over the past several years.

The above figures indicate a relatively low closure of the Upper Notec Basin in terms of migration flows, the share of intra-Basin moves among all moves, amounting to 0.31. (Even for rural areas, this proportion was not much above 0.5). In view of the prevalence of short- and intermediate-distance moves for the country as a whole, such proportions might seem very low indeed, unless it is recognized that large parts of the Basin are contained within migration fields of the cities of Bydgoszcz and Torun, and to a lesser extent, within the fields of of more distant provincial capitals, in particular of Poznan and Gdansk. Also, on a local scale, the southeastern, southern and southwestern sections of the Basin lie within migration fields of Wloclawek, Konin and Gniezno, which are middle-size cities situated just across the Basin's boundary. The only focal point for migration, of comparable size, within the Basin

* This section is based on a paper by A. Zurkowa: The Pattern of Migrations in the Upper Notec Basin, 1974-1976, to be published in Czasopismo Geograficzne.

is the city of Inowroclaw, which itself sends a substantial number of migrants to both Bydgoszcx and Torun. Another feature of intra-Basin flows is that small urban places receive the bulk of their in-migrants from the immediate hinterland with an exception of specialized industrial centers whose contacts are less adversely influenced by distance.

A more detailed picture of migration flows is revealed by disaggregating all moves into four conventional categories, i.e. rural-urban, urban-rural, urban-urban, and rural-rural. Their corresponding shares in 1974 were: 41, 17, 7, and 35% respectively. In the first group, two-fifths of all destinations were contained within the Basin, but if moves to urban places of the surrounding Voivodships are added, this percentage increases to over 80. Most of what remains is accounted for by more distant destinations, such as the urban agglomerations of Gdansk and Szczecin, as well as the Upper Silesian Conurbation, whose migration field is nation-wide.

Out of the total of 34,146 possible links between urban places located within the Basin (21 units) and all other urban places in the country (the total of 814 units) there were 1,005 actual migration flows in 1974, but nearly 90% of those involved five persons or less. Out of the remaining flows 26 were contained within the Basin (most of them focussed on the city of Inowroclaw), while 82 went to urban centers external to the Upper Notec Basin, in particular to Bydgoszcz. It may be noted that cities of 40,000 population and over, received over 95% of major migration streams.

Rural-to-rural migration, both within the Basin, and across its boundaries, are generally of a short-distance range. They do not seem to focus on particular areas (even such as outer zones of the cities of Bydgoszcz and Torun) but show a roughly uniform intensity over space. Urban-to-rural flows, while negligible in numbers, also take place over short distance. Over 60% of these moves were contained within the Basin. It has been hypothesized that a substantial part of such flows represent return migrations.

In general, the anatomy of migration flows in the Upper Notec Basin reveals the following features:

1) Rural-to-urban moves are the major component of migration patterns, accounting for over two-fifths of all moves. This is consistent with the predominantly rural character of the study area and its location within the hinterlands of several large and middle-size cities.
2) If urban places are divided into small, medium-size and large, it is found that rural-urban migrations are evenly distributed over these three size categories. Small towns within the Basin are destinations for flows originating mostly in the surrounding rural communes, but their absorbing capacity seems to be limited to streams representing, on an annual basis, up to 0.5% of a commune's population. The respective migration fields of bigger urban places are considerably larger, but still relatively compact.
3) Urban-to-urban migrations, as compared to the previous category, are more elastic with respect to distance. Their patterns basically follow urban-size structure and the administrative hierarchy. However, individual flows may bypass certain hierarchical levels; (for example, the small town of Mogilno sends most of its migrants directly to Bydgoszcz, rather than to nearby Inowroclaw, which in turn generates flows to the more distant metropolises of Gdansk and Poznan). Also, migration fields of middle-size urban centers do not tend to be wholly nested within the respective fields of large cities. Specialized industrial centers have specific migration patterns, as they attract labor from larger zones when compared to other urban places of comparable size. These centers also maintain linkages with other industrial towns in the same sector.

The spatial pattern of migratory movements in the area does not differ significantly from patterns prevailing in other parts of the country. Rural population moves over to small, middle-sized and large cities. In scale, these migrations may be defined as local, regional and macroregional migrations.

The latter cannot be defined as national because distance plays the decisive role in all of them. Local migrations take place within the radii of some 10 kilometers, the regional ones up to 30 and 50 kilometers, and macroregional migrations only rarely are over distances greater than some 100 or 120 kilometers. Small and middle-sized cities pass off their populace to the large ones and these migrations are of either regional macroregional scale. However, in migrations between large cities, distance plays a smaller role than the power of their attraction. Perhaps in countries larger than Poland, distances may still be important--in Poland such influence in the case of the largest cities (so far as urban-to-urban migrations are concerned) may be omitted. In addition there are some movements (exchange of population) between specific smaller cities and localities with others of similar industrial specialization.

COMMUTING PATTERNS AND THEIR RELATION TO MIGRATIONS

Studies on journey-to-work patterns for Poland as a whole indicate that the Upper Notec Basin is contained within the functional urban regions (or daily urban systems) of Bydgoszcz, Torun, and Inowroclaw. A detailed analysis of commuting, based on the employment census for 1973 reveals a more complicated pattern of spatial contacts. First, in addition to the centers mentioned above, there are several smaller urban places which attract considerable numbers of commuters from surrounding, as well as more distant, areas. These towns form their own commuting sheds which even extend beyond the Basin's boundary. Second, the southern, peripheral areas send most of their commuting labor force to the cities of Wloclawek, Kolo, Konin and Gniezno, situated outside of the study area, as well as--on a smaller scale--to the more distant city of Poznan. Third, spatial relations between commuting zones of individual centers are of the following nature:

a) the form of commuting sheds of individual urban places tends to be non-symmetrical, extending further in the direction away from bigger urban centers;

b) commuting zones of small and medium-size urban places, located within the distance range of up to 50-60 kilometers from a large city (i.e. of 100,000 population and over) are nested within its commuting shed. Thus, one notices extensive, and mostly uni-directional journey-to-work from a smaller to a larger city (for example, the city of Inowroclaw sends more than 500 commuters to Bydgoszcz and over 200 commuters to Torun, while receiving negligible flows from those centers);

c) a major part of the work trips to smaller centers originate within a belt of rural communes contiguous to these centers. Trips originating in a small town tend to bypass an intervening middle-size center while aiming at places of employment in a large city; and

c) there is relatively little overlap between commuting sheds of urban places of comparable size.

This latter aspect of commuting patterns has been studied extensively by J. Namyslowski for the Bydgoszcz-Torun area. According to his findings, the size of core-to-core flows, i.e. between the two cities situated some 40 kilometers apart, amounted in 1973 just over 2% of all trips to work within the area which involved the crossing of a commune or a city boundary and were hence classified as commuting. In addition, both Bydgoszcz and Torun have developed largely self-contained and territorially exclusive commuting sheds, each extending away from the other urban center. Their channels of integration, which are undoubtedly going to increase in importance in the near future, pass so far mainly through a limited number of smaller cities (in particular those of Inowroclaw and Solec), which are roughly equidistant to Bydgoszcz and Torun and send a sizeable number of commuters to each of these cities.

Some hypotheses have been proposed, and empirical studies carried out (notably by A. Gawryszewski) concerning the interrelationships between migration and commuting patterns in Poland. The existing evidence suggests that there is a high degree of correspondence between the two types of movement over space. Pearson's correlation coefficients for three different measures of migration and commuting were found significant at 0.1

confidence level for over 90% of spatial units under investigation (the study involved 108 former poviats, administrative units compared to counties). It was also found that the same functions, mostly the power, and a combined power-exponential formula, afford a good description of the shape of commuting and migration sheds, although, as expected, in the case of migration the b parameter values were significantly lower than in the case of commuting. A hypothesis behind the analysis was that because of various constraints (mainly related to the availability of housing) on the change of residence as a consequence of a move from "rural-type" to "urban-type" of occupation, the commuting, particularly over long distances, serves as a substitute to migration and tends to be followed by the change of residence once the constraints are relieved. Such a hypothesis which is supported by empirical data, apparently differs from the established rule according to which commuting serves as a substitute to migration within a short-distance range and does not generally lead to migration, which essentially involves moves over long or intermediate distances.

In the case of the Upper Notec Basin the visual comparison of migration and commuting patterns suggests the existence of a high degree of correspondence between the two types of movement. In fact, linear correlation coefficient between the size of outmigration and outcommuting among 42 spatial administrative units for 1973/1974 was a positive and significant ($r = 0.79$). On the other hand, Spearman's rank correlation turned out to be 0.56, while when calculated using rates per 1000 population, it showed a value of 0.18. This suggests that although general patterns of migration and commuting clearly correspond with each other over space, there are substantial variations between the two patterns when territorial units are disaggregated by urban-rural and by population size categories. The similar structural features between migration and commuting in the Upper Notec Basin include the following:

a) most of the flows move up the urban-size hierarchy, while flows between places (or areas) of comparable size are of smaller magnitude; and

b) urban residents travel longer distances to bigger urban places, while destinations of trips and moves originating in rural areas are more evenly distributed among small, medium-size, and large urban places (as well as rural places, in the case of migrations).

These differences may be explained by the existing variations in skills, accessibility to information, characteristics of the transportation network, and the sequence of migration stages.

PROBLEMS OF FUTURE CHANGES AND PLANNING

On the basis of the preceding analysis it is possible to state that the population dynamics in the whole Basin are on the whole well balanced. This is due, there is no doubt, to the high intensity of agricultural economy and to the satisfactory development of industries and urbanization in general. The question arises whether this kind of population equilibrium shall be sustained in the future. The answer lies in the role which is to be played by two factors: i) the future role and size of the largest adjacent cities and ii) further growth in the intensity of agricultural production.

There is no doubt, and the National Plan of the Physical Development till 1990 provides, that the city of Bydgoszcz will grow further into a major urban agglomeration (8th or 9th in rank and size in Poland). Its impact on the surrounding areas may imply the growing integration with the city of Torun and of Inowroclaw. With a large programme for housing construction, its field of daily commuting may perhaps not grow in its radium, still its daily urban system will be strengthened and developed, limiting the service functions of smaller cities in the area and turning them into industrial and housing estates within the agglomeration.

An interesting point in such a development is whether its sphere of economic and social influence will grow to cover the whole Basin. The size of agglomeration will be a strong incentive but the present administrative division and the probable and planned growth of their urban capitals (Wloclawek and Konin) may run counter to such change.

A very important element in the development of spatial patterns is the role which will be assigned by planners to the city of Inowroclaw. There is no doubt that it is developing within the shadow of Bydgoszcz. Therefore its role should be defined both as an important and the main center of the Upper Notec Valley and as a significant subcenter of the Bydgoszcz agglomeration. As the cities of Bydgoszcz, Torun and Wloclawek are not dependent in their water economy on Upper Notec--in fact they may be points of water transfer from Vistula and Brda to Notec river and basin, the city of Inowroclaw is completely dependent on Notec, and it should perhaps become the center of decisions and administration of the Upper Notec water-works.

It seems realistic to assume that the further growth in the intensity of agricultural economy should not involve any greater changes in the number of rural population although it may involve serious changes in its occupational/professional structures. The technological changes may diminish the number of required agricultural workers although the further growth of food production, based on an increased consumption of water may increase the labor-consuming technologies but there is no doubt that the progress in agriculture involves a definite increase of non-agricultural employment in rural areas. Therefore, as already stated, a decrease in employment in one sector will probably be compensated by an increase in others. The assumption of stabilized population in rural areas, however, provides for further outflow (at the present rate) from rural to urban areas. On the basis of the present population structure in the Basin and its mainly rural character it may be assumed that the present rates of natural increase are not endangered and will remain at the present level.

POSSIBLE MODELLING APPROACHES

The case study of the Upper Notec Basin calls for the formulation of a comprehensive modelling framework which would take into account both intersectoral labor productivity, demographic structure, as well as interregional linkages.

Such a framework implies the integration of regional economic growth concepts with those of population change and spatial interaction. One way to build a general model is to design a number of more restricted constructs which are then linked by feedback loops. From the population and migration perspective, two such partial models seem necessary as aids to spatial development policies in the study area.

1) A population redistribution model of the type developed by A. Rogers. At the first stage, the model could use a crude spatial disaggregation into three regions, i.e. a) the Upper Notec Basin, b) the remaining parts of the Bydgoszcz, Wloclawek and Konin Voivodships, and c) the rest of the country. The input data concerning migrations, based on the assumption of the validity of the commuting-migration sequences, should be modelled separately. A few development scenarios can be tested using the following assumptions: i) rapid increase in the housing supply within large cities outside the Basin may accelerate the transition from a commuter to a migrant status, ii) transportation improvements, when accompanied by the development of tertiary functions, particularly in small urban places, would encourage the growth of outcommuting while slowing down the commuting-migration sequence; and iii) increase in the size of basic employment, both primary and secondary, within the Basin, may lead to a cutting-down of both outcommuting and outmigration.
2) A model of the spatial growth of the Bydgoszcz-Torun agglomeration. This may be designed as a spatial interaction model to enable the testing of alternative decisions with respect to size and allocation of exogenous employment, transportation improvements, housing estates and recreational zones. As noted earlier, if past trends continue within the next 15-20 years, the northern and north-central part of the Basin, including the city of Inowroclaw, may be engulfed by the expanding urbanized area which is so far external to the Basin. This would bring in turn a number of consequences with respect to population structure, as well as the patterns of agricultural development in the study area.

GENERAL METHODOLOGY AND CONSTRUCTION OF SYSTEM OF MODELS FOR THE NOTEC DEVELOPMENT PROJECT

by R. Kulikowski, IIASA

1. INTRODUCTION

The Notec development project is primarily concerned with irrigation and drainage of a large agricultural region. It requires, however, that the entire regional water resources be evaluated and the water system extended in such a way that all the users (i.e. agriculture, industry, navigation and municipal users) are satisfied. Due to the hight cost of water system development involved, there is a lot of concern expressed with respect to the expected regional benefits. Disagreements exist as to whether water merely permits to grow or whether it can induce the growth. It is believed that no region can grow or prosper without adequate water supplies. But this does not mean that water is the main development factor. Examples are cited [5, 7] which show that the inexpensive supply of water is less important for new plant locations than other factors, such as the availability of labor and proximity to new materials and markets. It is therefore believed that water development may be helpful as one of several factors necessary to encourage regional economic development. In other words, it is necessary to investigate the general urbanization processes in conjuction with water development before a decision on water system development is taken.

Fast urbanization process, which have nowadays become common in many countries, have a considerable impact on regional growth. It is usually assumed that regional growth consists of rural (agricultural) and urban (industrial) components. Urbanization is accompanied by the so called transition in demography (which results in the decline of natural population growth) and followed by the transition in migration (i.e. increased rural-urban migration). The result is a change of regional employment and spatial settlement patterns.

The increased rural-urban migration reduces the agricultural labor supply and requires that technological change in farming, e.g. the substitution of labor by capital, follows.

In urban centers, the increased (by migration) population demands more housing and infrastructure (i.e. more urban capital investments and overhead expenses in transportation, health, education, environment quality, etc.). The economic benefits which are a result of migration, i.e. more labor and scale effects, are frequently counterbalanced by the impact of the so called diseconomies, created by agglomerations, such as environment pollution, congestion in transport, etc.

In rural areas, the aggregation of land in agriculture (i.e. farming acreage per head) produces scale benefits as well. In Poland, this process is supported by the government which gives credits to farmers who buy the excess land, or gives retirement pay for older farmers if they decide to give up the land. However, the structural change due to aggregation of small farms, which use traditional technologies, requires more capital, fertilizers, irrigation, and education. In large farms, especially those specializing in the production of meat, environmental pollution follows. All this indicates that the agglomeration of the population in urban centers (or aggregation of land in rural areas) generates economic benefits as well as increased costs. Planners and decision makers feel they are responsible to maximize the benefits, or to minimize the costs, involved. In countries with planned economies, such as Poland, a great deal of attention is being paid to the development of planning methods capable of optimizing regional growth and social welfare [1, 10]. The Notec Project is therefore regarded as the so called "Pilot Project". It if proves to be successful, the experience gained and the methodology developed can be used for the development of other, similar, regional projects in the future.

It is well known that an important factor in the analysis of regional development is the labor resource forecasts. It depends on the natural supply, which is predetermined by regional demography. In the rural areas, like that of Notec, the natural growth is above the average national figure.

The existing regional forecasts of population in the productive age in Poland are mainly based on natural growth. In order to construct long term population forecasting models it is necessary to construct regional migration models.

It is believed that migration is not an independent random process but depends much on the standard of living, jobs, housing available, environmental and social amenities.

In the typical agricultural region, like the Upper Notec, there is a constant out flow of labor to urban, industrial centers. Since the largest irrigation benefits follow in the case of production of labor intensive crops (such as, for example, the sugar beets), the outflow of labor due to rural-urban migration can significantly decrease the expected rise in agriculture production.

On the other hand, the labor migration contributes to the economic growth of the urban part of the Notec Region, while the agriculture land per head ratio increases. This enables the acceleration of structural change processes which take place in agriculture. As a result of this change the large state farms can be created and the regional labor efficiency will increase.

In order to evaluate the complex structure of benefits and socio-economic consequences of the Notec Project, a system analysis and a system of computerized mathematical models should be used. The models should not be regarded as a device which give an unique solution, but rather as useful tools which enable the investigation of the project's impact on the socio-economic growth of the region.

They should also enable the investigation of different regional policies and different scenarios for regional development. An interactive mode of operation of computerized models is needed for this purpose.

It should be observed that most of the existing regional economic models deal with constant return to scale, exogenous labor and other resources, while the migration models do not include the economic, structural and technological change factors. When one wants to build a useful regional model, it is advisable to follow the complex--or integrated--modelling approach. There is, however, a danger that wnen one trows too many things into one pot, the whole thing can become hopelessly entangled. It is therefore advisable to limit the number of productive sectors in the regional models studied to agriculture and the rest of the economy only (undertanding that agricultural economic activity takes place in a rural area, while the rest of the economy is active in the urban center).

The agriculture output of the Notec Region is produced by the privat and socialist (mainly state farms) sectors. Since the privately owned farms are small and belong to different size categories, the economic benefits due to irrigation depend much on the sector composition, technology used, and production mix at each subregion studied. In order to evaluate the value of these benefits, a complex agricultural model for the Notec Region is required.

Following these remarks in the presnt paper, the general methodological problems of regional development due to irrigation were primarily studied. In particular, the problem of modelling regional development, i.e. labor, investment and consumption allocation policy impact, as well as the agricultural model for evaluating policy impact on production, structural and technological change, were described and investigated.

Of course, besides the models, which deal with economic benefits and socio-economic processes, the Notec Project requires development of a number of models concerned with water expansion and water management systems. Fortunately, much more literature and computerized models exist on that area (see, for example, [8, 9]). These kinds of models and their application to the Notec Project are described in [4, 6].

The characteristics of the Notec Region, the Government Program and the Notec Project Research organization are described as well in "Short Description of the Notec Development Project", Paper 1, in this issue. At the present, initial stage of the Notec Project Development, the present paper sould be regarded as a proposal for future work and mainly as an introduction to constructive discussion.

2. PROPOSALS FOR THE CONSTRUCTION OF A SYSTEM OF MODELS

The models needed for the Notec Project development fall into three general categories:

a. regional benefit models;
b. water system expansion models; and
c. water system management models.

In the present paper it is only possible to discuss the main concept and assumptions underlying the construction of these models.

As far as the regional benefit models are concerned, it is necessary to observe that Notec cannot be detached from the national economic system. The national policy regarding the allocation of production factors, and firstly, capital and labor, as well as the allocation of consumption, is motivated by the expected regional economic gains and efficiency versus equity concepts. The regional gains depend on the existing allocation of factors and the comparison of interregional production efficiencies (i.e. the net production per employment) determines how effectively the regional resources are utilized. In other words, using this approach (for details, see Appendix I) it is possible to estimate the excess or shortage of labor resources in each particular region. The estimation of labor resources can be carried out in each elementary subregion, such as gmina or solectwo, is necessary. The outflow of labor by migration, outside the Notec Region, can be computed by a migration model (described in Appendix I). The model derives the migration ratio as a function of jobs and housing available and the income ratio (compared with national averages). The income of the rural population which consists mostly of owners of small farms and state farm employees is also computed. In order to investigate the private sector of agriculture income the model described in Appendix II can be used. The construction of the state farms model due to the availability of statistical data is, of course, much easier. The agriculture model is capable of producing the expected output, marginal costs, income and labor efficiencies for different farm sizes, production mix, input prices, etc. Then, the farmer's income, derived from the agriculture model, can be used as the input to the migration model.

Since the agriculture model is also capable of producing the farmer's gain, resulting from the irrigation water and the possible change of specialization (it is supposed that farmers chose water intensive crops when irrigation water is available) the corresponding change in the migration pattern can also be investigated.

The migration rates derived can be used for improving the regional population growth forecasts derived by demographic submodels. The improved demographic data can also be used for the evaluation of regional consumption, housing and job availability, which in turn influence migration.

The labor migration, from rural to urban areas within the Notec Region, decreases the rural production but at the same time, contributes to the urban part of the regional economy. In Appendix I, the method has been proposed which enables an easy computation of that benefit in monetary terms. The economic benefit resulting from rural $\rightarrow$ urban migration is, of course, reduced by the increased cost of services, such as housing, urban infrastructure and environment. Using the method of Appendix I, it is possible, however, to derive the net benefits connected with rural-urban and outside migration. The aggregation methods, described in Appendix II, enable computation of agriculture benefits for different types of soil, farm sizes, technology and production mix. The increase of farmers' expenses accrued to the cost of irrigation water can also be computed. Summarizing, one can say that the methods described in Appendices I and II, enable in principle, the evaluation of the total regional benefits, given the general regional development policy, i.e. the inter-regional allocation of investment and consumption funds.

Regarding the regional allocation of investments, (including irrigation, like the Notec Project), the following remarks should be made. The investment projects usually involve many choices among physically feasible alternatives. Each alternative that is given serious consideration should be made on economic grounds, i.e. the discounted (over the expected project life) costs and benefits in monetary units should be derived. In the engineering practice it became, for example, customary to convert the investment (I) into an equivalent annual cost by multiplying I by the capital recovery factor $r = i(1+i)^n/[(1+i)^n - 1]$, where i = the interest rate per annum, n = estimated project's life. The socio-economic impact of the project at each region should also be studied.

As far as the Notec Project is concerned the total irrigation investment funds should be regarded as split into two parts. One part, connected with water transfer, from a reservoir to the given farms and fields, maintenance of water facilities, etc. has been taken into account (in the model of Appendix II) as a component in the farmers annual water expenses (Y_W).

The main investement cost is however connected with the basic water system construction and extension, such as, construction of retension reservoirs, dams, channels, etc. The investment cost depends much on the number and size of the reservoirs. That in turn depends on the water demand claimed by the potential users, i.e. industry, navigation, municipal users and agriculture.

Using the water demand models, which are based on the regional population and urbanization forecasts, the expected water demand of the municipal, industrial, and navigation users of the Notec Region can be estimated. As shown in Appendix II the agriculture demand can be estimated using a cost-benefit analysis at the farm level and aggregation of the demands within each region. It is obvious that the demands derived will depend much on time and spatial coordinates. The capital return costs will, generally speaking, increase with the size of basic water investment. The economical size of the total project will be determined therefore by the comparison between the project's capital return with the average national figure. Due to the budget and construction potential limitations, the total project cannot be realized in one single year. The project is therefore expected to be realized in stages (e.g. one reservoir per year) in such a way that the economic benefits, derived over the total project life, are maximized. This requires, in particular, that each new reservoir and other water facilities be fully utilized starting with the end of the construction period.

It should be observed that the computation of the project size depends on the expected regional benefits. The regional benefits depend in turn on the available amount and price of water. In other words, to construct a system of models, which enables the realization of the Notec Project it is necessary to secure a linkage of regional benefit models, already discussed, with the water system expansion models, which deal primarily with the economy of the water system construction or expansion.

Regarding the expansion models, we shall first consider some of the major assumptions and formulate the problem statement. The existing and expanding water resources system is formuated in mathematical terms by providing an objective function, system equations, and constraints in the form of inequalities. The planning horizon is taken around the year 2000. The time variable, for the introduction of the new subproject, is discrete with one year increase. (Planning of capital investments on a yearly basis is the accepted procedure in Poland.) Controlled water releases within the system are, however, executed more frequently (one month or one decade), depending on the hydrological and meteorological data and consumption specification. The reservoir inputs over the project's life time can be assumed, at the beginning, as known and deterministic. That assumption may be dropped later in order to investigate the stochastic version of the expansion model.

In particular, it seems desirable to use the stochastic approach to the optimization of the reservoir capacity. The losses due to the shortage of water stored, depends much on the random meteorological conditions. The annual precipitation of the Notec Region changes over the years and the agricultural losses change accordingly. The right approach to chose the reservoir capacity can be based on the stochastic formulation of the expansion problem with the risk chosen as the objective function. In a similar way, it can be assumed that future water demands are deterministic. However, the mathematical model can incorporate any likely demand function and the sensitivity of the solution obtained to change in the demand can be ascertained.

It is as well proposed to neglect, at the beginning, the water quality and environmental pollution impacts.

The water resources system itself can be regarded to consist of the river (Upper Notec with two main West and East creeks) and a number of lakes which can be converted into retension reservoirs. The import of water from the Vistula or Warta Basins should be considered as alternatives. Different forecasts of increasing demand for municipal, industrial, recreation and navigation users should be considered as possible scenarios in the modelling process. A number of possible reservoir locations should be considered. Each reservoir may be built on several scales (each scale is considered as a different project). With each reservoir is associated a capital cost and an annual return. The decision maker is concerned with which project to undertake and at which time to start construction under budgetary constraints. Then, the general optimization problem to be solved by means of expansion models can be formulated as follows. Given the planning interval $T = 2000$ and a set of alternative projects, select a period (if any) when each subproject should start so the objective function is optimum under budgetary and other constraints.

As the objective function, the difference between the expected benefits and capital costs, connected with the project, can be taken. That function should be summed up over the set of alternatives project and discounted over time. The constraints should consist of:

a) budgetary (investment constraint);
b) construction capacity limitation (e.g. a single reservoir each year);
c) release constraints (releases to the streams between the reservoirs must exceed a certain minimum level and must be less than flood levels); and
d) reservoir shortage and mass balance constraints.

In the case of the series of connected reservoirs these constraints may assume a dynamical character (i.e. the irrigation water releases become delayed returns to the next reservoir).

It should be observed that the optimization problem connected with the solution of the water system expansion is generally a nonlinear (discrete) programming problem. There are know computational difficulties connected with the solution of such problems [8].

The Branch and Bound Method has recently gained attention as a possible optimization tool [8]. In order to enable the implementation of an operational policy with any new reservoir added the Fulkerson's Out of Kilter algorithm can be used in combination with Branch and Bound [8].

It should be observed that when the water system expansion problem is solved numerically, the supply of irrigation water in each region as well as the expected production and regional growth is determined. On the other hand, since the water system structure is known, the water system management models can be constructed and implemented.

Within this class of models, one is concerned with the operating rules for reservoir releases, mainly. The effectiveness of the water system, consisting of many reservoirs and canals, is dependent on the ability to operate the system in an optimum fashion. The overall objective of the water supply system is to meet the demand for water at minimum expense.

The demand for water depends mostly on the agriculture technology and production specialization. For example, there is an increased water demand for grain fields in May-June and for potatoes in August. In order to derive the optimum operating rules for water management, the stochastic formulation of the problem is also necessary.

Obviously, the successful construction of a system of models for the Notec Project requires that the three general categories of models listed (ile. regional benefit, water system expansion and management) are developed in such a way that linkage of exogeneous variables is possible.

It is also advisable to utilize as much as possible the experience gained in other existing large-scale irrigation modelling projects such as, for example, the Silistra Project in Bulgaria [3], the Texas Water System Project [9] or the Bratsk-Ilimsk Complex Development [2].

There are many differences among these projects. For example, the farms in Texas are privately owned, and in Silistra they are State owned, while in the Notec Region the ownership of farms is mixed. There are also differences in the climate, soil, water resources as well as in economical planning, social and mangement structure. On the other hand, many similarities exist in the optimization problem statements and the water system engineering methods.

Though there is a considerable part of engineering problems in the Notec Project, it is essential that the continuous consultative support from the specialists representing regional, economic, social and environmental sciences be secured. In this respect, IIASA's role as a unique international organization, which enables cooperation among research institutions and specialists representing different branches of science and different countries, is of great importance.

In conjunction with in-house research conducted within different Areas and Programs, IIASA's participation in the Notec Region Case Study may essentially contribute to the successful realization of the Notec Project.

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A CONCEPT FOR NORMATIVE MODELLING OF WATER SYSTEM DEVELOPMENT IN AN AGRICULTURAL REGION

Marek Makowski

Systems Research Institute, Polish Academy of Sciences

1. The Aim and Scope of Research

The research undertaken is aimed at construction of a model for water resource system /MWS/ in an agricultural region. This model will be actually applied - out of its other possible uses - in design and implementation of a "pilot" - prototype water resource system in an agricultural region within the framework of the governmental R&D program PR-7 dealing with water problems. In particular MWS will be used in planning of undertakings pertaining to formation and utilization of water resources. This model will also participate in planning and forecasting of socio-economic development of the region.

MWS is being constructed for a specific region, with assumption, however, that it will retain its applicability to other regions. This fact determines not only the structure of the model, but also the requirements concerning detailed specification of the model bases and preparation of documentation. The object modelled presently is the Upper Noteć watershed. It is a diversified agricultural region with 6190 sq.km of surface out of which 4550 sq.km are in agricultural use /80% of the latter is liable to irrigation/. Water deficit can be felt in the watershed already now. In conditions of developing urban and rural services and postulated growth of agriculture and water-consuming industry this deficit will get more severe [2] , [6] . At the same time the region offers possibilities of appropriate formation of water resources /construction of reservoirs, water transfer within the region and/or from neighbouring watersheds/.

A remarkable amount of investments planned for expansion of a water system and for development of agriculture justifies an effort for construction a model that can be treated as a tool for decision makers. As far as the water system expansion is conserned it is assumed that the goal of development is to maximize the net benefit to society caused by implementation of the plan. Application of so called supply oriented models does not quarantee that maximum of benefit is achieved. Neither the strategy of minimazation of water consumption in agriculture is accepted.

In the above described conditions it is necessary to apply a comprehensive computerized model in order to elaborate rational plans of the water systems development. It is understood here that rational decision making would involve joint consideration of the water resource system and the whole of the region's socio-economic development so that ultimately these two are treated as one regional water-economic system.

For purposes of comprehensive planning and forecasting of the whole of region's development a special model will be built / MRD -model of regional development, [3]/. It is assumed /see Fig.1/ that MRD will be used together with models of national development /e.g. from the MRI-models of development-series [5]/,

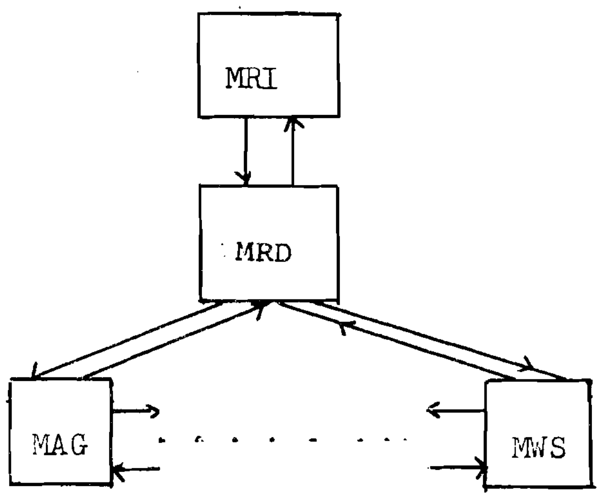

Fig.1. General structure of the model system

and also with more detailed models of specific spheres of activity, e.g. with model of agriculture /MAG/, of migration, of industry and others. MUST model would be helpful in determination of such variables exogenous to MWS as:

amounts of water both for external users and those having priority, investments volumes into water system, the value of agricultural production, costs associated with irrigation and formation of water resources and so on.

In modelling, and subsequently in design of water system developments the Upper Noteć watershed region considered here will be divided into N /N equal to about 20/ microregions /denoted further on by RM/. It is assumed that each RM has reasonably homogenous characteristic. Areas of RM's correspond to these for which well fitted data considering water flow and estimation of agriculture production function parameters can be collected. The structure of the whole watershed can be represented by a network /see Fig.2/, whose nodes are RM's and directed arcs are water flows in streams between individual RM's.

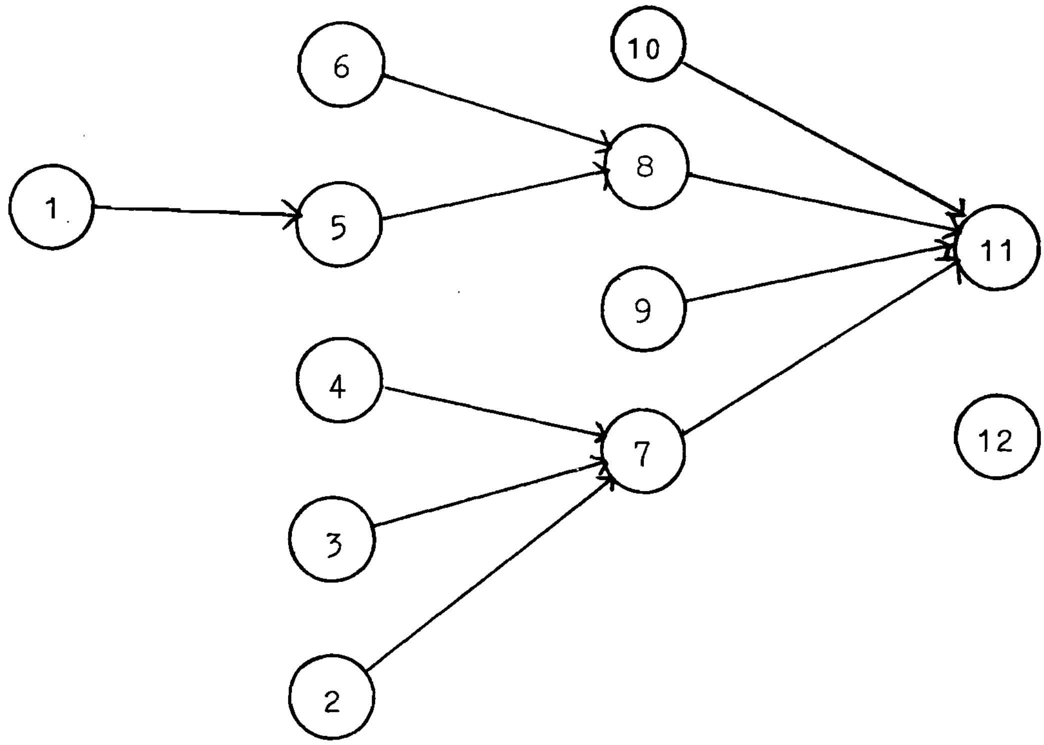

Fig.2. Network representation of the initial breakdown of the Upper Noteć Watershed into RM's

The MWS model will enable determination of the optimal allocation of existing water resources among individual RM's and of the optimal expansion of the water resources system through construction of reservoirs and through water transfer, either among RM's within given watershed or from outside. By optimal is understood such strategy which maximizes certain criterion /commented below/ connected with agriculture and which satisfies constraints specified in p.3.3. of the present paper. The character of this criterion implies the priority given to demands of non-agricultural water users. It is, however, imperative, to distinguish between demands and actual needs, and hence the MWS will provide valuation of water for agricultural uses in individual RM's. Such valuation may constitute a basis for verification of planned water demand of users having priority /especially in planning of new or additions to old capital investments, and in making of decisions pertaining to choice or change in technology/.

MWS will be a deterministic model. Adoption of this assumption results both from the purpose of the model and from the computational capacities. As the hydrological phenomena have random character the data for the model /this regards mainly volumes of natural flows and relation of increments in agricultural production to irrigation/ will be defined on the basis of statistical analysis of time series for 15 to 30 years.

The major limitations in the use of the model are listed below:

The MWS model will not serve for the real-time control. For these purposes another model is being constructed [1], described in the subsequent chapter.

The problem of water excess removal /in case it is not treated as a method of increasing disposable water resources/ is not considered in MWS.

The model does not account explicitly for water quality. The question of quality could be considered indirectly through increase of minimal admissible flow in a stream /restraints on minimal flows are integrated into MWS/ and simultaneous adoption of emission standards so that concentrations of pollution in the environment do not exceed given ambient normative standards.

The problems of water use for navigation projects that could improve the transportation network, for hydroelectric power generation and for public health and recreation projects are not taken into account in the model, neither are those uses which pertain to flood control.

2. The Structure for Model of Water System /MWS/

MWS will be composed of 4 mutually connected submodels and will cooperate with other models of the system illustrated in Fig.3. By cooperation it is meant that some inputs to MWS are determined on the basis of outputs of other models and conversely. As indicated in the title of the paper, it is assumed that MWS will have a normative character, i.e. it will enable definition of these values of decision variables which maximize the criterion chosen.

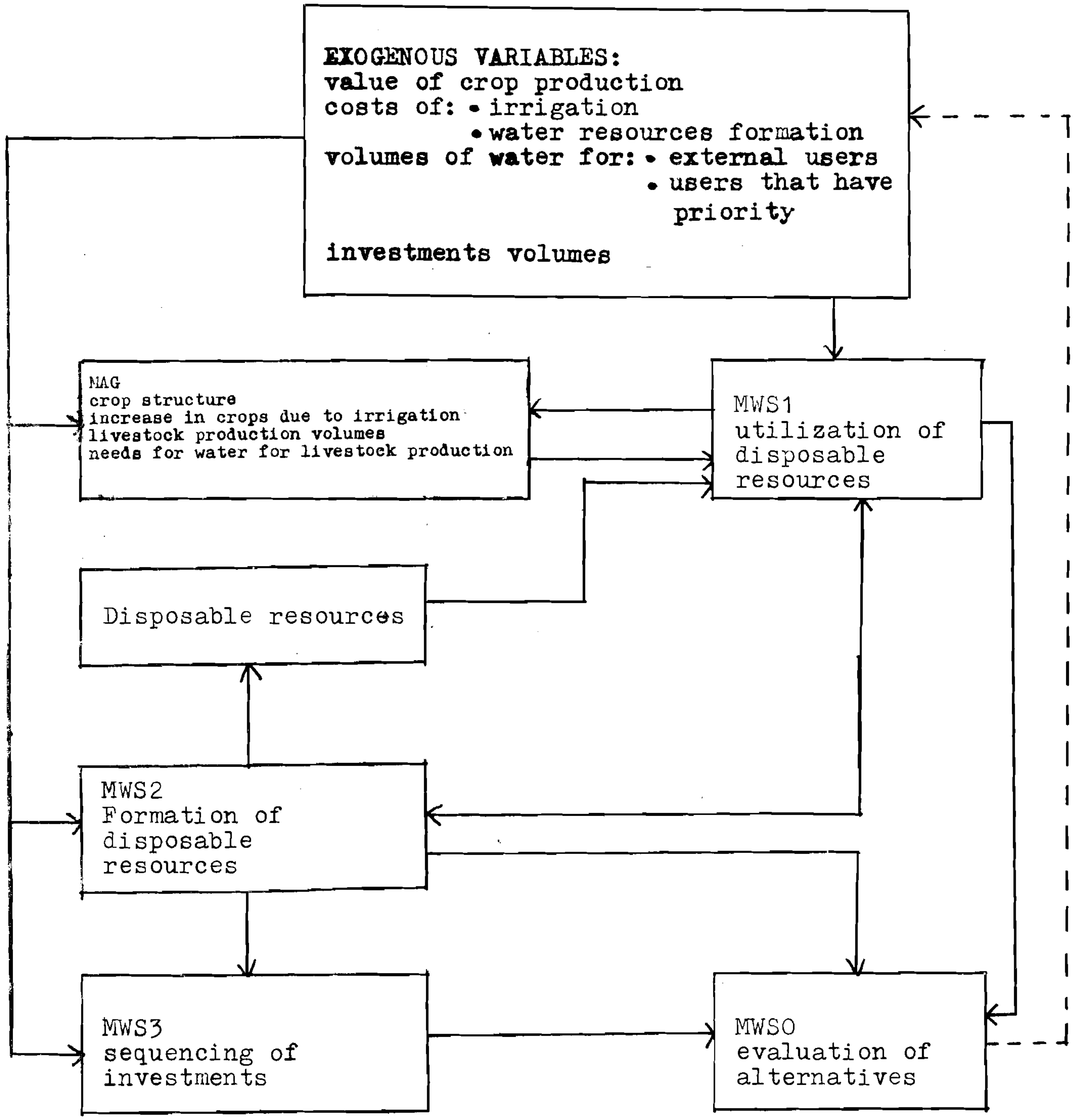

Fig.3. Structure of the MWS model

The MWSO submodel will make it possible to effectively utilize the other models in the conversational mode on an adequately equipped computer input/output configuration. Thus, it will be possible to analyze the influence of changes in some decision variables and compare effects of non-optimal strategies. This comparison would involve not only differences in criterion function, but also information pertaining to valuation of water, increases in agricultural production, other indices as e.g. investment efficiency, and information on violated constraints. It will be possible to analyze the influence of changes in exogenous variables, model parameters etc. and to perform an initial selection of alternatives /"scenarios"/ according to the criterion adopted. The model will enable selective output of results from the computer and choices in their processing. Because of its purpose MWSO will be elaborated after MWS1 and MWS2 have been completed and after detailed functional requirements have been formulated by future users of the model system.

The MWS1 submodel will serve for determination of optimal allocation of disposable resources among individual microregions RM. With help of MWS1 it will be possible to obtain valuations of water as a resource in various RM's in relation to, e.g. its quantity. MWS1 will be connected with the model of agriculture in the region, the latter model defining structure of crops increase in value of crop production, demand for water of livestock breeding and so on.

It should be pointed out that the model of agriculture must not extrapolate current situation. It is assumed, that for each RM the optimal structure of crops /taking into account the possibility of irrigation/ and volumes of livestock production will be designed. according to a goal function for agriculture and constrained resources. The general idea of such model is presented in [4].

The results of others researches performed in Poland pertaining to evaluation of crop increase due to irrigation and structure of agriculture will also be adopted.

The concept for construction of model MWS1 is presented in some more detail in p.3 of the present paper.

The MWS2 submodel is meant for defining the optimal formation of water resources /through determination of sites and volumes of retention reservoirs and water transfers/. MWS2 will thus change the disposable resources.

It is assumed that neither supply oriented models nor minimization of water consumption in agriculture is accepted. Thus, the MWS2 goal function will include both evaluation of effects due to irrigation and costs of formation of water resources. Hence MWS1 will serve as a submodel for MWS2. Description of MWS2 is given in p.4.

Activation of this submodel will necessitate information concerning capacities and costs of water system investments in the region /see p.4/.

The MWS3 submodel will serve for optimization of sequencing of investments determined within MWS2 so that certain investment effect index will be maximized over the investment period and the constraints on annual investment volumes and construction capacities are not violated. More detailed structure of this submodel will be specified at a later stage of research.

3. The Concept for MWS1 Submodel

3.1 . Optimality criterion

The MWS1 submodel will serve, as said, for determination of optimal allocation of disposable resources among individual RM's for each decade during vegetation period. Optimality criterion will concern exclusively agriculture while satisfaction of non-agricultural users demand will be warranted through appropriate priority supply volumes.

It is postulated for the criterion that it consequently comprise the whole of the agricultural production, i.e. both crops and livestock. Solution to thus formulated problem depends upon possibilities of specifying data and constructing agricultural model for the region. With the help of the latter it would be possible to specify optimal volumes and structures of crop and livestock productions for each RM with constraints on water volume and other resources such as labour, machines, fertilizers etc. In the first version of MWS1 the optimality criterion, however, will only account for crop production increases. Water demand for livestock breeding will be therefore treated as an external priority constraint.

It does not cause any limitation of using the model because the model of agriculture, as said, will designe the optimal structure of whole regional agriculture. Thus the simplification results only in introducing into the goal function a part of effects due to irrigation alone i.e. crop production increase.

The aim of optimization is to allocate water among RM's in consecutive decades of the vegetation period in such a way that the sum of income H(Q) resulting from irrigation in individual RM's will attain its maximum:

$$H(Q) = \sum_{i=1}^{N} \left(D_i(q_i) - S_i(q_i) \right) \qquad (1)$$

Q - irrigation flows,

$Q=(q_1, q_2, \ldots, q_N)$, $q_i=(q_i(1), q_i(2), \ldots, q_i(T))$

N - number of RM's , T - number of decades in the vegetation period,

$D_i(q_i)$ - increments to crop production value from irrigation,

$S_i(q_i)$ - sums of costs on irrigation.

Because the agricultural production in Poland is partly subsidized by the state budget an essential parameter in specification of D_i function is introduced by prices of agricultural products. As the function D_i is estimated for production represented in natural units it will be left as such and only additionally it will be multiplied by prices /with due account to so-called "calculation prices" rectifying relations to other sectors' prices/ treated as exogenously given. This will facilitate analysis of influence of various calculation prices on volumes of profitable irrigation. Relations serving this purpose will be comprised in the model, are, however, omitted in the present simplified description.

The sum of costs S_i will comprise all costs pertainig to irrigation, i.e. annual operating costs, annual capital investment repayment rate, increments to costs of agricultural production entailed by irrigation, and others.
No costs associated with water resources formation are included into S_i.

Consider, for the sake of illustration, one RM and one decade. The character of dependence of agricultural production increase D, irrigation costs S and difference /D-S/ on the water quantity q is presented in Fig.4 below

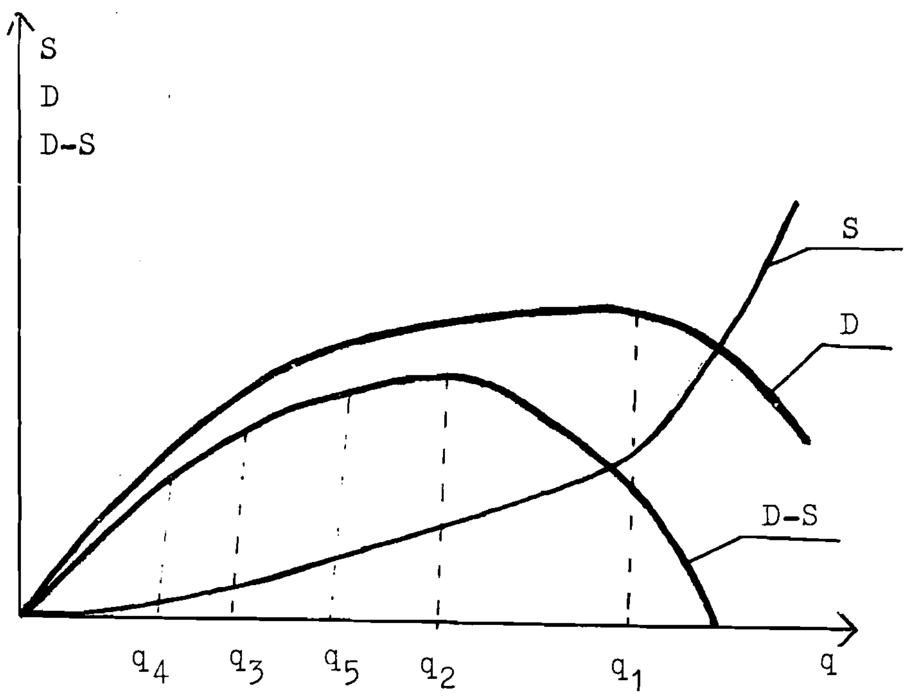

Fig.4. Illustration of functions D, S, and /D-S/ and of optimal irrigation level for an RM and a decade

Quantity q_1 could be interpreted as biological optimum, i.e. such amount of water should be used for irrigation in given RM if there were no costs associated, with it. Quantity q_2 is an economic optimum in conditions of sufficient supply of water. If supply is limited below this last optimum for a separate RM, then there would be some other optimal point q_3. As there exists a possibility of transferring water from one RM to another the local optimum could even in conditions of limited supply be higher than q_3, e.g. q_5. In this situation some amount of water from an RM where it still could be used is left to be consumed within another RM - downstream - with higher efficiency. The optimum for supplying RM would then be lower - e.g. q_4.

Two following aspects having essential influence on volume of crop production increase have been incorporated in the model:

1. Question of incomplete irrigation. It is well-known that for a given crop a prescribed desirable level ql(t) of water supply per 1 sq.km can be specified yielding awaited increase in crops. Consequently, knowing the water supply $q_i(t)$ the irrigation area f_i can be determined for given RM as

$$f_i = \min_t \left(q_i(t)/ql_i(t) \right) \qquad (2)$$

It must, however, be assessed, whether better results for the given water supply cannot be achieved with irrigation less intensive than ql(t)

$$qr_i(t) = a_i(t) \cdot ql_i(t) \qquad 0 < a_i(t) \leq 1 \qquad (3)$$

that would enable an increase of the area irrigated and subsequently also increase in crops notwithstanding drop in yield per hectare. An additional reason for such analysis is the fact that MWS is a deterministic model basing upon so called representative year data, so that in practice production increase usually will be greater.

2. Rational planning of crop structures in individual RM's. It is assumed in the model that the crop structure is given exogenously. Prescribed desirable irrigation volumes for various crops attain, however, their extrema in differing time periods. The model will therefore output information aiding in planning of crop structures in individual RM's so as to possibly fully utilize water during the whole vegetation period, adding water for individual crops according to their needs, i.e. in various periods/varius RM's.

3.2. Decision variables

Quantities of water for irrigation in individual RM's and decades of vegetation period: $q_i(t)$, $i=1,2,\ldots,N$; $t=1,2,\ldots,T$; will be main decision variables of the model. If the solution stipulating incomplete irrigation can be accepted, then also irrigated areas f_i will be treated as decision variables.

3.3. Constraints

Decision variables must satisfy following constraints:

$$0 \leq Q \leq Qmax \quad (4)$$

$$Q \leq QD \quad (5)$$

$$0 \leq F \leq Fmax \quad (6)$$

where Fmax is given vector of maximal surfaces to be irrigated in individual RM's, Qmax is given matrix of maximal irrigating flows for individual RM's and decades, and QD is a matrix of disposable flows determined as below:

$$QD = QN - QZ - QPB - QM \qquad (7)$$

where QN is a matrix of natural flows, i.e. amounts of water that would exist in the system in the absence of consumption.

QPB is water consumption by external priority users. These users have guaranteed supply of QP of water, but actually consume only a portion of QP. Elements of QPB matrix will therefore be defined as

$$qpb_{it} = qp_{it} \cdot b_{it} \qquad (8)$$

where $B = \left[b_{it}\right]$ is a matrix of indices of consumption for external priority users $0 \leqslant b_{it} \leqslant 1$.

Knowing consumption of water for irrigation Q for regions upstream one can determine entire consumption of water up the stream from given RM:

$$QZ = C\left(QPB + Q\right) \qquad (9)$$

where C is a matrix describing network of connections among individual RM's. It is a 0 - 1 matrix with $c_{ij}=1$ iff there exists a flow connection from j-th RM to i-th RM.

Note that QN-QPB-QZ denotes this amount of water which actually is in a stream in individual RM's and decades.

QM is the minimal flow and is given by

$$QM = MAX\left(QB, QPIB\right) \qquad (10)$$

where QB is biologically admissible minimal flow, QPIB is the volume of water consumed by external priority users and returned to the system. Operation MAX consists in chosing the greater of the corresponding elements of two matrices and in creation of new matrix from these elements.

4. The Concept for MWS2 Submodel

4.1. Optimality criterion

The MWS2 submodel will be used in planning studies pertaining to increases in disposable water resources for individual RM's in vegetation period. These increases can be effected through diminishing of disposable resources outside of the vegetation period /storage of water in reservoirs/, or even through decreases in resources of other RM's/other watersheds. It is assumed that the two above solutions are profitable from the point of view of the whole economy. This remark specifically concerns diminishing of resources outside of vegetation period and of the region considered as this fact will not be accounted for in the optimality criterion adopted for MWS.

As, on the one hand, there is a lot of potential possibilities of increasing disposable resources and on the other hand the operational and applicable computer model should be built as soon as possible, it was assumed that MWS2 will serve for evaluation of selected investment alternatives /which primarily concerns transfers of water and capacities of reservoirs/. Selection of alternatives would be performed beforehand at the stage of data preparation. /Results from MWS1 could be used for this purpose./ MWS2 model would then for a given set of potential locations of reservoirs and of water transfer network determine optimal volumes, or only values of criterion function L if the influence of various solutions, differing from the optimal ones, were analysed. In MWS2 model there will also exist a possibility of determination of some decision variables /e.g. volumes of some reservoirs/.

The criterion function /denoted L/ for MWS2 has been adopted in the form:

$$L\,(V,X) = E - \sum_{j=1}^{J} JZ_j\,(v_j) - \sum_{j=1}^{K} JP_j\,(x_j) \qquad (11)$$

where V, X - vectors of decision variables, i.e. volumes of reservoirs and of water transferred /to given RM's/ respectively,

E - investment effects,

JZ_j - annual capital investment repayment rate and operating costs for j-th reservoir,

JP_j - annual capital investment repayment rate and costs for j-th water transfer,

J, K - numbers of reservoirs and water transfers, respectively.

It is assumed that JZ_j and JD_j are convex functions of their arguments. By investment effect E is meant here the difference between values of the criterion (1) for MWS1 submodel calculated with and without investments /reservoir construction, possibilities of water transfer/. For this purpose equation (7) of MWS1 submodel will be replaced by equation:

$$QD = QN - QZ - QM - QPB + (C+I) \cdot (U+X) \tag{12}$$

where: I - identity matrix,

U - outflow of water stored in a reservoir.

$$U = \frac{-dG}{dt} \tag{13}$$

G - degree of reservoir utilization /filling/.

Transfers can be made from one RM to another, so that some components of vector X can be negative.

Because volume of reservoirs is one of decision variables and the criterion (1) is influenced by disposable flows in each decade the model will also determine optimal strategy of utilizing the reservoirs /i.e. of controlling the outflows from reservoirs in consecutive decades/.

4.2. Decision variables

$V = (v_1, v_2, \ldots, v_J)$ - volumes of individual reservoirs,

$X = (x_1, x_2, \ldots, x_K)$ - transfer flows intensities.

4.3. Constraints

In addition to constraints listed in sec.3.3 following condition, have to be fulfilled:

Constraints on reservoir volumes:

$$V_{min} \leqslant V \leqslant V_{max} \tag{14}$$

Constraints on degree of reservoir filling:

$$0 \leqslant G(t) \leqslant V \tag{15}$$

Constraints on transfer intensities:

$$X \leqslant X_{max} \tag{16}$$

Constraints on maximal disposable flow

$$QD \leqslant QDM \tag{17}$$

4. Notation

Types: A - abbreviation

M - matrix

S - scalar

V - vector

Components of vectors and rows of matrices correspond to individual RM's, columns of matrices /except matrice C commented in the text/ - to individual decades.

type	notation	meaning
M	A	degree of irrigation due to prescribed best level
M	B	index of non-returnable water use by external priority consumers
M	C	RM connection structure
V	D	increase in value of agricultural production due to irrigation
S	E	value of the MWS1 model criterion function increase due to expansion of the water system
S	f	element of vector F
V	F	irrigated areas
V	F_{max}	maximal irrigated areas

type	notation	meaning
V	G	degree of reservoir utilization /filling/
S	H	MWS1 criterion function value
S	i	subscript for microregions RM
M	I	identity matrix
S	J	number of reservoirs
V	JP	annual capital investment repayment rate and operation costs of water transfers
V	JZ	annual capital investment repayment rate and operation costs of reservoirs
S	K	number of water transfers
S	L	MWS2 criterion function value
A	MAG	model of regional agriculture [4]
A	MRI	models of the MR series [5]
A	MRD	model of regional development [3.]
S	N	number of RM's
S	q	element of Q matrix
V	q_i	row of Q matrix that corresponds to i-th RM
M	Q	irrigation flows
M	QB	minimal, non-violable biological flow
M	QD	disposable flow
M	QL	prescribed desirable irrigation levels
M	QM	minimal flow
M	QDM	maximal disposable flows
M	Q_{max}	maximal irrigation flows
M	QN	natural flow
M	QP	flow of water for external priority consumers
M	QPB	non-returnable part of QP
M	QPIB	returnable part of QP
M	QR	less intensive irrigation level

type	notation	meaning
M	QZ	consumption of water in upstream regions
A	RM	microregion
V	S	value of costs related to irrigation
S	t	number of decade
S	T	number of decades in vegetation period
M	U	outflow of water stored in a reservoir
V	V	volumes of reservoirs
V	V_{max}	maximal volumes of reservoirs
V	V_{min}	minimal volumes of reservoirs
M	X	water transfer intensities
M	X_{max}	maximal water transfer intensities

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MODEL for OPTIMAL WATER DISTRIBUTION in a WATER MANAGEMENT SYSTEM

Prof. Jakub Gutenbaum
Ph.D. Michał Inkielman
MSc. Janusz Babarowski
MSc. Hanna Pietkiewicz-Sałdan

Systems Research Institute, Polish Academy of Sciences

1. Introduction

The difficulty in solving the problem of optimal control in a complex water resource system stems from the fact that distributed quantities of water should differ both with regard to time and with regard to points in the area considered. It is, therefore, a dynamic and multidimensional problem. Because of the random nature of precipitation, constituting main water supply source, the problem is also stochastic.

The present short description concerns the water system of Upper Noteć. Specific features of this area are reflected through goals of water distribution and through complexity of water network /number of reservoirs, flows, number and characteristics of water users/.

2. Optimization problem

The main aim of water distribution in the system consists in minimization of losses incurred by water shortage. Depending on the type of user these losses may have socio-economic /e.g. for agriculture, for industries/, socio-communal /for households/

or environmental /losses resulting from too low or too high levels of water in reservoirs and in flows/ character.

Optimization of water distribution is therefore a multicriterial task, which ultimately can be made unicriterial by introducing a surrogate of an overall utility function or by chosing among given criteria the one to be optimized and treating the other ones as appropriate constraints.

As the basic societal task fulfilled by the Upper Noteć region consists in supply of agricultural products it is assumed here that the optimization criterion will only concern agriculture. Needs of other users will be accounted for through constraints. This does not exclude the possibility of incorporating the non--agricultural uses into the criterion, if only a common economic effects measure could be formulated. It should, however, be realized, that such inclusions will muchly increase the number of decision variables. Besides that the price structure presently in force in Poland for agricultural and industrial products would make a joint optimization very disadvantageous for agriculture.

In compliance with above it will be further on assumed that the optimization will be aimed at maximizing of agricultural production. Additionally, all the crops in the whole region are supposed to measurable in some common units. Optimization criterion represents the annual value of agricultural production, which depends on irrigations, being functions of time. The criterion is therefore a functional defined over a yearly time period denoted by T. Adoption of one year as a time horizon results also from the assumption that the volume of reservoirs is small enough to ignore the interactions among consecutive years.

The mathematical problem of water distribution optimization will be formulated in the following way:

Time paths of decision variables $\hat{W}(t)$, $\hat{q}(t)$, $\hat{x}(t)$, $\hat{s}(t)$ should be found such that functional G_o representing the agricultural production is maximized:

$$\max_{W(\cdot),\ q(\cdot),\ x(\cdot),\ s(\cdot)} G_o[W(\cdot),\ r(\cdot)] = G_o[\hat{W}(\cdot),\ r(\cdot)]; \quad t \in \langle t_o, t_o+T \rangle \qquad (1)$$

and that equations resulting from flow balances in water system:

$$N[\hat{W}(t),\ \hat{q}(t),\ \hat{x}(t),\ \hat{s}(t),\ r_f(t),\ r_p(t),\ x^o(t)] = 0 \qquad (2)$$

as well as inequalities resulting from constraints on water levels in reservoirs and on flows in streams, and from needs of non-agricultural users:

$$G_m[\hat{q}(t),\ \hat{x}(t),\ \hat{s}(t)] \leq 0; \qquad m=1,\ldots,M \qquad (3)$$

hold.

Additionally:

$$\hat{W}(t) \in A_w(t),\ \hat{q}(t) \in A_q(t),\ \hat{x}(t) \in A_x(t),\ \hat{s}(t) \in A_s(t) \qquad (4)$$

where:

- t_o - initial time point of the optimization period, defined by the yearly vegetation cycle,
- $W(t)$ - vector function of agricultural users' consumption /of irrigated fields/,
- $q(t)$ - vector function of consumption of non-agrucultural users,
- $x(t)$ - vector function of flows in individual branches of the water net,
- $s(t)$ - vector function of states in individual reservoirs,
- $r(t)$ - random vector function of precipitation for individual cultivated field areas,
- $r_f(t)$ - random runoff vector function for individual reservoirs,

$r_p(t)$ - random water losses vector function for individual reservoirs,

$x^o(t)$ - random vector function of sources and external inflows to the water system,

$A_W(t)$, $A_q(t)$, $A_x(t)$, $A_s(t)$ - sets of feasible /physically possible/ values of corresponding variables.

Variables with argument t denote momentary values, while $W(\cdot)$, $q(\cdot)$, $x(\cdot)$, $s(\cdot)$, $r(\cdot)$ denote trajectories over the whole period $\langle t_o, t_o+T \rangle$.

3. Decomposition of the Optimization Problem

The problem (1) - (4) has a very high dimensionality. In particular, the vector $W(t)$ introduces many dimensions /number of irrigated fields in the region/. Equations (2), however, because the individual groups of users /i.e."irrigated complexes"/ get the water from one water intake, can be rewritten to the effect:

$$N'[q_d(t),\ q(t),\ x(t),\ s(t),\ r_f(t),\ r_p(t),\ x^o(t)] = 0 \qquad (2')$$

with

$$q_d(t) = \left\{ q_d^1(t), \dots, q_d^j(t), \dots, q_d^J(t) \right\}$$

$$A_W[q_d^j(t)] = \left\{ W^{j,k}(t):\ \sum_{k=1}^{K_j} W^{j,k}(t) = q_d^j(t)\ ;\ W^{j,k}(t) \in A_W(t) \right\} \qquad (5)$$

$$j=1,\dots,J$$

where:

$W^{j,k}(t)$ - consumption by k-th user in j-th intake,

$q_d^j(t)$ - consumption from one intake by j-th agricultural user /"irrigated complex"/,

J - number of irrigated complexes,

K_j - number of fields /crops/ in the j-th complex.

Simultaneously, the criterion functional can be written in an additive form:

$$G_o[W(t),\ r(t)] = \sum_{j=1}^{J} G_o^{\,j}[W^{j,1}(t),\dots,W^{j,K_j}(t),\ r^j(t)] \qquad (6)$$

Hence, it is possible to solve the task (1) - (4) in two stages, decomposing the Ist stage problem into J disjoint subproblems, parametrized through $q_d^j(t)$, $j=1,\dots,J$. Assume that in order to effectively solve an optimization problem it may furthermore be discretized in time through division of yearly period into I intervals /e.g. decades/. Finally, the task (1) - (4) can be reformulated as a two-level search for optimal $\hat{q}_{d_i}^j$, $\hat{q}_i$, $\hat{x}_i$, $\hat{s}_i$ $i=1,\dots,I$ within the upper-level problem and for optimal $\hat{W}^j(t)$, $j=1,\dots,J$, in J subproblems of the lower level, realized according to the following decomposition procedure:

$$\max_{W(\cdot),q(\cdot),x(\cdot),s(\cdot)} G_o[W(\cdot),r(\cdot)] \approx \max_{q,x,s,q_d} \Big[\sum_{j=1}^{J} \max_{W_j(\cdot)\in A_W(q_d^j)} G_o^j(W^j(\cdot),r^j(\cdot))\Big] =$$

$$= \max_{q,x,s,q_d} \sum_{j=1}^{J} \hat{G}^j(q_d^j,\ r^j(\cdot)) \qquad (7)$$

subject to discrete constraints (2'),(3) - (5), with $W^j(t) = \{W^{j,1}(t),\dots,W^{j,K_j}(t)\}$

where

$$q = \{q_i^j;\ j = 1,\dots,J,\ i = 1,\dots,I\}$$

$$x = \{x_i^j;\ j = 1,\dots,J,\ i = 1,\dots,I\}$$

$$s = \{s_i^j;\ j = j,\dots,J,\ i = 1,\dots,I\}$$

$$q_d = \{q_{d_i}^j;\ j = 1,\dots,J,\ i = 1,\dots,I\}$$

are matrices of dimension J x I with rows q^j, x^j, s^j, $q_d{}^j$ and columns q_i, x_i, s_i q_{di} respectively.

Subscript i denotes the number of time interval. It is assumed that the flows: q_i, x_i, q_{di} are integrals of $q(t)$, $x(t)$ and $q_d(t)$ over i-th time interval, and the discrete states of reservoirs s_i are taken at the end of the intervals.

The manner in which task (7) is decomposed into two levels is illustrated in Fig.1. It should be noticed that the discrete time is introduced only to the upper-level problem.

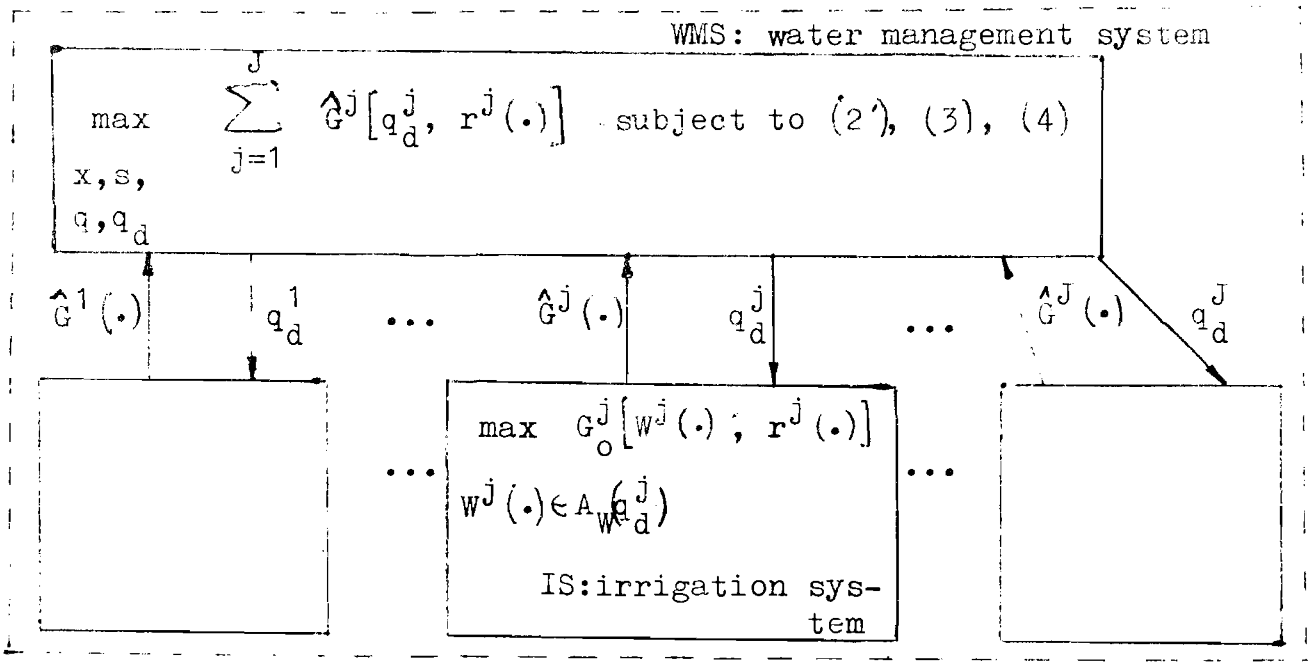

Fig.1: Two-level structure of the water distribution optimization task

4. Irrigation System /IS/ Optimization Problem

Optimization problem represented within the formula (7) by expression in square brackets together with corresponding constraints (5) is being solved on the lower level, i.e. locally, for controlled irrigated complexes called further on irrigation systems /IS/. This problem can be presented in the following way:

For all $j \in [1,J]$ find the set of time functions /optimal irrigations/

$$\left\{ \hat{W}^{j,k}(t), \quad k = 1,\ldots,K_j \right\} \in A_W(q_d^j) \tag{8}$$

defined over the time intervals /vegetation periods/ $[t_o^{jk}, t_1^{jk}]$, yielding k-th crops in the j-th IS in the harvest time point t_1^{jk} equal to

$$\hat{y}^{j,k}(t_1^{j,k}) = f^{j,k}\left[\hat{W}^{j,k}(\cdot), r^j(\cdot)\right] \tag{9}$$

satisfying constraint (5) with discrete q_d^j
and maximizing production value of the j-th IS, i.e.

$$\max_{W^{j,1}(\cdot),\ldots,W^{j,K_j}(\cdot)} G^j\left\{f^{j,1}\left[W^{j,1}(\cdot), r^j(\cdot)\right],\ldots,f^{j,K_j}\left[W^{j,K_j}(\cdot), r^j(\cdot)\right]\right\} =$$

$$= G_o^j\left[\hat{W}^j(\cdot), r^j(\cdot)\right] = \hat{G}^j\left[q_d^j, r^j(\cdot)\right]; \; t \in \langle t_o, t_o+T \rangle \tag{10}$$

In the above notation $f^{j,k}(.,.)$ is the so-called crop functional for k-th crop in j-th IS. It results from the crop growth model and from the soil moisture model for given area. Maximal production value for the j-th IS - $\hat{G}^j$ - is a functional on allocated to the system water resources q_{di}^j and precipitation $r(t)$. The above lower--level problem will also be discretized in time, but more densely than the upper-level problem. That is why in the present description it has been illustratively treated as continuous.

5. Water Management System /WMS/ Optimization Problem

5.1. Inequality Constraints

The upper-level problem consists in maximization of the sum of $\hat{G}^j$'s:

$$\max_{q^j, q_d^j, x^j, s^j} \sum_{j=1}^{J} \hat{G}^j\left[q_d^j,\ r^j(\cdot)\right] = \sum_{j=1}^{J} \hat{G}^j\left[\hat{q}_d^j,\ r^j(\cdot)\right] \qquad (11)$$

$$j=1,\ldots,J$$

subject to constraints (2'), (3), (4) in their discrete forms. Solution to this problem is attained in the broader /see Fig.1/ Water Management System /WMS/.

Constraints (3), securing the interests of water users not accounted for in the criterion (11) and representing also the social and environmental aims of water distribution, can be more precisely formulated as follows:

a/ For non-agricultural water users satisfaction of their needs is assumed to be assured with given probability. Non-satisfaction of needs may occur because of random changes in resources available. The aim of water distribution is to maintain the probability levels for such situations below certain limit level defined by so-called guarantees, differing for different users. Such guarantees may concern full needs or just minimal volumes ensuring realization of user's basic tasks, and they can generally be written as constraints on magnitudes of appropriate probabilities:

$$P\left\{q_i \geqslant q_i^{gw}\right\} \geqslant \alpha_i, \quad i=1,\ldots,I \qquad (12)$$

where: α_i - vector of guarantee probabilities,

q_i^{gw} - vector of warranted levels.

Constraints of type (12) may also be formulated for users accounted for in the optimization criterion.

b/ Other socio-environmental objectives are considered through constraints akin to (12), with guarantees concerning minimal and maximal flows in streams, and minimal and maximal levels in reservoirs.

Choice of guarantee parameters constitutes a compromise among all the aims of water distribution. This compromise should comply with the concept of development of given region. It should be emphasized here, that the constraining action of guarantees depends upon probability distributions of precipitation and outside inflows. When programming the guarantee parameters one should then also take into account climatic conditions of the region.

5.2. Equality Constraints

Constraints (2′) and (4) represent physical limitations to the water network of the system. They will be presented here for the simplified network structure. If the network can be divided into J partial watersheds comprising each one reservoir, one irrigation system and one non-agricultural user, then the balance equation of the net can be decomposed. For the j-th partial watershed this equation can be written as:

$$\left.\begin{aligned} s_i^j - s_{i-1}^j &= x_i^{j,1} + r_{fi}^j - r_{pi}^j - x_i^{j,2} \qquad (13) \\ x_i^{j,3} &= x_i^{j,2} - q_{di}^j - q_i^j \qquad (14) \end{aligned}\right\} \quad i=1,\dots,I$$

where: $x_i^{j,1}$ - inflow into the j-th watershed from other watershed in the i-th stage,

$x_i^{j,2}$ - controlled outflow from the reservoir in the i-th stage,

$x_i^{j,3}$ - outflow from j-th watershed in the i-th stage,

q_{di}^j - consumption of water by agricultural irrigation system in the i-th stage,

q_i^j - consumption of water by non-agricultural user in the i-th stage,

s_i^j - state of j-th reservoir at the end of the i-th stage.

Interconnections of individual partial watersheds are described in the 0-1 matrix defining the network structure. For the real water net the balance equations are certainly more intricate because in each partial watershed there may be several users with different points of intake and discharge, several input and also output streams, and not all of them may be controlled. This causes increase in number of variables and complicates the notation, but it leaves unchanged the qualitative character of individual relations.

6. A Concept for Approximate Solution of WMS Problem

The optimization task as formulated above even with all the simplifications introduced is too complex to be solved on line as a whole. The basic difficulty lies in the inequality constraints (12) on probabilities. Hence, the following method for approximate solution is proposed:

Assume initially that there is a plan for water distribution for subsequent decades, defined with parameters

$$s_i^j = s_i^{*j}, \quad q_{di}^j = q_{di}^{*j}, \; q_i^j = q_i^{*j} \qquad (15)$$

$$\text{for } i=1,\dots,I; \quad j=1,\dots,J$$

For operative current control certain arbitrary, but intuitively well-based linear decision rules are introduced /see e.g. Ch.Revelle, E.Joeres, W.Kirby: The linear decision rule in reservoir management and design. 1/ Development of the stochastic model. Water Resources Research, 5(4), 1969, as well as other works in the field/. These rules define the relation of consumption by users q_{di}^j, q_i^j and outflows from reservoirs $x_i^{j,2}$ in current time intervals i to precipitation r_{i-1}^j, states of reservoirs s_{i-1}^j and to planned values s_i^{*j}, q_{di}^{*j}, q_i^{*j}:

$$\begin{bmatrix} q_{di} \\ q_i \\ *_i \end{bmatrix} = R_i \cdot \begin{bmatrix} q^{*}_{di} \\ q^{*}_{i} \\ s^{*}_{i} \\ s_{i-1}(\cdot) \\ r_i(\cdot) \end{bmatrix},$$

where R_i-matrix of appropriate dimensions,

$$T_i(\cdot) = \{ T_i, T_{i-1}, \dots \}^T,$$

$$S_{i-1}(\cdot) = \{ S_{i-1}, S_{i-2}, \dots \}^T. \qquad (16)$$

Taking into account (16) the upper-level optimization task - (11), (2'), (3), (4) - /the planning task within WMS/ - can be represented in the form:

$$\max_{q^{*},\, s^{*},\, q^{*}_{d}} \sum_{j=1}^{J} \hat{G}^j(q^{*j}_{d}, Mr^j) = \hat{G}^j(\hat{q}^{*j}_{d}, Mr^j) \qquad (17)$$

with

$$\left.\begin{array}{l} (2') \\ (3) \\ (4) \\ (16) \\ \text{distribution} \\ \text{functions of} \\ \text{random} \\ \text{disturbances} \end{array}\right\} \Rightarrow \quad A\hat{q}^{*} + B\hat{q}^{*}_{d} + C\hat{s}^{*} \leqslant d \qquad (18)$$

where Mr^j is an expected value of the random vector r^j. Matrices A, B and C result from the net structure (2'), and vector d depends on distribution functions of random magnitudes r_{fi}, r_{pi}, x^{o}_{i} and on guarantee parameters given.

Solving equation (17), (18) one obtains optimal values of plan parameters (15).

Such an approach was applied with good results to optimization problems for one-reservoir systems /see Revelle et al., op.cit./. For a complex net, comprising many reservoirs /e.g. the Upper Noteć System/ constraint (18) takes the form of vector inequality with very high dimensionality /several thousand components/, whose definition is connected with difficulties in explicit formulation of (2′) with regard to appropriate variables. This problem can be effectively solved through decomposition by taking advantage of specific features of water net. Additional decrease in problem′s dimensionality /for time-discrete form/ can be obtained by division of year into three periods: pre-vegetation, vegetation and post-vegetation, in which differing aims of water distribution are considered. For instance in the pre-vegetation period the final state of the reservoirs can be maximized with due account to various weights of reservoirs′ utilities resulting from their position in the net /flexibility in water handling/ and from losses of water in reservoirs.

Independently of these simplifying methods it should be anticipated that the effective solution of the optimization problem will necessitate its reformulation to linear or quadratic programming task.

Attention should also be paid to following specific feature of the problem (16) , (17). The fact that the criterion does not depend on s_i^* and that q_{di}^* and s_i^* are connected but through inequality constraints means that solutions of the problem do not yield unique values of s^* but rather certain feasible decision domain $A_{s^*}(\hat{q}_d^*)$. Inside $A_{s^*}(\hat{q}_d^*)$ the states of reservoirs can be chosen according to additional principles, ensuring the most flexible use of water: gathering of water in these reservoirs, from which the water is available to the greatest possible portions of the net and the losses of water are minimal. This additional task can be solved by linear programming.

7. Functioning of the Control System

Current realization of the above described plan for water distribution /operative control/ consists first of all in applying decision rules defining control of water consumption and reservoir outflows as adopted for the task of planning above.

In case of non-realizability of decision rules it is possible to modify currently s_i^* inside $A_{s^*}(\hat{q}_d^*)$ according to the principle of water gathering described in the planning task above.

Subsequent function of the operative control consists in distribution of water among various crops within one IS depending on the local hydrological conditions and on the state of culture /which, in turn, depends upon many random factors/. If this does not entail changes in q_{di}^j than additional, strict decision rules are not necessary in view of local effects of control. Otherwise the functioning must follow the decision rules, or, if they are not specified, the need may at some time point arise to solve anew the optimization /planning/ problem beginning with the current time point till the end of the year /hence in a shortened time horizon/.

In the water distribution model described here only the planning task for the whole WMS is being tackled centrally for the whole region. Optimization and operative control of individual IS's are realized locally, and for the purposes of planning IS's transmit to WMS aggregated values of criteria: $\hat{G}^j(q_d^j, Mr^j)$ for values of q_{di}^j proposed by WMS.

Operative control of WMS is, owing to application of decision rules, also realized locally for each reservoir and each user. This, however, necessitates the assumption that local decision makers observe the decision rules independently of their subjectively evaluated interests. In practice it may turn out that for persuading decision makers to follow decision rules more attention should be paid to their simplicity and possibility of testing and to psychological motivations of decision makers.

8. Final Remarks

The simplified method presented here makes it possible to effectively control the complex water net comprising a wide land area and many dispersed users.

Procedure proposed assumes existence of crop, soil moisture, and rainfall-runoff models. Each of these is in itself a serious problem, requiring vast amount of research work.

Of essential importance for the whole problem is determination of guarantee parameters, which should be defined from the viewpoint of global socio-economic tasks of the given region.

Appendix I

REGIONAL DEVELOPMENT MODELLING — LABOR, INVESTMENTS AND CONSUMPTION ALLOCATION POLICY IMPACT

by R. Kulikowski
IIASA

1. INTRODUCTION

In many countries, a growing demand for computerized regional models, which could be used for long term socio-economic planning exists. For example, in Poland, the planned economy requires that the decisions regarding the allocation of production factors (i.e. the productive capital and labor) are optimized at each regional level. A multilevel decentralized system of regional planning and management for that purpose exists (with the Planning Commission at the top and Voivodship Planning Units on the second level). The smallest administrative unit (gmina) consists usually of an urban center with an agriculture neighborhood.

Regional planners are concerned with the allocation of local resources, production, consumption and they exchange the information with higher level units. They would like to achieve the optimum local results while the higher levels are concerned with the coordination of local proposals with national goals and strategies. It is important that the local comparative advantages in production are utilized in the interest of the whole country, while the regional standard of living is maximized (though not at the expense of the rest of the country). The multiobjective goal structure and complex socio-economic factors involved require that a number of different regional policies, scenarios and strategies be investigated before a decision is taken.

Decision makers feel that a "good" computerized regional model may be very useful for the investigation of different developments and, in particular, the investment alternatives. The production factor's budget is usually predetermined by macro-economic analysis and a number of localization alternatives are being studied. It is belived that the investment localization decisions should take into account regional economic aspects (such as, agglomeration benefits) as well as socio-economic factors, including employment, migration, standard of living, environment, pollution, etc.

As a typical example, the large irrigation project in the Upper Notec Region in Poland can be mentioned. Since investment funds are limited, decision makers would like to know what the optimum size of the irrigation project should be. It is expected that the irrigation will increase the regional agriculture production. However, the agriculture output depends on (besides water) other factors including firstly the labor force which is presently migrating out of the region. There is a large percentage of small, privately owned, farms in the Notec Region which can hardly utilize the benefits of large scale irrigation. The structural and technological change, which takes place in the Polish agriculture, has also an important impact on the production efficiency. All this indicates that the estimation of the benefits of the Notec Project as well as the investment size of the project, is not easy and can hardly be done without a good regional policy model.

The present paper is concerned with the methodology of policy-oriented models for the evaluation of investments and consumption impacts on regional growth. The region is regarded as part of a larger region or the whole country. The optimum labor allocation and economic benefits resulting out of labor migrations have been derived for Polish Voivodships system. Then the migration models and the cost of migration were studied. An attempt has been made to endogenize the migration model within the regional model structure. Using these results, the regional policy model was proposed and analyzed.

2. OPTIMUM LABOR ALLOCATION AND ECONOMIC IMPACT OF LABOR MIGRATIONS

Consider the model of n regions, R_i, $i = 1,\ldots,n$, within a given country, each including the rural (A_i) and urban (U_i) part, as shown in Figure 1. The number of workers at A_i and U_i are denoted by L_{ia} and L_{iu} respectively. Introduce also the notion

$$L_i = L_{ia} + L_{iu} \quad , \qquad i = 1,\ldots,n \quad ,$$

$$L = \sum_{i=1}^{n} L_i \quad ,$$

$$a_i = \frac{L_i}{L} \quad , \qquad a_{ia} = \frac{L_{ia}}{L_i} \quad , \qquad i = 1,\ldots,n \quad .$$

The number of rural and urban migrants per year (M_{ia}, M_{iu}) determine the net (balance) urban inflow:

$$\overline{S}_i = M_{ia} - M_{iu} \quad , \qquad i = 1,\ldots,n \quad .$$

In a similar way, the net inflow of migration for region R_i is:

$$S_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} M_{ji} \quad , \qquad i = 1,\ldots,n \quad ,$$

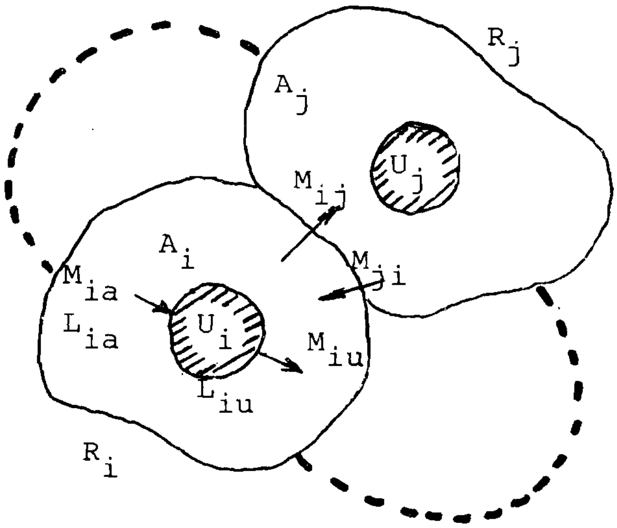

Figure 1. A model of systems of regions R_i, each including a rural A_i and urban U_i part.

where

M_{ji} = inflow of migrants from R_j to R_i ($M_{ji} = -M_{ij}$) .

The regional economy is described by the so called "Cobb-Douglas" production function:

$$X_i = A_i L_i^{\beta_{1i}} K_i^{\beta_{2i}} \quad , \quad \beta_{1i} + \beta_{2i} = \beta_i \quad , \tag{1}$$

where

X_i = regional product

K_i = regional productive capital

A_i, β_{1i}, β_{2i} = given positive coefficients

According to the general theory developed in [3], the inputs K_i, L_i satisfy the nonlinear, monetary constraints:

$$\omega_1 L_i^{\gamma_{1i}} \leq Z_i \quad ,$$

$$\omega_2 K_i^{\gamma_{2i}} \leq C_i \quad ,$$

where ω_1, ω_2 are the prices (i.e. wages and rent of capital) attached to L_i, K_i while L_i, C_i are the cost of labor and capital.

As shown in [3] the regional agglomeration creates the of scale benefits (i.e. $\beta_i > 1$) but at the same time the increased input costs (i.e. $\gamma_{1i} > 1$, $\gamma_{2i} > 1$) appear, which counter balance the of scale benefits.

The regional economy is supposed to operate under optimal conditions, i.e. the allocation of capital and choice of production technology over time and space follows the labor available (or vice-versa), as in [3]:

$$\hat{K}_i = [\frac{C_i}{Z_i} \frac{\omega_1}{\omega_2} L_i^{\gamma_{1i}}]^{\frac{1}{\gamma_{2i}}} , \tag{2}$$

while C_i, Z_i are chosen in such a way that:

$$\hat{C}_i/\hat{Z}_{1i} = {}^{\alpha_{2i}}/_{\alpha_{1i}} , \quad \alpha_{2i} = {}^{\beta_{2i}}/_{\gamma_{2i}} , \quad \alpha_{1i} = {}^{\beta_{1i}}/_{\gamma_{1i}} \tag{3}$$

Under this strategy, the output production in monetary terms $Y_i = p_i X_i$ (where p_i = marginal production cost) attains a maximum subject to the condition that the output generated is accrued to the factor endowments, i.e. $Y_i = C_i + Z_i$ $(\alpha_{1i} + \alpha_{2i} = 1)$.

As shown in [3] the unknown paramters p_{1i}, p_{2i}, γ_{1i}, γ_{2i} and prices ${}^{\omega}2/\omega_1$, p_i can be estimated from the statistical data regarding ${}^{K}i/_{L_i}$, L_i, ${}^{Y}i/_{L_i}$. Assuming for this purpose that the regional economy operates under the optimality conditions of (2) and (3), one has to fit the relations:

$$\log \frac{Y_i}{L_i} = \log c_{1i} + b_{1i} \log L_i , \tag{4}$$

$$\log {}^{K}i/_{L_i} = \log c_{2i} + b_{2i} \log L_i , \tag{5}$$

where

$$c_{1i} = p_i A_i c_{2i}^{\beta_2} , \quad c_{2i} = (\frac{\alpha_{2i}}{\alpha_{1i}} \frac{\omega_1}{\omega_2})^{\frac{1}{\gamma_{2i}}}$$

$$b_{1i} = {}^{\gamma}1i - 1 , \quad b_{2i} = \frac{\gamma_{1i}}{\gamma_{2i}} - 1 ,$$

to the statistical data available.

An important task is to estimate the production function parameters for major regions of the country. In Poland, for example, the regional data are being collected according to the Voivodship structure. There were 17 Voivodships before 1976 and according to the new admistrative division, there are presently 50 Voivodships in Poland. Since the time sequences are rather short, [7], the cross-regional estimation approach is most advisable. It gives 17 or 50 samples for a chosen year but at the same time some regional properties are inevitably neglected. A combination of cross-regional and time analyses is therefore more appropriate. As an example, in Table I the data for 17 Voivodships in 1973 have been given. Using least squares and assuming $\gamma_{1i} = \gamma_1$, $\gamma_{2i} = \gamma_2$, $i = 1,\ldots,17$, the estimates $\gamma_1 = 1.10$, $\gamma_2 = 1.09$ have been derived and the corresponding values of $\beta_{1i} = \gamma_1\alpha_{1i}$, $\beta_{2i} = \gamma_2(1-\alpha_{1i})$ were computed. However, the fitting under the assumption $\gamma_{1i} = \gamma_1$, $\gamma_{2i} = \gamma_2$, $i = 1,\ldots,17$ does not seem to be the best possible and a combination of a cross-regional and time series estimation is planned in future. The regions should then be grouped according to the economic specialization.

It should be observed that the urban and rural production functions (within each region R_i) can be written in a form similar to (1), i.e.,

$$X_{iu} = A_{iu}L_{iu}^{\beta_{1iu}}K_{iu}^{\beta_{2iu}} \quad ,$$

$$X_{ia} = A_{ia}L_{ia}^{\beta_{1ia}}K_{ia}^{\beta_{2ia}} \quad ,$$

and the β_{jiu}, β_{jia}, γ_{jiu}, γ_{jia}, $j = 1,2$, paramters can also be estimated by using corresponding statistical data.

The main problem which faces us in the present section is the derivation of optimum regional employments $L_i = \hat{L}_i$, $i = 1,\ldots,n$, which maximize the gross national (or regional) product:

Table 1

Estimation of Production Function Parameters for Polish Voivodships

$\alpha_{1i} + \alpha_{2i} = 1$, $\gamma_1 = 1.10$, $\gamma_2 = 1.09$

No.	Voivodship	$L_i \cdot 10^3$	$\frac{K_i}{L_i}$[zl 10^3]	$\frac{Y_i}{L_i}$ [zl]	α_{1i}	β_{1i}	β_{2i}
1	Bialostockie	533.4	114.7	51487	0.63	0.69	0.40
2	Bydgoskie	722.1	180.4	64191	0.66	0.73	0.37
3	Gdanskie	576.3	230.5	92605	0.63	0.69	0.40
4	Katowickie	1682.5	207.9	92611	0.63	0.69	0.40
5	Kieleckie	925.6	107.5	52974	0.60	0.66	0.44
6	Koszalinskie	314.4	181.0	54039	0.66	0.73	0.37
7	Krakowskie & Krakow	1222.5	164.8	74919	0.70	0.77	0.33
8	Lubelskie	923.0	109.9	49291	0.67	0.74	0.36
9	Lodzkie & Lodz	1124.5	121.9	79325	0.65	0.72	0.38
10	Olsztynskie	385.6	196.2	54627	0.67	0.74	0.36
11	Opolskie	446.9	224.5	71902	0.70	0.77	0.33
12	Poznanskie & Poznan	1082.3	179.2	70708	0.67	0.74	0.36
13	Rzeszowskie	860.8	124.3	57105	0.63	0.69	0.40
14	Szczecinskie	381.8	261.8	80938	0.61	0.66	0.42
15	Warszawskie & Warszawa	1673.2	146.3	93032	0.66	0.72	0.37
16	Wroclawskie & Wroclaw	1044.1	217.1	81342	0.71	0.78	0.32
17	Zielonogorskie	362.7	202.6	69529	0.64	0.71	0.39
18	POLAND	14311.7	167.8	73654	0.66	0.72	0.37

$$X = \sum_{i=1}^{n} X_i \tag{6}$$

subject to the condition that the total employment is not greater than given number L, i.e.

$$\sum_{i=1}^{n} L_i \leq L \quad . \tag{7}$$

Since the regional macrodata, regarding production and capital, are usually given in monetary terms, the problem (6) and (7) can also be expressed (by elimination of $L_i = (\frac{Z_i}{\omega_1})^{\frac{1}{\gamma_{1i}}}$ and $K_i = (\frac{C_i}{\omega_2})^{\frac{1}{\gamma_{2i}}}$) in the form:

$$\max_{Z_i \in \Omega} \sum_{i=1}^{n} F_i^{q_i} Z_i^{\alpha_i} \quad , \tag{8}$$

where

$$\Omega = \{Z_i | \sum_{i=1}^{n} Z_i \leq Z \quad , \quad Z_i \geq 0 \quad , \quad i = 1,\ldots,n\} \tag{9}$$

$$F_i^{q_i} = p_i A_i \omega_1^{-\alpha_i} [\frac{C_i}{\omega_2}]^{q_i} \quad , \quad \alpha_i = \frac{\beta_{1i}}{\gamma_{1i}} \quad , \quad q_i = 1 - \alpha_i \quad ,$$

Z_i, Z = regional and total labor cost respectively.

The optimization problem formulated in the case when $\alpha_i = \alpha$, i = 1,...,n, can be solved explicitly. Indeed, since the objective function (8) is strictly concave in the compact set Ω the unique solution $Z_i = \hat{Z}_i$, i = 1,...,n exists and can be easily derived [3]:

$$\hat{Z}_i = \frac{F_i}{F} Z \quad , \quad i = 1,\ldots,n \quad ,$$

where

$$F = \sum_{i=1}^{n} F_i \quad .$$

When $Z_i = \omega_1 L_i$, $i = 1,...,n$ the last relations can be written in the simpler form:

$$\hat{L}_i = \frac{G_i}{G} L \quad , \quad i = 1,...,n \quad , \tag{10}$$

where

$$G = \sum_{i=1}^{n} G_i \quad , \; G_i = L_i y_i^{1/q} \quad ,$$

$y_i = \frac{Y_i}{L_i}$ = labor efficiency, i.e. production per worker.

In order to estimate the labor shortages in the given region, one can introduce the indices:

$$x_i = \frac{\hat{L}_i - L_i}{L_i} \quad , \quad i = 1,...,n \quad ,$$

the additional labor needed with respect to the existing employment L_i. When $\hat{L}_i < L_i$ one can say that there exists an excess of labor in the region studied.

Since

$$x_i = \frac{L_i}{a_i L} - 1 = \frac{G_i}{a_i G} - 1$$

and

$$G_i = L_i y_i^{1/q} \quad ,$$

one obtains:

$$x_i = [\sum_{j=1}^{n} a_j b_{ij}]^{-1} - 1 \quad , \quad b_{ij} = ({}^{y_j}/_{y_i})^{1/q} \quad , \quad i = 1,...,n \tag{11}$$

Taking into account that $G_i = (p_i A_i)^{1/q} K_i$ one can see that the shortages of labor in the region R_i increase along with new capital investments, i.e. ${}^{K_i}/_{K_j}$.

In the case of $x_i \neq 0$, $i = 1,\ldots,n$, one can derive the losses due to the nonoptimum allocation of labor in terms of GNP. For this purpose it is necessary to derive the difference $\Delta = \bar{Y} - Y$ between the GNP generated under the optimum allocation of labor resources ($\bar{Y}$) and the real GNP generated (Y).

It can easily be shown that

$$\bar{Y} = G^q L^\alpha \quad ,$$

while

$$Y = \sum_{i=1}^{n} G_i^q L_i^\alpha \quad .$$

Then,

$$\Delta = \bar{Y}\ [1 - \sum_{i=1}^{n} (\frac{G_i}{G})^q\ (\frac{L_i}{L})^\alpha\ ] = \bar{Y}\ [1 - \sum_{i=1}^{n} a_i\ (\sum_{j=1}^{n} a_j b_{ij})^{-q}\ ] \quad (12)$$

Another important index of economic benefits is the GNP increase resulting from elementary (S_i = one worker) in migration:

$$\sigma_i = \frac{\partial Y(S_i)}{\partial S_i} \Big|\ S_i = 0 = - \frac{\partial \Delta(S_i)}{\partial S_i} \Big|\ S_i = 0 \quad ,$$

where

$$Y(S_i) = \sum_{i=1}^{n} G_i^{q_i} (L_i + S_i)^{\alpha_i} \quad , \quad \sum_{i=1}^{n} S_i = 0 \quad .$$

One easily finds

$$\sigma_i = \alpha_i G_i^{q_i} L_i^{\alpha_i - 1} = \alpha_i \frac{Y_i}{L_i} \quad ,$$

or

$$\sigma_i = \alpha_i y_i \quad , \qquad i = 1,\ldots,n \quad . \qquad (13)$$

For "small" labor migrations S_i, one can also write:

$$\Delta(S_i) \cong - \sum_{i=1}^{n} \sigma_i S_i \quad .$$

In the case when the system of regions is closed with respect to migrations $\sum_{i=1}^{n} S_i = 0$.

The general formulae (11) and (13) for the case of two (closed with respect to migration) regions, i.e. $x_1 = -x_2 = x$, $(S_1 > 0,\ S_2 < 0,\ {}^{y_2}/_{y_3} < 1)$ yield:

$$x = \left[\frac{L_1}{L} + \frac{L_2}{L}\left(\frac{y_2}{y_1}\right)^{\frac{1}{q}}\right]^{-1} - 1 \quad ,$$

$$\sigma_1 = \alpha_1 y_1 \quad , \quad \sigma_2 = -\alpha_2 y_2 \quad ,$$

and the resulting benefit is $\bar{\sigma} = \alpha_1 y_1 - \alpha_2 y_2$. Then the total benefit to the subregion R_i consisting of rural (with $y_{ia} = \frac{Y_{ia}}{L_{ia}}$) and urban (with $y_{iu} = \frac{Y_{iu}}{L_{iu}}$, $L_{ia} + L_{iu} = L_i$, $Y_{ia} + Y_{iu} = Y_i$) parts becomes:

$$\bar{\sigma}_i = \alpha_{iu} y_{iu} - \alpha_{ia} y_{ia} \quad . \qquad (14)$$

In order to facilitate the computation of economic benefits resulting from the migrations in Table II the basic data for the system of Voivodships in Poland are given. These data were chosen from the Main Statistical Office (G.U.S.) publications [7] and the results of the estimation of α_i parameters given in Table I were also taken into account. The value of α (for the computation of x_i has been assumed equal $\alpha = \frac{1}{3}$ $(q = \frac{2}{3})$ which is close to the average value of $\alpha = 0.66$. For the agriculture part of the regional economy, the value of $\alpha = 0.68$ has been assumed. The reason is that the rural-urban migration comes mostly from small private farms with a production function having α close to 0.68 (see [4]).

Table II

Economic Benefits Resulting out of Migrations Among Polish Voivodships in 1973

No.	Voivodship	$a_i = \frac{L_i}{L}$	$a_{ia} = \frac{L_{ia}}{L_i}$	$a_{iu} = \frac{L_{iu}}{L_i}$	$\frac{Y_{iu}}{Y_{ia}}$	X_i (%)	σ_i (zl)	$\bar{\sigma}_i$ (zl)
1	Bialostockie	0.0373	0.579	0.421	2.550	-69.71	32437	32897
2	Bydgoskie	0.0539	0.388	0.612	1.798	-58.66	42366	23397
3	Gdanskie	0.0403	0.234	0.766	2.738	76.24	58391	46940
4	Katowickie	0.1176	0.117	0.883	4.176	76.27	58345	52567
5	Kieleckie	0.0646	0.485	0.515	3.518	-66.17	31784	39528
6	Koszalinskie	0.0219	0.444	0.536	2.123	-64.67	35666	25416
7	Krakowskie & Krakow	0.0855	0.370	0.630	5.076	- 6,70	52443	58205
8	Lubelskie	0.0645	0.609	0.391	2.790	-73.41	33025	35282
9	Lodzkie & Lodz	0.0786	0.346	0.654	3.560	11.25	51561	51635
10	Olsztynskie	0.0269	0.497	0.503	3.257	-63.83	36600	35693
11	Opolskie	0.0313	0.354	0.646	2.939	-17.52	53366	42081
12	Poznanskie & Poznan	0.0756	0.390	0.610	2.173	-21.40	47374	32861
13	Rzeszowskie	0.0602	0.507	0.493	4.529	-56.68	35976	49984
14	Szczecinskie	0.0266	0.314	0.686	2.754	17.65	53419	43795
15	Warszawskie & Warszawa	0.1169	0.329	0.671	3.383	78.70	61401	58005
16	Wroclawskie & Wroclaw	0.0729	0.249	0.751	2.703	19.40	57752	39976
17	Zielonogorskie	0.0254	0.361	0.639	3.145	-25.41	44497	42764

Then, using formulae (11), (13) and (14), the values of x_i,[*] σ_i, $\bar{\sigma}_i$ have been derived and given in Table II. It is interesting to observe that the mostly agricultural Voivodships (e.g. No. 1, 5, 6, 8, 10 and 13) possess large surplusses of labor (x_i is around -70%), while the industrial regions (e.g. No. 3, 4 and 15) have considerable shortages of labor. When a worker is transfered from the Voivodship No. 1 (where $x_i \simeq 70\%$) the net benefit to the national economy is $\sigma_4 - \sigma_1$ which is 58345 zl - 32437 zl = 25908 zl. That benefit is over 62% larger than the similar benefit for the migration to Voivodship No. 2, i.e. 58345 zl - 42366 zl = 15979 zl.

At the same time the benefits to the Voivodship No. 2, when one worker migrates from a rural to an urban area (within the Voivodship No. 2) is:

$\bar{\sigma}_2$ = 23387 zl.

It is possible to observe that using the indices of Table II, one can easily compute the economic benefits for a given migration structure provided the migration rates $\frac{S_i}{L_i}$ are small numbers. In the last years, the intervoivodship migration rates were not larger than a few percent. In the case of larger migration rates, the approximation of $Y_i(S_i)$ by $\sigma_i S_i$ is not accurate enough and one has to use the general Δ expression (12).

It should also be observed that the method of evaluation of economic benefits discussed can also be applied in the case of a decentralized administrative system of regions, in which each Voivodship is subdivided into smaller units (such as, for example,

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[*]The computation of x_i was done by W. Kulikowska.

"gmina" and "solectwo" in Poland). The decentralized system of data acquisition, existing in Poland, enables the computation of σ_i, $\bar{\sigma}_i$ indices.

3. MIGRATION MODELS AND THE COST OF MIGRATION

An abundant literature exists on rural-urban and inter-regional migration models (see, for example, [2] and [6]). Regarding the migration and settlement system in Poland, relevant information and useful data are included in [1]. The present paper is concerned with formal migration models. The basic idea employed rests on the assumption that the potential migrants base the decision to move on the ratio of utilities $U = {}^{U_2}/_{U_1}$, attached to the source residence area (R_1) and the destination residence area R_2.

Since the number of migrants in a large population is proportional to the population size (P_2) it has become customary to deal with the migration rate $s_2 = {}^{S_2}/_{P_2}$, where S_2 is the net (balance) number of migrants coming to region R_2 from region R_1. Generally, the migration rate depends also on the distance between R_1 and R_2. For the concrete regions chosen, the distance may be regarded however as a constant parameter.

A typical migration model of the two regions (R_1, R_2) system can be described by the relation:

$$\frac{P_2 + S_2}{P_2} = 1 + s_2 = d\,\frac{U_2}{U_1} \,, \qquad d = \text{constant} \,. \tag{15}$$

The utilities U_1, and U_2 are assumed as the product of $F_\nu^{\alpha_\nu}$ indices:

$$U = \frac{U_2}{U_1} = \prod_{\nu=1}^{m} F_\nu^{\alpha_\nu} \,, \qquad F_\nu = \frac{f_\nu^{\,2}}{f_\nu^{\,1}} \,, \tag{16}$$

where

f_ν^i $(i = 1, 2)$ = factors influencing migrants' decisions, such as income, personal and aggregate consumption level, jobs and housing available, service level, environment pollution, social amenities, etc;

α_ν = positive numbers, $\sum_{\nu=1}^{m} \alpha_\nu \leq 1$.

Since

$$\alpha_\nu = \frac{dU}{U} : \frac{dF_\nu}{F_\nu} \quad , \qquad \nu = 1,\ldots,m \quad ,$$

one can say that α_ν express the migrants' sensitivity to the elementary change of the F_ν index. When α_ν is close to zero the corresponding index can be dropped from the migration model.

When the model is supposed to be used for socio-economic planning, the general methodology can be summarized as follows:

a) try to fit the model (ex post) to the available regional data by using regression analysis, i.e. estimate the values of d and α_ν, $\nu = 1,\ldots,m$, parameters; and

b) assuming that the migrants' behavior and residential preferences do not change much over time, use the model in the ex ante sense.

The main problem when one wants to use this methodology to construct models for rural-urban and interregional migration in Poland, is the scarcity or absence of (long enough) time sequences regarding many import f_ν factors. For example, the values of regional, personal, and aggregate consumptions were not collected in a systematic way (the data for 1960, 1965, 1970, and 1973 are available only). The demographic and housing related data are, however, complete and available. That enables the construction of housing and employment submodels which, generally speaking, have a considerable impact on migration in Poland. In order to show how these submodels can be constructed consider firstly the housing submodel.

The availability of housing for a family, at a given region, can be characterized by the factor:

$$f_h = \frac{a}{h} = \frac{\text{number of apartments available}}{\text{number of existing households}} \tag{17}$$

Since each year t, a number n(t) of new apartments is constructed, and a fraction $\delta a(t)$ is demolished the following first order difference equation

$$\Delta a(t) + \delta a(t) = n(t) \quad , \quad \Delta a(t) = a(t) - a(t-1) \quad ,$$

should hold.

Then, given the initial condition a(0) the number of apartments at the year t becomes

$$a(t) = a(0)e^{-\delta t} + \sum_{\tau=0}^{t} e^{-\delta(t-\tau)} n(\tau) \quad . \tag{18}$$

The model for the number of households h(t) can be constructed in a similar form, i.e.:

$$h(t) = h(0)e^{-\vartheta t} + \sum_{\tau=0}^{t} e^{-\vartheta(t-\tau)} m(\tau) \quad , \tag{19}$$

where

$m(\tau)$ = number of marriages in the year τ

ϑ = fraction of households dissolved (by death or divorce).

The unknown parameters δ, ϑ can be estimated using the relations:

$$\delta = \frac{n(t) - [a(t) - a(t-1)]}{a(t)} \quad ,$$

$$\vartheta = \frac{m(t) - [h(t) - h(t-1)]}{h(t)} \quad .$$

Using the statistical data published annually by the Main Statistical Office in Poland [7], one can estimate (by linear regression), the δ, ϑ parameters. The estimates (average for the whole country) are: $\delta = 0{,}00389$, $\vartheta = 0{,}01817$. The value of $f_h(1974)$ for urban areas was $f_{hu} = 0{,}844$ and $f_{hr} = 0{,}893$ for rural areas. The crossregional analysis shows that these estimates change according to the housing construction and demography.

Since $\frac{f_{hu}}{f_{hr}} = \frac{0{,}844}{0{,}893} = 0.945$, an average migrant contemplating to move in 1974 from a rural or urban area was, generally speaking, discouraged by housing shortages. However, besides housing, the other indices were prevailing, and the rural → urban migration was, in most regions in 1974, positive.

The next important submodel of migration deals with employment. The regional employment impact on migration can be described by the number of jobs e(t) to the productive part of the population Z(t) ratio, i.e.

$$f_e = \frac{e(t)}{Z(t)} \quad . \tag{20}$$

The model for e(t) takes into account the productive capital K(t) which is created by investments i(t), i.e.,

$$e(t) = A\left[K(0)e^{-\delta t} + \sum_{\tau=0}^{t} e^{-\delta(t-\tau)} i(\tau)\right] \quad ,$$

where

$$A = \frac{e(0)}{K(0)} \quad .$$

The population in the production age Z(t) can be derived by using a regional standard demographic submodel.

A characteristic feature of the models described by (17) to (20) is that the index level in the given year t depends not only on the inputs n(t), m(t) and i(t) in the year t, but also on the inputs in all the previous years t - 1, t - 2,..., etc.

From the computational point of view, more simple are the models in which $f_\nu(t)$ depends on the inputs instantly. A typical model of this type deals with the personal and/or aggregate consumption per head index, i.e.:

$$F_c = \frac{c_2}{c_1} \quad \text{, where } c_i,\ c_2 = \text{consumption per head in } R_i,\ R_2 \qquad (21)$$

Since the net (balance) migration is the most important factor in the regional employment models, it is also possible to construct models in which the regional indices f_ν are compared with the average national indices $\bar{f}_\nu$. In this case, instead of (21) one can write:

$$F_{ci} = \frac{c_i}{\bar{c}} = 1 + \frac{\Delta c_i}{\bar{c}} \quad , \quad \Delta c_i = c_i - \bar{c} \quad , \quad i = 1,\ 2.$$

In the case of n regions, the last model deals with n components instead of $n(n-1)/_2$ components, which are necessary to describe the individual interregional migrations.

As an example, in Table III the data $\frac{c_i}{\bar{c}}$ for the 17 Voivodships in Poland and the corresponding migration rates s_i and z_i (net number of migrants in productive age over the population) in 1973 have been given. Using these data it is possible to compare how much the migrant's consumption will change when he changes his residence area. For example when a migrant moved

Table III

Migration Rates and Consumption Distribution Among Polish Voivodships in 1973.

No.	Voivodships	Migration rates		Consumption $c_i/\bar{c}$	
		$s_i \cdot 10^{-3}$	$z_i \cdot 10^{-3}$	Total	Personal
1	Bialostockie	-4.313	-0.205	0.821	0.827
2	Bydgoskie	-0.533	-0.526	0.932	0.939
3	Gdanskie	3.553	2.651	1.106	1.108
4	Katowickie	4.956	3.398	1.125	1.121
5	Kieleckie	-3.960	-2.981	0.798	0.807
6	Koszalinskie	-0.782	-0.289	1.053	1.053
7	Krakowskie & Krakow	0.0536	0.007	0.968	0.959
8	Lubelskie	-3.051	-2.310	0.820	0.829
9	Lodzkie & Lodz	-0.635	-0.650	0.963	0.962
10	Olsztynskie	-3.704	-2.131	0.936	0.924
11	Opolskie	0.119	0.033	0.983	0.970
12	Poznanskie & Poznan	-0.258	-0.225	0.980	0.994
13	Rzeszowskie	-1.146	-0.989	0.817	0.819
14	Szczecinskie	1.387	1.219	1.160	1.167
15	Warszawskie & Warszawa	2.380	1.733	1.172	1.189
16	Wroclawskie & Wroclawa	-2.315	-1.385	1.086	1.048
17	Zielonogorskie	-1.138	-0.460	0.995	0.985

from Voivodship No. 1 to No. 4 in 1973; his consumption increase was $\frac{\Delta c}{\bar{c}}$ = 1.125 - 0.821 = 0.304, i.e. 30.4% above the average national consumption level $\bar{c}$. The increase out of personal income was (1.121 - 0.827) x 100% = 29.4%, while the increase in the aggregate consumption, i.e. the social and environmental services was even larger: (1.143 - 0.79) x 100% = 35.3%.

Using the (long enough) time sequences of the s_i, $c_i/\bar{c}$ data it is possible to construct a simple econometrical migration model of the following form:

$$\log (s_i + 1) = \log d_i + \alpha_i \log \frac{c_i}{\bar{c}} \ , \quad i = 1,\dots,n \ , \qquad (22)$$

where the unknown paramters α_i, d_i can be determined by linear regression.

In the model (22), all the factors, such as availability of jobs and housing, environmental and social amenities, are represented by the single parameter d_i. It is also tacitly assumed that the migrants react strongly to the change of personal and aggregate consumption level. Despite the evident shortcomings of the last model, it is attractive for planning purposes. The reason is that using model (22) one can easily derive by (13) the socio-economic costs connected with migration, i.e.

$$C_i(s_i) \cong \Delta c_i s_i P_i \ , \quad i = 1,\dots,n \ . \qquad (23)$$

Since (22) can be written as:

$$1 + \frac{\Delta c_i}{\bar{c}} = \frac{c_i}{\bar{c}} = \left(\frac{s_i+1}{d_i}\right)^{\frac{1}{\alpha_i}} \ , \quad \Delta c_i = c_i - \bar{c} \ ,$$

one can compute the cost components:

$$C_i(s_i) = s_i P_i \bar{c} \; [(\frac{s_i+1}{d_i})^{\frac{1}{\alpha_i}} - 1] \quad , \quad i = 1,\ldots,n \quad . \qquad (24)$$

The estimation of α_i, d_i parameters by fitting (22) to the statistical data have a yield for Voivodships Nos. 2, 5, 8, 9, 11 and 17: $\alpha \approx 0.0166$, $d \approx 1,0005$. For Voivodships Nos. 1, 3, 4 and 7: $\alpha \approx 0.025$, $d \approx 1,0002$. For large cities like Warsaw Krakow, Lodz, and Poznan, $\alpha = 0.05$ while $d = 0.994$. It should be observed that the elasticities connected with the impact of regional consumption change on the migration rate (α) are generally small numbers. As a result, the corresponding cost functions (24) increase (along with s_i) very fast.

4. REGIONAL POLICY MODEL

One of the most important goals in regional socio-economic planning is to achieve such an allocation of production factors over space and time that at each region, the productive capital is used in the right proportion to the productive employment. Due to the demographic differences and migrations, the labor force is allocated over time and space in varying proportions. Besides, capital is not frequently attracted to these areas which have the largest labor resources. As a result, the labor efficiency Y_i/L_i varies for different regions R_i, $i = 1,\ldots,n$, and a loss in national product $Y = \sum_{i=1}^{n} Y_i$ follows. National economic planners, who are mostly concerned with the GNP(Y), would like to allocate the labor force in such a way that Y is maximized. For that purpose they look at the region with an excess of labour ($x_i < 0$) as a potential labor reservoir. There are, of course, two possible ways or policies to utilize the excess regional labor resources.

The first is connected with the localization of new productive investments in the region discussed. The second consists in encouraging potential migrants to migrate into the regions in which there is a shortate of labor force. The last policy requires that the regional benefits ($\frac{c_i}{\bar{c}}$, $i = 1,\ldots,n$) housing, etc. should be regarded as the policy variables stimulating the optimum migration flows. In oder to decide on the best possible policy, a cost-benefit analysis should be carried out. As previously shown in Section 2, the right flow of migrants produces a gain to the economy R_i, which is (for the small migration rates s_i), equal to

$$\sigma_i s_i e_i P_i \quad , \tag{25}$$

where e_i is the employed migrants share in s_i (in the case when e_i data are not available, one can assume that e_i is equal to the employment share in the destination region population).

At the same time, the migration cost (24) appears so the resulting benefit is:

$$B_i(s_i) = \sigma_i s_i e_i P_i - C_i(s_i) \quad , \quad i = 1,\ldots,n \quad . \tag{26}$$

Then, the general problem of finding the optimum $s_i = \hat{s}_i$, $i = 1,\ldots,n$ which maximizes $\sum_{i=1}^{n} B_i(s_i)$ subject to the constraint: $\sum_{i=1}^{n} s_i = 0$, can be solved. Since $B_i(s_i)$ is a strictly concave function, the optimum $\hat{s}_i$, $i = 1,\ldots,n$ exist and they are unique.

The necessary condition for rural-urban migration optimality requires that $B_i'(s_i) = \bar{\sigma}_i e_i L_i - C_i'(s_i) = 0$ or (introducing (24)):

$$\left(\frac{1+s_i}{d_i}\right)^{\frac{1}{\alpha_i}} \left[1 + \frac{s_i}{\alpha_i(1+s_i)}\right] = b_i \quad , \tag{27}$$

where

$$b_i = \frac{\sigma_i e_i}{\bar{c}} + 1 \quad , \quad i = 1,\ldots,n \quad .$$

It can be verified that for all the Voivodships, the existing migration rates are below $\hat{s}_i$, $i = 1,\ldots n$, computed by (27). That can be explained by observing that the change of regional allocation of consumption does not represent the total costs accrued to the interregional migration. The urban infrastructure construction and environment pollution costs may be listed as additional components. Another important migration limiting factor is the availability of jobs and housing, which are in limited supply due to the limitation of regional investment funds. It should be observed that housing cost per apartment and data for migration costs of urban construction per additional resident or migrant in major Polish urban centers are available.

An extended version of the model (22) should therefore include (in the place of d_i), the housing (17) and employment component (20).

The complete structure of such a model, containing the demographic, employment, economical, consumption, housing, and environment submodels, is shown in Figure 2. The model is supposed to be used for planning purposes in countries with planned economies, with decentralized planning, and decision structures. Each regional planning and decision unit is concerned

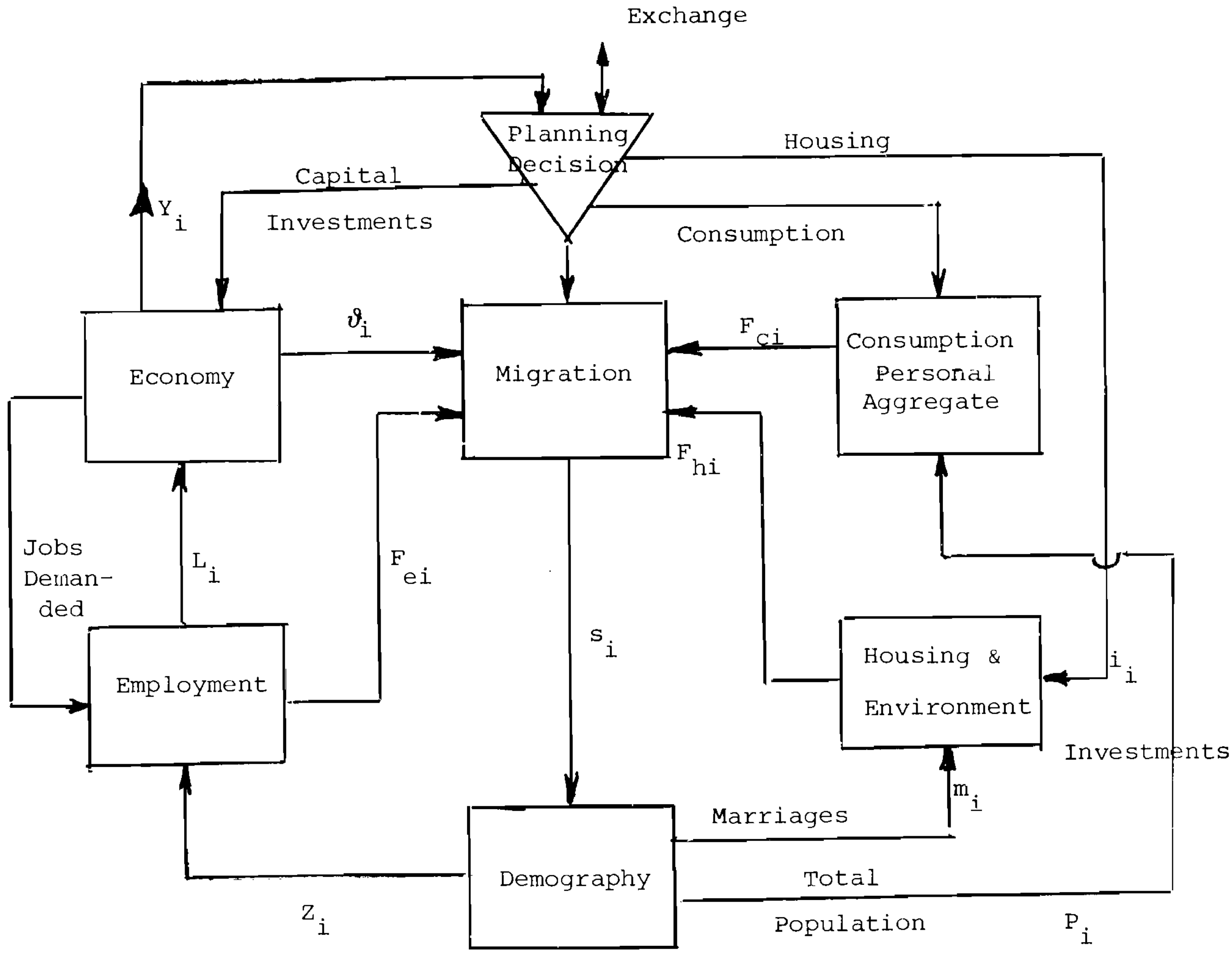

Figure 2. Regional Policy and Migration Model

with allocation of regional product Y_i among investments, personal and aggregate consumption (i.e. services, housing, environment, etc.) and it exchanges information with the higher order planning and decision units. Any decision regarding new productive investments affects the production output Y_i and the employment index (F_{ei}) which, together with housing and consumption per head indices (F_{hi}, F_{ci}) affect the migration rate (s_i). The economic part supplies the migration submodel with information (σ_i) regarding the migration benefits while consumption and housing blocks supply the migration cost components. The migration rate is sent to the regional demographic submodel, which derives each year the productive population (Z_i), marriages (m_i) and total population (P_i) needed for computation of F_{hi} and F_{ci} indices. The model can be used for forecasting the regional production, employment, consumption, migration, etc. processes.

In order to construct a model for investigation of rural-urban interactions and development it is necessary to split the basic blocks of Figure 2 into two separate submodels. Since the rural economy in many countries (including Poland) contains the privately owned farms, the level of capital investments, as well as consumption, cannot be controlled directly, (e.g., by changing wages as is being done in the case of urban consumption). The indirect control of rural capital investments and consumption can be achieved by influencing the input and output prices which affect the private farming sector. The agriculture economic model which uses such an approach and is capable of cooperating with the rest of the submodels (within the model of Figure 2) has been described elsewhere [4].

It should be observed that in order to run the regional model successfully it is necessary to exchange the information regarding the level of regional investments, labor efficiencies Y_i/L_i, consumption levels c_i, etc. with the higher level planning unit which compares the indices and decides what the optimum regional participation should be in national production and consumption. The higher level planning unit usually proposes a sectorial investment plan based on the compromise between the economic efficiencies and regional equities. The regions come out with their own proposals and the final version of the investment plan is a result of coordination of the sectorial (called in Poland "vertical") plans with the regional (called "horizontal) versions of the investment plan, [8]. The of scale benefits usually favor the industrial and urbanized regions within the country. In order to stimulate the growth of rural regions a nubmer of policy instruments are being used. For example, in Poland, the structural and technological change of agriculture takes place. It consists in the aggregation of small private farms and an increase of the number of large, state owned farms. The latter use more productive capital, irrigation and specialize in production, which has a considerable impact on the increase of agricultural efficiency and rural growth.

In order to investigate different regional investment strategies and their impact on production, employment, inter-regional migrations and consumption levels, the computer operated regional policy model, shown in Figure 2, can be used. In countries with planned economies, such as Poland, basic statistical data exist, which make the construction of the model proposed quite feasible.

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APPENDIX II

AGRICULTURE MODEL FOR EVALUATION OF POLICY IMPACT ON PRODUCTION, STRUCTURAL AND TECHNOLOGICAL CHANGE

by R. Kulikowski
IIASA

SUMMARY

The paper deals with the policy oriented model for studying the structural and technological change in farms belonging to different size categories. The farm is described by a number of production processes, including crop and livestock products. Each process uses as input factors, land labor, capital, water, fertilizers, etc. and it is subdivided into a number of operations (such as ploughing, fertilizing, sowing, irrigation, harvesting, etc.), which take place in sequence during the production cycle. The farmers are trying to allocate the inputs over time and space in an optimum manner.

The model describes the optimum farmers strategies. Then, by linear regression, the parameters of production function for the Polish private farms subsector have been estimated. The impact of water and fertilizers use on the farm yield has also been investigated.

AGRICULTURE MODEL FOR EVALUATION OF POLICY IMPACT ON PRODUCTION, STRUCTURAL AND TECHNOLOGICAL CHANGE

by R. Kulikowski

1. INTRODUCTION

In many countries the agriculture production sector consists entirely, (or partly as is the case in Poland) of privately owned farms. In Poland, besides the small private farms, the state or collectively owned subsector exists as well. The farmers are trying to adapt their production technology and production mix to existing prices of inputs and outputs (which are controlled to a certain extent by government policy) in such a way that the objective (usually net income) is maximum.

The fast urbanization process, which stimulates the rural-urban migration, as well as the demographic processes, i.e. the aging of farmers observed recently in Poland, endangers the agriculture production efficiency. The government has therefore started a pension program for aged farmers who wish to retire and give up the land. The large state farms are created out of the excess of land or the land is sold to farmers who want to increase the farm acreage. As a result of all these processes the structural and technological change in Polish agriculture takes place.

The planners and decision makers would like to estimate the impact of different policies in prices, taxes, subsidies, wages, credits, employment and migrations on the agriculture production and resulting national or regional growth. They would also like to investigate the impact of large regional investment projects, such as the Upper Notec Irrigation Project in Poland, on the regional development. They feel that the computerized agricultural models may help to evaluate different alternatives and may help to find an optimum policy for regional development [1], [5].

The model of a typical farm consists of a number of production processes, generally including crop and livestock products. Each process uses as input factors land, labor, capital, water, fertilizers, etc. and it is subdivided into a number of operations (such as ploughing, fertilizing, sowing, irrigation, harvesting, etc.) which take place in sequence during the production cycle. The farmers are trying to allocate the inputs over time and space in an optimum manner.

Starting with the farm micro-economic model, by means of aggregation over time and space, the typical (generalized Cobb-Douglas) macro-economic production function is being constructed. Using statistical data and least squares the coefficients of aggregated production function have been estimated (for different farm size category).

Using the model described one can also investigate:

a) techological and production change resulting out of changes of input prices, wages, taxes and land rent;
b) the scale benefits resulting from an increase of average farm area; and
c) the marginal production cost, income, and consumption per head in farms of different size category.

2. FACTOR ALLOCATION OVER TIME

The agriculture output production x is assumed to depend on a number of inputs x_ν, $\nu = 1,\ldots,m$, such as land, labor force, capital, water, fertilizers, etc. and a stochastic variable ω, which characterizes the impact of weather, soil, etc. random changes. Since one is interested in the expected value of x, given x_ν, the relation between x and x_ν (which is called the production function) should be regarded as the so called regression function, i.e.:

$$x = \underset{\omega}{E}\,\{\, x(\omega) \mid x_1,\ldots,x_m \} = f(x_1,\ldots,x_m) \quad .$$

The typical production function is the generalized Cobb-Douglas function

$$x(t) = a(t) \prod_{\nu=1}^{m} [x_\nu(t)]^{\beta_\nu} \quad , \tag{1}$$

where

t = time variable

$a(t)$ = given positive function

β_ν = given positive parameters.

Generally speaking, of scale production is possible, so

$$\beta = \sum_{\nu=1}^{m} \beta_\nu \geq 1 \quad .$$

The output production value within the given accounting or planning period [O, T] becomes:

$$Y = \int_0^T p(t)x(t)dt \quad , \tag{2}$$

where

$p(t)$ = price attached to $x(t)$.

The economic activity is connected with input costs which in [O, T] should be less the given numbers Y_ν, i.e.:

$$\int_0^T \phi_\nu[x_\nu(t)]\ dt \leq Y_\nu \ , \ \nu = 1,\dots,m \quad . \tag{3}$$

The typical cost function is:

$$\phi_\nu[x_\nu(t)] = \omega_\nu(t)[x_\nu(t)]^{\gamma_\nu} \quad . \tag{4}$$

where

$\omega_\nu(t)$ = exogenously given input prices

γ_ν = given positive numbers, $\nu = 1,\dots,m$.

As shown in the paper [2] the scale benefits ($\beta > 1$) which are taking place in urban economy are accompanied by increased input costs ($\gamma_\nu > 1$) due to transportation cost, congestion and environmental pollution. In a rural economy one can expect, generally speaking, benefits connected with aggregation of small farms and specialization in production. On the other hand, due to indivisibilities and unequal utilization of inputs within the production cycle, the cost functions should be regarded as convex, i.e. $\gamma_\nu > 1$. It should also be observed that when one sets $x_\nu = [{}^{Y_\nu}/\omega_\nu]^{\frac{1}{\gamma_\nu}}$ into (1) the of scale benefits are counterbalanced by increasing input costs.

The basic factor allocation problem can be formulated as follows. Find the nonnegative strategy $x_\nu(t) = \hat{x}_\nu(t)$, $\nu = 2,\dots,m$ [$x_1(t)$ be given] which maximizes (2) subject to the constraints (3). In the simple cases (1), (4) the solution of the optimization problem is given by the following theorem (which was proven in [2]):

Theorem 1

Let $\omega_1(t)[x_1(t)]^{\gamma_1}$ be integrable in [O, T] and

$\sum_{\nu=1}^{m} \beta_\nu/\gamma_\nu = 1$. Then the nonnegative strategy

$$\hat{x}_\nu(t) = \left\{\frac{Y_\nu}{Y_1}\frac{\omega_1}{\omega_\nu}[x_1(t)]^{\gamma_1}\right\}^{\frac{1}{\gamma_\nu}} \quad , \quad \nu = 2,\dots,m \quad , \qquad (5)$$

exists and it is unique. Under this strategy the marginal production cost becomes

$$p(t) = \frac{W}{a(t)}\prod_{\nu=1}^{m}[\omega_\nu(t)]^{\alpha_\nu} \quad , \quad \alpha_\nu = \beta_\nu/\gamma_\nu \qquad (6)$$

$$W = \sum_{\nu=1}^{m} Y_\nu \prod_{\nu=1}^{m} Y_\nu^{-\alpha_\nu}$$

and the output (2) becomes

$$\hat{Y} = W\prod_{\nu=1}^{m} Y_\nu^{\alpha_\nu} = \sum_{\nu=1}^{m} Y_\nu \quad .$$

The proof of Theorem 1 is based on the generalized Hölder inequality:

$$Y = \int_0^T W(t)\prod_{\nu=1}^{m}\psi_\nu(t)dt \le W\left\{\int_0^T |\psi_\nu(t)|^{\frac{1}{\alpha_\nu}}dt\right\}^{\alpha_\nu} \quad ,$$

where

$$\psi_\nu(t) = [\omega_\nu(t)]^{\alpha_\nu}[x_\nu(t)]^{\beta_\nu} \quad ,$$

$$W(t) = p(t)a(t)\prod_{\nu=1}^{m}[\omega_\nu(t)]^{-\alpha_\nu} \quad ,$$

which becomes equality if $\psi_\nu(t) = C_\nu \psi_1(t)$, $\nu = 2,\dots,m$ (C_ν = const) and $W(t) = W$ = const., i.e. when $p(t)$ is equal the production marginal cost

$$p(t) = \frac{\sum_{\nu=1}^{m} \omega_\nu(t) \, [x_\nu(t)]^{\gamma_\nu}}{a(t) \prod_{\nu=1}^{m} [x_\nu(t)]^{\beta_\nu}} .$$

Assuming that $\sum_{\nu=1}^{m} Y_\nu \leq \hat{Y}$, i.e. the expenses accrued to factor endowments Y_ν cannot exceed the output generated $\hat{Y}$, we can easily find the optimum values of $Y_\nu = \hat{Y}_\nu$, $\nu = 1,\dots,m$, which minimize W:

$$\hat{Y}_\nu = \alpha_\nu \hat{Y} , \quad \nu = 1,\dots,m \quad , \quad W = \prod_{\nu=1}^{m} \alpha_\nu^{-\alpha_\nu} . \tag{7}$$

The strategy (5), (7) determines the optimum allocation of resources within [O, T].

Using Theorem 1 it is also possible to allocate resources in a more complicated (but closer to practice) system of M processes which are taking place parallel in time, but generally, at different fields $A_1,\dots,A_M$. Each process in turn consists of a number of operations (such as ploughing, fertilizing, sowing, irrigation, harvesting, etc.) denoted by $O_{ji},\dots,O_{jn_j}$, and taking place in sequence during the production cycle (as shown by the chart in Figure 1).

In order to describe the factor allocation strategy for an operation one can use Theorem 1. For that purpose we shall assume that the optimization period T is equal to the production cycle. Within that cycle the intensity of factor utilization is determined by agrotechnological knowledge mainly. It can be described by the operation intensity function a(t), which is zero outside the operation subinterval and has the property

$$\int_0^T a(t)dt = 1 .$$

For example, the recommended sowing subinterval takes usually several days in the spring time, while the harvesting takes place rather in autumn. It can be observed that Theorem 1 determines the coordination of factors, according to the exogenously given $x_1(t)$. In the case of operations a(t) is given exogeneously and $x_\nu(t)$ (according to Theorem 1) are co-ordinated by a(t):

$$\hat{x}_\nu(t) = [\frac{Y_\nu}{\omega_\nu} a(t)]^{\frac{1}{\gamma_\nu}} \quad , \nu = 1,\dots,m \quad . \tag{8}$$

Obviously, by eliminating, i.e. setting

$$a(t) = \frac{\omega_1}{Y_1} [x_1(t)]^{\gamma_1}$$

into (8), one gets (5).

In the case of the system of N operations, each desribed by $a_i(t)$, the production function

$$x_i(t) = a_i(t) \prod_{\nu=1}^{m} [x_{i\nu}(t)]^{\beta_{\nu i}} \quad , \tag{9}$$

and cost functions:

$$\int_0^T \omega_{i\nu} [x_{i\nu}(t)]^{\gamma_{\nu i}} dt \leq Y_{\nu i} \quad , \quad i = 1,\dots,N \quad \nu = 1,\dots,m \quad , \tag{10}$$

it is possible to find by (8) the optimum allocation of resources:

$$\hat{x}_{i\nu}(t) = [\frac{Y_{i\nu}}{\omega_{i\nu}} a_i(t)] \frac{1}{\gamma_{i\nu}} \quad ,$$

and marginal production costs

$$p_i(t) = \frac{W_i}{a_i(t)} \prod_{\nu=1}^{m} [\omega_{i\nu}(t)]^{\alpha_{i\nu}} \quad , \; i = 1,\dots,N \quad \nu = 1,\dots,m \quad .$$

For each operation one can also derive the output Y_i, which contributes to the final production output Y, according to the formula:

$$Y = \prod_{i=1}^{N} Y_i^{\delta_i} \quad , \quad \sum_{i=1}^{N} \delta_i = 1 \quad .$$

It can be shown easily that the optimum allocation of Y among individual operations can be derived by the formulae:

$$\hat{Y}_i = \delta_i Y \quad , \quad i = 1,\dots,N \quad ,$$

while

$$\hat{Y}_{i\nu} = \alpha_{i\nu}\hat{Y}_i \quad , \nu = 1,\dots,m \quad .$$

The marginal price of the final product becomes:

$$p = \prod_{i=1}^{N} \left(\frac{p_i}{\delta_i}\right)^{\delta_i} \quad .$$

3. FACTOR ALLOCATION OVER SPACE

When t and operation index i is suppressed the problem of the allocation of m factors among M fields $A_1,\dots,A_M$ (see Figure 1) can be formulated as follows. Find the nonnegative strategy $X_{j\nu} = \hat{X}_{j\nu}$, $j = 1,\dots,M$, $\nu = 1,\dots,m$ which maximizes

$$Y = \sum_{j=1}^{M} Y_j \quad , \text{ i.e. } \max_{X_{j\nu}\varepsilon\Omega} \sum_{j=1}^{M} f_j(X_{j1},\dots,X_{jm}) \quad , \qquad (11)$$

where

$$\Omega = \{X_{j\nu} : X_{j\nu} \geq 0 \ \sum_{j=1}^{M} \phi_j(X_{j\nu}) \leq Y_\nu \quad , \nu = 1,\dots,m \quad j = 1,\dots,M\} \quad .$$

When $f_j\ [\phi_{j1}^{-1}\ (Y_{j1}),\dots,\phi_{jm}^{-1}\ (Y_{jm})] = a_j f\ [Y_{j1},\dots,Y_{jm}]$ (12)

where a_j = positive numbers, the problem (11) can be solved using the following aggregation theorem.

Theorem 2

Let $f(\cdot)$ be

a) homogeneous, i.e. $f(\lambda_1 Y_{j1},\dots,\lambda_m Y_{jm}) = f(Y_{j1},\dots,Y_{jm}) \prod_{\nu=1}^{m} \lambda_\nu^{\alpha_\nu}$

λ_ν = arbitrary, $\alpha_\nu > 0$, $\nu = 1,\dots,m$, $\sum_{\nu=1}^{m}\alpha_\nu < 1$,

b) differentiable in Ω with nonzero gradient, i.e. $\|\text{grad } f\| > 0$.

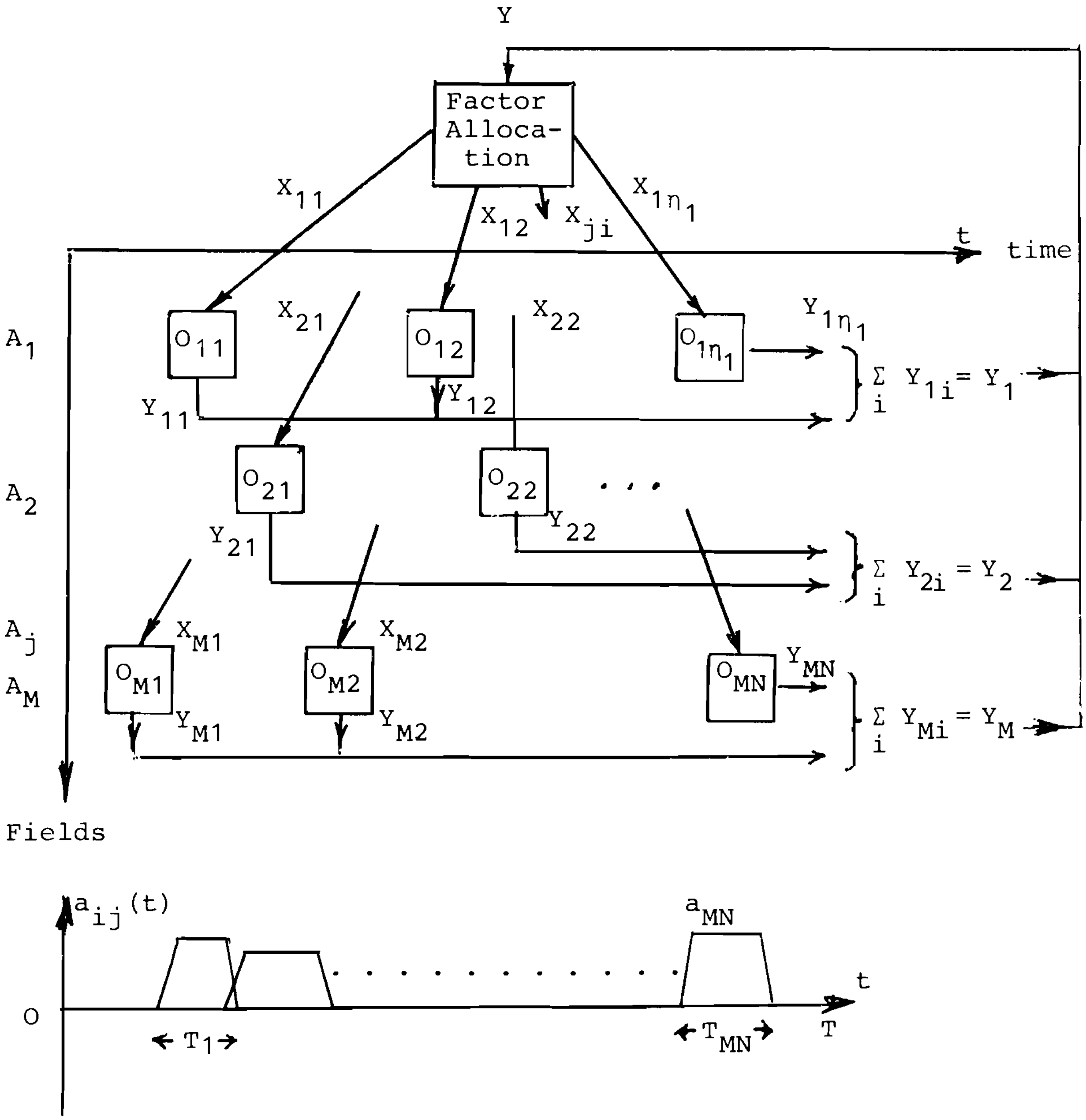

Figure 1. Factor Allocation Chart for a Typical Farm

Then the function

$$Y = \sum_{j=1}^{M} a_j f(Y_{j1},\dots,Y_{jm}) \quad , \quad a_j \text{ - given, positive, attains}$$

at an unique point $\hat{Y}_{j\nu} \in \Omega$, $j = 1,\dots,M,\quad \nu = 1,\dots,m$, the maximum value

$$\hat{Y} = Y(\hat{Y}_{j\nu}) = af(Y_1,\dots,Y_m) \ , \qquad (13)$$

where

$$a = \sum_{j=1}^{M} a_j \prod_{\nu=1}^{m} (\eta_{\nu j})^{\alpha_\nu} \quad , \quad \eta_{\nu j} = \hat{Y}_{j\nu}/Y_\nu \quad , \quad j = 1,\dots,M \ , \quad \nu = 1,\dots,m \ .$$

Proof

Since $\sum_{\nu=1}^{m} \alpha_\nu < 1$, the function $f(\cdot)$ is strictly concave in the compact set Ω . Then, according to the generalized Weierstrass theorem, (which says that the continuous function attains an extreme point in the compact set), a point $\hat{Y}_{j\nu} \varepsilon \Omega$, $j = 1,\dots,M,\ \nu = 1,\dots,m$, exists such that $Y(\hat{Y}_{j\nu}) = \hat{y}$. Since the gradient of f is not zero there is no stationary point in Ω and the optimum solution must be on the boundary of Ω , i.e. the constraints $\sum_{j=1}^{M} \phi_j(X_{j\nu}) \leq Y_\nu$, $\nu = 1,\dots,m,\ j = 1,\dots,M$ must be active at $\hat{X}_{j\nu}$. Then taking into account the property a) one gets (13) Q.E.D.

An interesting aspect of the aggregation Theorem 2 is that the aggregated production function has the same analytic form (13) as the component functions $f_j(\cdot)$.

In the case when the production functions are Cobb-Douglas the aggregate function can be derived explicitly.

Example 1

Assume the component p.f. to be

$$Y_j = k_j^q \prod_{\nu=1}^{m} Y_{j\nu}^{\alpha_\nu} \quad , \quad j = 1,\dots,M$$

where

$$\sum_{\nu=1}^{m} \alpha_\nu = \alpha = 1 - q \ .$$

It is easy to show that the strategies $Y_{j\nu} = \hat{Y}_{j\nu}$, $j = 1,\dots,M$, $\nu = 1,\dots,m$, exist such that

$$Y = \sum_{j=1}^{M} Y_j$$

attains maximum $(\hat{Y})$ subject to the constraints $\sum_{j=1}^{M} Y_{j\nu} \leq Y_\nu$, $\nu = 1,\dots,m$. These strategies become

$$\hat{Y}_{j\nu} = \frac{k_j}{k} Y_\nu \quad , \quad j = 1,\dots,M \quad , \nu = 1,\dots,m \quad ,$$

where

$$k = \sum_{j=1}^{M} k_j \quad ,$$

and

$$\hat{Y} = k^q \prod_{\nu=1}^{m} Y_\nu^{\alpha_\nu} \quad .$$

Obviously, in the present case $k_j^q = a_j$, $\eta_{\nu j} = \frac{k_j}{k}$.

4. IMPACT OF WATER AND FERTILIZERS USE ON THE FARM YIELD

As a more concreate application of Theorem 2 consider the water and fertilizers allocation problem. The rest of input factors is regarded as fixed. Suppose the farm consists of M fields, having A_j[ha] each, $j = 1,\dots,M$, which are used to cultivate the given M crops. The farmer should decide how much out of his total expenses for irrigation (Y_W) and fertilizers (Y_f) to spend on each field. It is also necessary to derive the values $Y_W = \hat{Y}_W$, $Y_f = \hat{Y}_f$ which yield the maximum total benefits.

It is firstly necessary to observe that the crop irrigation requirement W is the difference between the consumptive use of water (or the so called evapotranspiration) and the effective (or natural) precipitation b. The crop yield Y is a function of $U = W + b$ and for typical (dry and wet soil) conditions is usually given in graphic form as shown in Figure 2. Observe that if no water will be used, due to natural precipitation characterized by b_1 (dry soil) and b_2 (wet soil), the crops $\tilde{Y}_1$, $\tilde{Y}_2$ can be obtained respecitvely. A similar situation occurs for fertilizers.

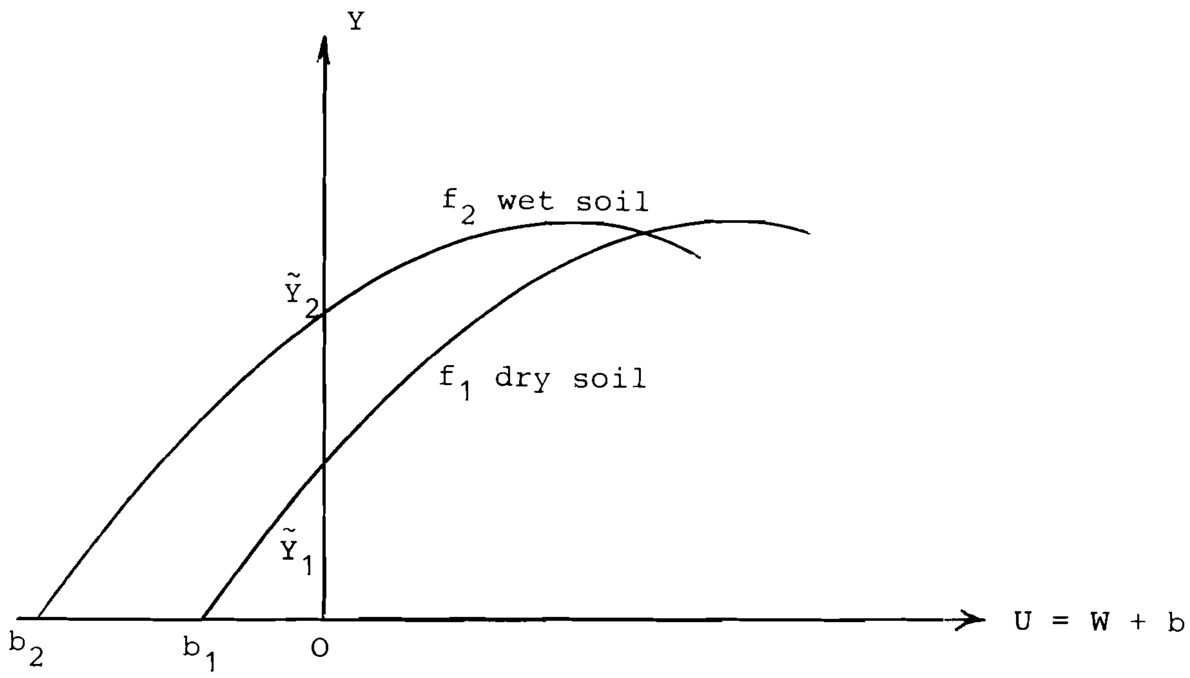

Figure 2. Production Function Given in Graphical Form

Then the yield optimization problem, given the expenses Y_W and Y_f can be formulated as follows.

Maximize the net income

$$Y = \sum_{j=1}^{M} f_j \{\phi_{jW} [A_j(W_j + b_j)] \ \phi_{jf} [A_j(F_j + c_j)]\} \tag{14}$$

W_j = water $[\frac{\text{acre feet}}{\text{acre year}}]$

b_j = effective precipitation

F_j = fertilizers $[\frac{\text{acre feet}}{\text{acre year}}]$

c_j = natural soil fertility

subject to:

$$\sum_{j=1}^{M} \{\phi_{jM}[A_j(W_j + b_j)] - B_j\} \leq Y_W \quad , \tag{15}$$

$$\sum_{j=1}^{M} \{\phi_{jf}[A_j(F_j + c_j)] - C_j\} \leq Y_f \quad , \tag{16}$$

$$B_j = \phi_{jW}[A_j(b_j)] \quad , \quad C_j = \phi_{jF}[A_j(c_j)] \quad .$$

According to the constraints (15) and (16) the expenses Y_W and Y_f accrue to the costs of additional water and fertilizers required.

Replacing $A_j(W_j + b_j)$ by $\phi_{jW}^{-1}[Y_{jW} + B_j]$; $A_j(F_j + c_j)$ by $\phi_{jf}^{-1}[Y_{jf} + C_j]$ and assuming that the assumptions of Theorem 2 hold, one can write

$$Y = \sum_{j=1}^{M} a_j f[Y_{jW} + B_j, Y_{jf} + C_j]$$

and

$$\hat{Y} = af[Y_W + B, Y_f + C] \tag{17}$$

where

$$B = \sum_{j=1}^{M} B_j \quad , \quad C = \sum_{j=1}^{M} C_j \quad .$$

When $Y_W = Y_f = 0$ the farm will still yield

$$\tilde{Y} = af[B, C] \quad . \tag{18}$$

The farmer's gain (out of using water and fertilizers) becomes

$$\Delta Y = \hat{Y} - \tilde{Y} - Y_W - Y_f \ . \tag{19}$$

Example 2

Assuming $f \equiv (\cdot)^{\alpha_W} (\cdot)^{\alpha_f}$ one gets (following Example 1)

$$k_j = a_j^{\frac{1}{q}} \ , \ j = 1,\dots,M \ , \quad q = 1 - \alpha_W - \alpha_f \ .$$

Then

$$\hat{Y} = \Big(\sum_{j=1}^{M} a_j^{\frac{1}{q}}\Big)^q (Y_W + B)^{\alpha_W} (Y_f + C)^{\alpha_f} \ .$$

In Figure 3 the graph of the function of

$\Delta Y = a[(Y_W + B)^{\alpha_W} - B^{\alpha_W}] - Y_W$ for $B = 1$, $\alpha_W = 0.1$, and different a is given. It can be observed that ΔY attains a maximum value for certain $Y_W = \hat{Y}_W$. The value $\Delta Y(\hat{Y}_W)$ increases along with a and it decreases when B increases. That means the irrigation is more effective when the soil is dry, but of good quality (fertile). The $\Delta Y(\hat{Y}_W)$ increases also along with $\alpha_W = {}^{\beta_W}/\gamma_W$. To benefit from this effect it is necessary to choose the water intensive crop and low production cost technology in such a way that β_W is maximum with respect to irrigation costs exponent γ_W. It is also important that all the remaining production factors are coordinated in time as required by the optimum production schedule [4].

When $\hat{Y}_W$ is derived, the allocation of water among the A_j fields can be computed by the formula:

$$W_j = A_j^{-1} \ \phi_{jW}^{-1} \ \{\hat{Y}_{jW} + B_j\} - b_j \ , \tag{20}$$

where

$$\hat{Y}_{jW} = \frac{k_j}{k} \hat{Y}_W = \frac{a_j^{\frac{1}{q}}}{\sum_j a_j^{\frac{1}{q}}} \hat{Y}_W \ , \quad j = 1,\dots,M \ .$$

5. ESTIMATION OF PRODUCTION FUNCTION PARAMETERS

In the present section the problem of fitting the model to the existing (ex post) data will be studied. Since the data are usually connected with a national or regional accounting

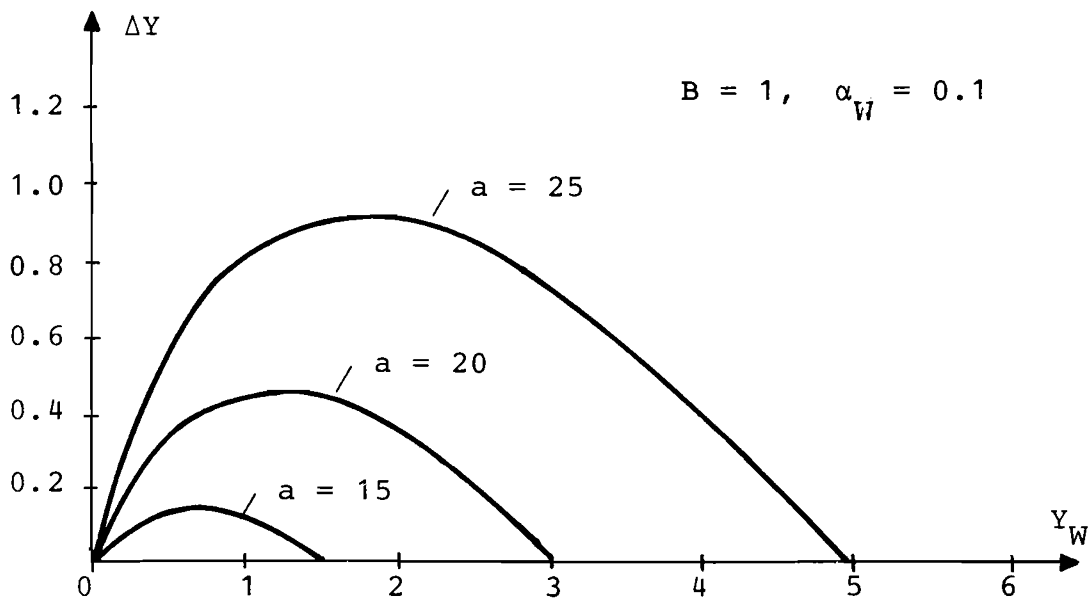

Figure 3. Farmer's Gain Versus Irrigation Cost

system, which produces the data annually, we can select a year (e.g. 1975) and drop the t and i indexes in our general model of Section 2. We shall be concerned with the aggregated output (X) and land (A), labor (L) and capital (K) as the main inputs.

In other words, we shall deal with the production function

$$X = aA^{\beta_1}L^{\beta_2}K^{\beta_3} \tag{21}$$

and input constraints:

$$\omega_1 A^{\gamma_1} \leq Y_1 \quad , \tag{22}$$

$$\omega_2 L^{\gamma_2} \leq Y_2 \quad , \tag{23}$$

$$\omega_3 K^{\gamma_3} \leq Y_3 \quad . \tag{24}$$

Under the optimum strategy (5), (7)

$$\hat{L} = [\frac{Y_2}{Y_1}\frac{\omega_1}{\omega_2} A^{\gamma_1}]^{\frac{1}{\gamma_2}} , \tag{25}$$

$$\hat{K} = [\frac{Y_3}{Y_1}\frac{\omega_1}{\omega_3} A^{\gamma_1}]^{\frac{1}{\gamma_3}} , \tag{26}$$

$$\hat{Y}_2/_{Y_1} = {}^{\alpha_2}/_{\alpha_1} \quad , \quad \hat{Y}_3/_{Y_1} = {}^{\alpha_3}/_{\alpha_1} \tag{27}$$

and the marginal output price becomes

$$p = (\frac{\omega_1}{\alpha_1})^{\alpha_1} (\frac{\omega_2}{\alpha_2})^{\alpha_2} (\frac{\omega_3}{\alpha_3})^{\alpha_3} a^{-1} \quad . \tag{28}$$

Our problem consists in the estimation of β_1, β_2, β_3, p, a, γ_1, γ_2, γ_3, and price ratios ω_1/ω_2, ω_3/ω_2. The wage ω_2 can be regarded as given exogeneously, while the aggregated prices for land and capital are difficult to obtain. The capital rent (or price) depends for example on the tools and machinery used, which changes when the farm size and specialization changes.

For the data bank one can use data collected for a set of representative farms, which use the so called agriculture accounting systems. The data for such a system (consisting of over 1500 carefully chosen farms) are collected each year by the I.E.R. (the Institute of Agriculture Economy) in Warsaw, (Poland) and are published by the Central Statistical Office G.U.S., Warszawa, 1977.

The data chosen from that source are shown in Table 1 No. 1 ÷ 5. The values of the parameters $\alpha 1$, $\alpha 2$, $\alpha 3$ were derived from farmers expenses accrued to land (taxes, land rent, fertilizers) consumption and capital.

The first problem is to check whether the farmers follow the optimum strategy (25, (26) and (27) when the size of the farm changes. In other words, it is necessary to check whether the data No. 1, 2, and 3 of Table 1 fit to the relations, based on (25), (26) and (27):

$$\log \frac{L}{A} = \log C_2 + b_2 \log A$$

$$\log \frac{K}{A} = \log C_3 + b_3 \log A$$

where

$$C_2 = \left(\frac{\alpha_2}{\alpha_1}\frac{\omega_1}{\omega_2}\right)^{\frac{1}{\gamma_2}}, \quad b_2 = {}^{\gamma_1}/_{\gamma_2} - 1$$

$$C_3 = \left(\frac{\alpha_3}{\alpha_1}\frac{\omega_1}{\omega_3}\right)^{\frac{1}{\gamma_3}}, \quad b_3 = {}^{\gamma_1}/_{\gamma_3} - 1$$

Using the linear regression (see Figure 4) one obtains:

$$\log C_2 = 2.36, \quad \log C_3 = 2.14, \quad {}^{\gamma_1}/_{\gamma_2} = 0.36, \quad {}^{\gamma_1}/_{\gamma_3} = 0.58$$

The value of γ_1 can be determined by setting the strategies (25), (26) into (21), i.e.:

$$X = aA^{\beta_1}(C_2A^{\gamma_1/\gamma_2})^{\beta_2}(C_3A^{\gamma_1/\gamma_3})^{\beta_3} = CA^{\gamma_1} ,$$

where

$$C = aC_2^{\beta_2}C_3^{\beta_3} .$$

Table I

Representative Sample Data of Polish Private Farming Sector, 1974/75.

No.	L E G E N D	General or Average	Farm Size (in ha)				
			Less 3	3-7	7-10	10-15	15 and more
1	Number of farms	1517	131	398	360	397	239
2	Arable land per farm (A)	6.75	2.40	5.24	8.46	12.07	19.05
3	Labor man days/ farm (L)	434	288	413	505	573	646
4	Capital per farm in 10^3 zl (K)	395.8	248.4	350.8	445.6	577.4	785.8
5	Final production in 10^3 zl (Y)	133.6	70.7	115.5	154.5	219.1	305.7
6	$\alpha_1 = Y_1/Y$	0.11	0.06	0.10	0.12	0.13	0.15
7	$\alpha_2 = Y_2/Y$	0.68	0.77	0.71	0.68	0.60	0.53
8	$\alpha_3 = Y_3/Y$	0.21	0.17	0.19	0.20	0.27	0.32
9	$\beta_1 = \gamma_1\alpha_1$	0.08	0.04	0.07	0.09	0.09	0.11
10	$\beta_2 = \gamma_2\alpha_2$	1.36	1.54	1.42	1.36	1.20	1.06
11	$\beta_3 = \gamma_3\alpha_3$	0.26	0.21	0.24	0.25	0.33	0.40
12	$\beta = \beta_1 + \beta_2 + \beta_3$	1.70	1.79	1.73	1.70	1.62	1.57
13	$P/\omega_1 p_m$	0.268	0.492	0.295	0.246	0.227	0.197
14	$P/\bar{p} = \bar{\alpha}_1/\alpha_1$	1	1.83	1.10	0.92	0.85	0.73
15	Labor Efficiency Y/L	0.308	0.245	0.279	0.306	0.382	0.473
16	Consumption $\alpha_2 Y = Y_2$	90.8	54.4	82.0	105.1	131.5	162.0
17	Consumption per working man/day	0.209	0.189	0.199	0.208	0.229	0.251

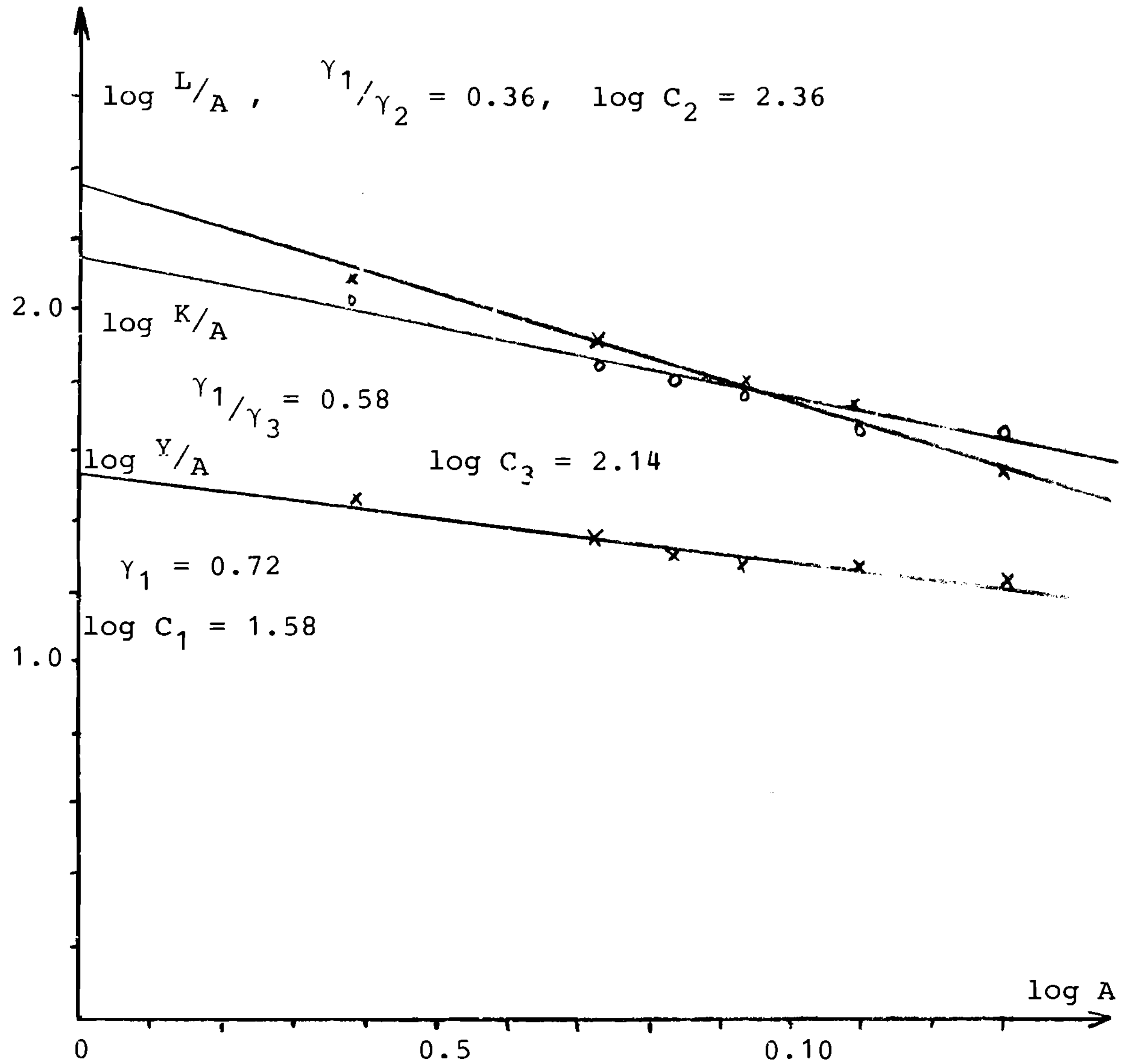

Figure 4. Estimation of p. f. Parameters

Then γ_1 can be determined by fitting (by linear regression) the function:

$$\log {}^{Y}/_{A} = \log C_1 + b \log A \quad ,$$

where

$$b = \gamma_1 - 1 \quad , \quad C_1 = p_m C$$

p_m = market price of X

to the data given in Table 1.

The corresponding calculations, illustrated by Figure 4 yield $\gamma_1 = 0.72$, $\log C_1 = 1.53$. Then $\gamma_2 = \gamma_1/_{0.36} = 2.00$, $\gamma_3 = \gamma_1/_{0.58} = 1.24$.

Since α_1, α_2, α_3 are given in Table 1 it is also possible to derive the corresponding values of $\beta_i = \gamma_i \alpha_i$, $i = 1, 2, 3$; and $\beta = \beta_1 + \beta_2 + \beta_3$. The results pertaining to farms of different size, are given in Table 1.

The next problem is to derive the p/p_m ratio.

Since

$$p = \frac{\omega_1}{a} [\alpha_1^{\alpha_1} (\omega_1 \frac{\alpha_2}{\omega_2})^{\alpha_2} (\omega_1 \frac{\alpha_3}{\omega_3})^{\alpha_3}]^{-1} = \frac{\omega_1}{a} [\alpha_1 C_2^{\beta_2} C_3^{\beta_3}]^{-1} \quad ,$$

one gets

$$\frac{p}{p_m} = \frac{\omega_1}{c_1 \alpha_1} \quad .$$

The values of $\frac{p}{\omega_1 p_m}$ for different size categories are also given in Table 1. Another comparison of marginal production cost refers to the average farm production cost $\bar{p}$. Obviously $\frac{p}{\bar{p}} = \frac{\bar{\alpha}_1}{\alpha_1}$, where $\bar{\alpha}_1 = 0.11$ (see Table 1, No. 14). For the purpose of further analysis in Table 1 the values of labor efficiencies $Y/_L$, consumption $Y_2 = \alpha_2 Y$, and consumption per man-day have been given.

6. ANALYSIS OF RESULTS OBTAINED

a. The model fits very well to the data in the cross section sense; i.e. for each chosen year. This can be explained by the absence of random weather and price change effects. The γ_ν and C_ν, $\nu = 2, 3$ derived for consecutive years change slightly (less 3%) while γ_1 and C_1 change more, especially when weather or prices have changed. The values of α_ν and consequently β_ν change accordingly to the adaptation of farming technology to the changing prices.

b. It is necessary to observe that an attempt to fit the data to the simpler model with $\gamma_\nu = 1$, $\alpha_\nu = \beta_\nu$, $\nu = 1, 2, 3$ was unsuccessful. This can also be seen in Figure 4 when one wants to fit the data with a line parallel to log A axis. The error resulting from such a fitting is unacceptable. The values $\gamma_\nu > 1$ indicate that costs of input factors increase faster than the linear function. However, β is also higher unity, which indicates that of scale effects counter balance the increasing input costs in such a way that

$$\sum_1^m \beta_\nu / \gamma_\nu = 1 \quad .$$

c. The of scale effect, characterized by β, decreases along with the farm size. An approximation of this trend shows that the of scale effect would disappear at a farm size of around 55 ha. This figure should be regarded as a limit size when the of scale benefits are exhausted. Obviously the substituion of labor by capital is very expensive and much of agriculture education is needed. Since the process of farm aggregation is so far developing by merging the smallest farms, the benefit can be derived directly using data of Table 1. If, for example, two farms (from the first size category) merge into one farm (of the second category) the final production is less by $[115.5 - 2 \times 70.7 = -25.9]$ 10^3 zl. However, there is a raise of labor efficiency by $\frac{0.279-0.245}{0.245} \times 100 = 13.9\%$ and one worker can emigrate to the more efficient production sector of national economy. The consumption per head in the aggregated farm increases by 5%.

d. Using the methodology proposed it is possible to construct an extended version of the agriculture model which contains the main crops and livestock categories. Finding $^{p}/p_m$ for all products and the production quantities, it is possible to see how farmers adapt their production technology to the existing p_m prices. If the decision maker wants to change the existing production structure, by changing input and output prices, he should firstly compute the resulting $^{p}/p_m$ prices in order to see whether the farmers will have enough incentive to produce what is required.
The present model can easily be extended to include the collective and state farm sector as well.
In a similar way, when the new regional irrigation project is planned in order to see whether the project will contribute to the agriculture income and regional growth, it is necessary to compute the resulting technological changes in terms of γ_ν, β_ν and α_ν parameters and the corresponding $^{p}/p_m$, as well as consumption per head structure. In order to investigate the structural changes it is also necessary to construct a model for rural-urban migration (including the demographic submodel). In order to make the model operational, the implementation of results obtained in the computerized form is needed.

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SUMMARY OF DISCUSSIONS

J. Owsinski

Discussions during the workshop centered around a number of problems which were thought to be of crucial importance for both modelling of and actual planning for the Upper Noteć River Valley region. The problems and short summaries of corresponding discussions are given below according to the order of presentations to which these discussions pretained (see agenda). The summaries are accompanied by the list of the workshop participants who expressed their opinions on given subjects.

1. Delimitation of the Region

Discussants: M.M. Albegov, K. Dziewonski, J. Kostrowicki, M. Makowski, J. Owsinski, K. Parikh, C. Somorowski

It was argued that the region under consideration should be greater than just the Upper Noteć basin, i.e., that such delimitation is somewhat artificial from the point of view of criteria other than watershed boundaries. Thus, the close connection of the basin with the traditionally defined Cuiavia region and with the Vistula Water System--especially if water transfers from the Vistula eventually takes place--and the low and sometimes hardly traceable watershed boundaries were pointed out as arguments for broadening the region, as was the existence just outside the region of two big agglomerations (Bydgoszcz and Toruń) to which a major portion of the region's activities gravitate. It was therefore stated that although from the purely water economical point of view, the choice of the region as an initial object of consideration, was correct (taking as a criterion, e.g., the value of water for a given area), for other subsystems and purposes (spatially) broader studies should be conducted so as to, at least, establish (optimal) solution sensitivities to the region's size.

2. Mobility Transition and Migration/Commuting Propensities

Discussants: M.M. Albegov, K. Dziewonski, P. Korcelli, J. Kostrowicki, R. Kulikowski, A. La Bella, K. Parikh, Z. Pawlowski, F. Willekens

The proposition forwarded by F. Willekens in his paper, that spatial demographic processes in Poland are switching from the first to the second of the four phases he describes, was challenged on the basis of inadequacy of data and it was stated that Poland presumably is nearer to the third than the to the second phase already. Similarly, it was argued that neither the income nor wage differences played the major role in causing migration, but rather differences in possibilities of job choice and in social infrastructure. On the other hand, commuting was attributed to income reasons. Thus, commuting cannot be generally fully considered as a substitution to migration, although in specific cases it can. In view of the various possible ways of attaining the regional economical development, it was deemed appropriate to study in some more detail possible future migratory/commuting patterns, especially with regard to neighboring agglomerations.

3. <u>Agricultural Labor Force Changes and Its Relation to Production and Activity Structure</u>

Discussants: M.M. Albegov, K. Dziewonski, J. Kostrowicki, R. Kulikowski

The question of the future changes in the region's population structure in connection with factor utilization possibilities brought with investments related to irrigation projects was discussed. Although an estimation was forwarded that in the medium or even long-term, future population will be stable in this area (no major rural depopulation), thus seemingly not creating efficiency (productivity) and intensiveness problems, it is also necessary to assess the educational and professional structure changes, until, perhaps, the creation of a special education system model.

4. <u>Types of Production Function and the Rationale for Their Prospective Use</u>

Discussants: M.M. Albegov, Z. Kaczmarek, R. Kulikowski, Z. Pawlowski

Besides the production functions, the problem of the use of historically estimated parameters for future (intentional) planned change pruposes was assessed. In particular, it has been pointed out that the Cobb-Douglas functions of the form used, do well for a sufficiently slow technological progress. It was pointed out that the use of specific forms of functions in initial, exploratory studies were caused by their relative simplicity (possibility of applying linear regression), and that if necessary, the functions could be made more intricate with little detriment to simplicity of analysis. Before, however, passing over to temporal changes in production functions it was deemed advisable to consider their various static forms. This triggered a discussion on the subsequent subject.

5. Aggregation and Disaggregation of Production Units

Discussants: R. Domanski, J. Kindler, J. Kostrowicki, M. Makowski

It was concluded that in order to adequately represent the behavior of the agricultural production sector, it would be necessary to consider separately the state and the private farms in the region and then within these two main categories to discern a certain minimal number of farm types based upon various soil, acreage and urban market closeness criteria. Such behavior submodels could then, possibly, be used as production functions. With regard to an evident diversity of behaviors, views were expressed stipulating reconsideration of the notion used and of homogeneity of optimum. As far as the farm structure goes, it was also deemed appropriate to project or at least envisage future changes, rather than to adopt a constant structure (e.g., share of private and state farming).

6. Inclusion of Other Sectors

Discussants: R. Domanski, J. Kostrowicki, R. Kulikowski

A proposition was forwarded, but then dropped, of considering the recreation and tourism sector based upon lakelands of the Upper Noteć basin and upon available labor force. Development of this sector was not regarded as having any special opportunities there, and therefore, as being of great possible importance to the regional economy.

7. Water System Optimization Options

Discussants: M.M. Albegov, V. Chernyatin, K. Dziewonski, M. Makowski, Z. Pawlowski, C. Somorowski, O. Vasiliev

The question of feasible regional features for optimization resulting from specification of technically possible reservoirs' and other elements' designs was discussed. Then the discussion turned to these factors which could place the global optimum outside of the feasible or search region as defined by technical and other assumptions. The problems proposed for consideration here were: multi-year rather than one-year storage, dynamics of drying (or of hypothetical "steppization") of the soils in the region, and (in connection with the latter) possibilities for "evolutionary" rather than drastic changes in the water system so as to maintain appropriate correspondence with the pace and character of natural processes. Although within the presently defined design problem the above problems are not explicitly taken into account, they should in general, be looked at, at least for assessment of optimal solutions' sensitivities.

Another problem discussed touched upon the connections of the investment model to other socio-economic models and it was proposed that they be stronger and more explicit (i.e., mere stating that some parameters will be given as exogeneous is not sufficient).

It was especially felt that the specification of priorities should be given more attention and be subject to economic analysis.

In addition, it was deemed appropriate to reconsider the way stochasticity is incorporated in the water system investment and operational models. In particular, it was proposed that more stochasticity could be introduced to the investment model, while the operational one did not necessitate that much of it.

8. Correspondence of Optimization Techniques to Institutional Systems

Discussants: J. Gutenbaum, N. Okada, H. Pietkiewicz-Saldan

In view of the utilization of decomposition techniques within the operational model, the question was discussed whether any correspondence exists between the real and optimization algorithm stucturalization. The conclusion was reached, that in future modifications of the model this question will be given adequate attention.

SUMMARY

CONCLUSIONS

The Notec Regional Development Project Task Force Meeting was held on May 10-11, 1978, at the International Institute for Applied Systems Analysis, in Laxenburg, Austria, as a consecutive stage in the realization of the Agreement between IIASA and SRI-PAS on scientific cooperation in matters concerning the development of the Notec river valley region.

The purpose of this introductory Task Force Meeting was to receive presentations from the Polish side on the main features and problems of the region in question and on the research directions in which the modelling work will be pursued within the SRI (see Appendix 1 for the Agenda of the Task Force Meeting). These presentations have therefore laid down the basis for discussions with the IIASA staff and other participating scholars (see Appendix 2 for the list of participants) concerning the actual scientific contents and organization and the cooperative work.

In the course of discussion, the following conclusions (concerning the contents of research) were reached:

It was deemed to be of utmost importance to preserve, throughout the study, the broad perspective of the regional socio-economic system and its linkages with outside regions and with the country as a whole. Especially the optimal path of agricultural growth should be very closely looked at. Thus, the emphasis on operational techniques for water system planning and management represents the initial stage of realization of the modelling project. In order for this stage to provide an adequate starting point for the creation of the overall system of models for integrative regional planning, it must enable a rational estimation of economic effects of water resource uses in agriculture and in other types of activities. This will make it senseful to conjointly use the water resource models and agricultural, as well as other economic sectoral models. Furthermore, if such a core of a system were created it would be justified to expand it with the models of urbanization (migration and settlement dynamics) services-transportation, education (professional training) and health care systems, rather than rely on exogenously given parameters.

Specifically, it was postulated that the modelling work should account for changes in agricultural structure (farmers' age and skill shifts, types of farms and their orientation, etc.) and farmers' behavior. This will make it possible to arrive at the constructs corresponding to production functions (classified according to farm types, soil, and subareas). On the other hand, there is a need for adequate soil and crop models reflecting influence of various factors with due account taken of water.

In view of the essential influence of existing, or emerging, agglomerations bordering on the area under study and also because of the anticipated structural changes within the area, it was proposed to elaborate models of demographic and urban processes. This could comprise the settlement system changes model for the Notec Basin, the urban growth model for the neighboring agglomerations and the resulting consequences for the Notec Basin, and the migrations model. In connection with the latter, reference was made to techniques worked out within the Human Settlements and Services Area at IIASA.

The final result of the work on the system of models should ensure that the synthetic view of the future spatial organization of the region should be obtained with the help of models contained therein.

(Concerning the organization of cooperation):

The essential contribution that IIASA will make to the cooperative research will have a methodological character and will be made through the evaluation and modification of approaches elaborated within the SRI or through propositions as to other methods. In the latter case, it is anticipated that modelling and computer implementation could be made within IIASA by interested IIASA staff with data provided by the Polish side.

It was concluded that the programming of the cooperation should be coordinated with the schedule of the Polish Governmental R & D Programme PR-7 concerned with water resources, especially in the part pertaining to the Notec river watershed, and with the schedules of the IIASA activities dealing with regional problems, especially with the Working Plan for the Elaboration of the System of Models for Integrated Regional Development of the Silistra Region, in Bulgaria. This would mean, for example, the organization of common meetings for the Notec and Silistra projects, as well as other projects included in IRD activities whenever this would meet the interests of all sides. On the other hand, there should be a provision for individual consultations, either through short visits of IIASA representatives to Poland with expenses covered by the Polish side or through the short visits of the Polish specialists to IIASA with expenses covered by IIASA. The guidelines set out in the Agreement between IIASA and SRI-PAS should be observed.

Thus, it was considered appropriate for the cooperative research to be conducted according to the following time frame:

September 1978	Conference in Jablonna (near Warsaw). The conference will constitute an opportunity for the participants from both the Polish and IIASA side to present and discuss models and newly obtained results for the Notec project, as well as for more generally conceived regional development. During the conference, a number of representatives of Polish design and construction organizations involved in work in drainage and irrigation in the Notec watershed will participate. Hence, it will be possible, through discussions between methodologists and practitioners, to establish the basis on which to adjust and modify the actual system of models' structure and also the individual models. It is anticipated that a number of IIASA scientists presenting papers at this conference could expect to receive financial support from the Polisn side.
	It will therefore be possible to consider
November 1978	the system of models' structure and contents for the Notec region together with the General Concept for the Silistra system of models.

Throughout 1979	Further work in the next year will consist of testing water resource planning and management models and elaborating other subsystems--firstly the models of regional agriculture and of their links with other sectors and other regions, and then the models accounting for settlement and migration dynamics. All this work should make the concept of the system of models more accurate.
April/May 1979 August/September 1979	The above will require two workshop-type meetings scheduled according to the PR-7 Research Programme's timing and to IRD activities at IIASA.
1980 end of the 5 - year plan period in Poland	By the end of the 5-year planning period a report on water aspects of the Notec Region should be prepared in the framework of the PR-7 Programme. The work on water resource models has therefore to reach the implementation phase and simultaneously all these other subsystems which define prerequisites for water system development and management (agricultural and industrial growth, migrations and settlements) must be operational.
Beyond 1980	In order to obtain a fuller and nearer to the optimal picture of regional development, the work would go on in the direction of synthesis of the overall system and of the elaboration of further, complementary, subsystems (education, health care, environmental protection). A model should also be built or adopted to incorporate the links with neighboring, industrialized and urbanized regions and with the whole of the country's economy.

The above summary conclusions of the Notec Regional Development Task Force Meeting are meant to serve as guidelines for future cooperation between IIASA and SRI-PAS on the Notec Integrated Regional Development Project.

I.I.A.S.A.
Prof. Murat Albegov

S.R.I.-P.A.S.
Prof. Roman Kulikowski

LIST OF PARTICIPANTS

Prof. N.G. Chomachenko
Director of the Institute of Industrial Economics
All Union Research Institute for Systems Investigation
Releeva Str. 29
Moscow - U. S. S. R.

Prof. R. Domanski
Rector
Academy of Economics
ul. Marchlewskiego 146/150
Poznan - POLAND

Prof. K. Dziewonski
Institute of Geography and Spatial Organization
Polish Academy of Sciences
Krakowskie Przedmiescie 30
00927 Warszawa - POLAND

Dr. N. Grigorov
Deputy Director
Institute of Regional Planning and Urbanization
Rakovski 134
Sofia - BULGARIA

Prof. Y. Gutenbaum
Systems Research Institute of the Polish Academy of Sciences
ul. Newelska 6
01447 Warsaw - POLAND

Dr. J. Heinzmann
Head of Scientific Secretariat
Institute of Geography and Geo-cology of the GDR Academy of Sciences
Dimitroffplatz 1
Leipzig - G. D. R.

Dr. P. Korcelli
Institute of Geography and Spatial Organization
Polish Academy of Sciences
Krakowskie Przedmiescie 30
00927 Warszawa - POLAND

Prof. J. Kostrowicki
Director
Institute of Geography and Spatial Organization
Polish Academy of Sciences
Krakowskie Przedmiescie 30
00927 Warszawa - POLAND

Prof. I.I. Lukinov
Director of the Economic Studies Institute of Kiev
All Union Research Institute for Systems Investigation
Releeva Str. 29
Moscow - U. S. S. R.

Dr. M. Makowski
Systems Research Institute of the Polish Academy of Sciences
ul. Newelska 6
01447 Warszawa - POLAND

Dr. V. Matousek
Ohre River Authority
43126 Chomutov
Povodi Ohre
CHECHOSLOVAKIA

Prof. Z. Pawlowski
Instytut Ekonometrii
Akademii Ekonomicznej im Karola Adamieckiego
ul. Bogucicka 3
40226 Katowice - POLAND

Ms. H. Pietkiewicz-Saldan
Systems Research Institute of the Polish Academy of Sciences
ul. Newelska 6
01447 Warszawa - POLAND

Dr. F. Sforzi
Istituto Regionale per la Programmazione Economica della Toscana
via la Farina 27
50127 Firenze - ITALY

Prof. C. Somorowski
Director
Institute of Land Reclamation
and Grassland Farming
Falenty - 05-550 Raszyn
POLAND

IIASA PARTICIPANTS

	Area/Task:
M. Albegov (USSR)	GEN/IRD
R. Arcangeli (ITALY)	GEN/IRD
V. Chernyatin (USSR)	REN
S. Ikeka (JAPAN)	MMT
Z. Kaczmarek (POLAND)	REN
T. Kawashima (JAPAN)	HSS
J. Kindler (POLAND)	REN
R. KULIKOWSKI (POLAND)	FAP and GEN/IRD
A. La Bella (ITALY)	GEN/IRD
R. Levien (USA)	Director of IIASA
B. Mihailov (BULGARIA)	GEN/IRD
N. Okada (JAPAN)	REN
J. Owsinski (POLAND)	MMT and GEN/IRD
K. Parikh (INDIA)	FAP
A. Propio (USSR)	SDS
F. Rabar (HUNGARY)	FAP
M. Shah (UK/KENYA)	FAP
A. Straszak (POLAND)	MMT
O. Vasiliev (USSR)	REN
F. Willekens (BELGIUM)	HSS