GUIDELINES FOR THE ELABORATION OF THE SUBSYSTEM: REGIONAL WATER SUPPLY

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"REGIONAL WATER SUPPLY"

INTRODUCTION

The regional water supply model must be one of the blocks of the system of models for regional planning. The main ideas of the common approach for the construction of this system were described in the report to the XIII European Congress of the Regional Science Association, Krakow, Poland, August 1977.

The central idea of one of the possible approaches consists of the following: a plan of perspective development is elaborated by the region using special functions which accumulate an effect of manufacture of the main (base) products in the region under analysis. These functions of effect per unit of resource (for example per unit of labour) can be constructed on the basis of sectoral optimization models and a system of marginal costs (prices) of the regional products. In this scheme the choice of the level of regional activities can be made as a result of the coordination of all kinds of activities with the help of a number of "effect" functions.

Another approach is based on the assumption that sectoral or other calculations can give the opportunity to fix the level of regional production for the future.

The first of these approaches is laid in the core of the analyses because the second one can be seen as a particular case.

The regional water supply model must supply other blocks (subsystems) of the IRD model with the information which is needed for the solution of the following tasks:

a) the choice of directions of regional economic specialization and calculation of the growth rate;
b) the solution of the tasks of intraregional location of the industry and agriculure, the growth of the urban and rurual settlements network, etc; and
c) the verrification of the allowance of the assigned variants within permissible limits of future regional and sub-regional growth.

I. COMMON THEME OF ANALYSIS[1]

1. As mentioned previously the starting point for regional analysis is the problem of choosing the level of its activities (industrial, agricultural, services). Therefore in the proposed sequence of analyses (Figure 1) the first line in the scheme is taken by the problem of regional specialization.

This problem can be solved if the following assumptions are fulfilled:

A. There exists a system of marginal costs for the products which correspond to the possible regional specialization (this system can be obtained on the basis of retailed sectoral models) or, at least, there exist prices for such kinds of products (services).

B. Main local resources are known which could restrict the future regional development.

C. For global (flexible) resources their marginal costs or prices are known as a fucntion of the volume of consumption of these resources.

To fulfill the first assumption one must have sectoral optimization models which give us the opportunity to investigate the vicinity of the optimum point and to obtain a "reaction" function. The idea of how to construct this function consists of the following:

Let us suppose that we have the following non-linear one-sectoral task of the location of productive activities:

$$F = \sum_i [L_i(X_i)X_i + \sum_j (W_{ij} + S_j)\ Y_{ij}] \rightarrow \min \qquad (1)$$

subject to:

$$\sum_j Y_{ij} = X_i \leq A_i \qquad (2)$$

$(i = 1,2,\ldots,r,\ldots,m)$ where r is the point of production under consideration

$$\sum_i \sigma_i Y_{ij} = B_j \qquad (3)$$

$(j = 1,2,\ldots,n)$ the set of points of the consumer location

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[1]The following analysis is based on a version of regional system of models which exist at the moment but which can be changed in the future.

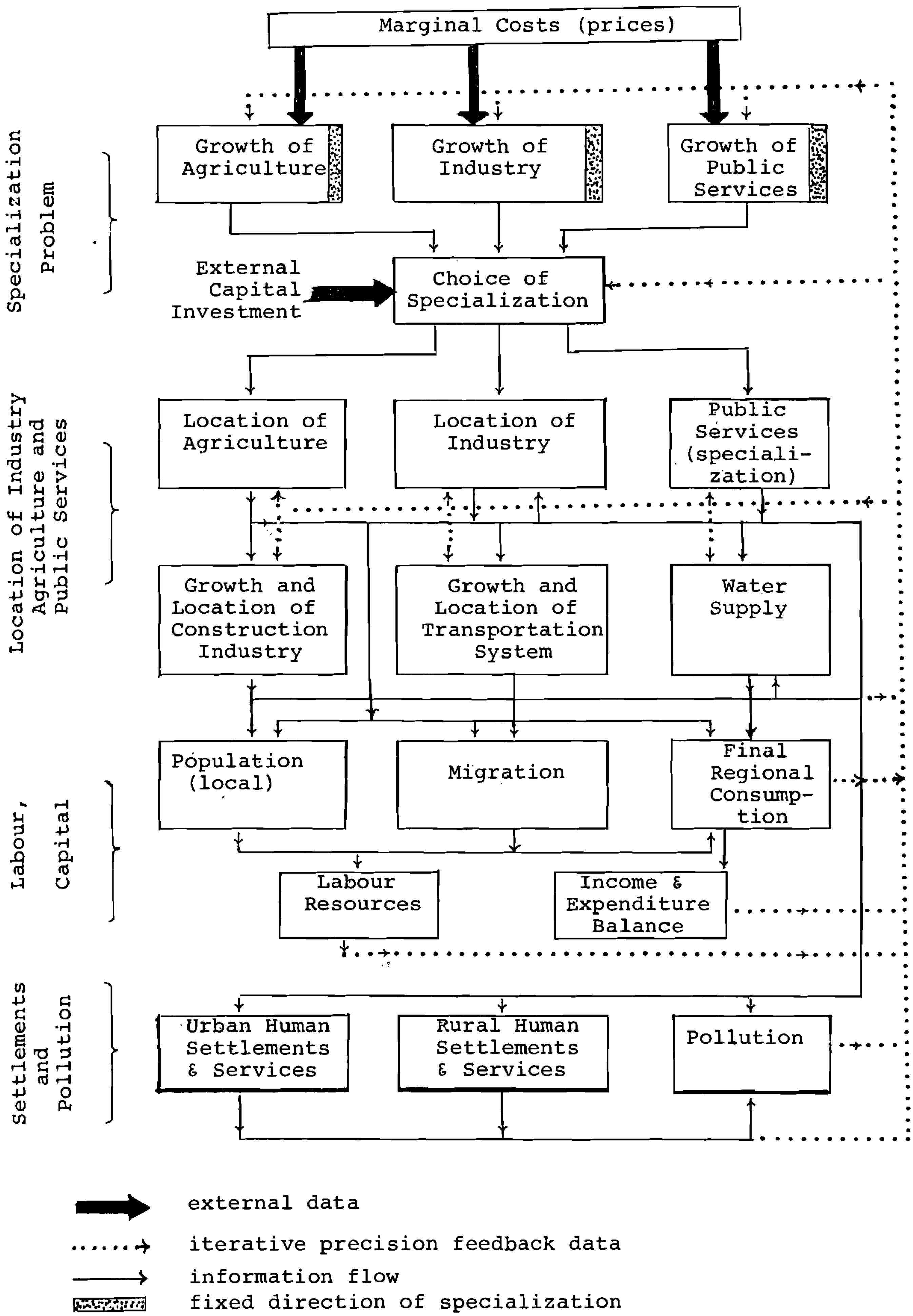
Marginal Costs (prices)
Specialization Problem
Growth of Agriculture
Growth of Industry
Growth of Public Services
External Capital Investment
Choice of Specialization
Location of Industry Agriculture and Public Services
Location of Agriculture
Location of Industry
Public Services (speciali-zation)
Growth and Location of Construction Industry
Growth and Location of Transportation System
Water Supply
Labour, Capital
Population (local)
Migration
Final Regional Consump-tion
Labour Resources
Income & Expenditure Balance
Settlements and Pollution
Urban Human Settlements & Services
Rural Human Settlements & Services
Pollution
external data
iterative precision feedback data
information flow
fixed direction of specialization

Figure 1

$$X_i,\ Y_{ij} \geq 0 \qquad (i = 1,2,\ldots,r,\ldots,m; \quad j = 1,2,\ldots,n) \quad . \tag{4}$$

where

A_i = available capacity in point i,

B_j = consumption of products in point j,

σ_i = effectiveness of products utilization shipped from point i into point j,

$L_i(x_i)$ = expenditures of enterprises in point i,

W_{ij} = transportation cost,

S_j = cost of utilization in point j,

X_i = dimension of production in point i.

Y_{ij} = shimpment of products from point i to point j,

$\overline{X}^o = (X_1^o, X_2, \ldots, X_r^o, \ldots, X_n^o)$ and F^o corresponds to the optimal solution then one must calculate F* for $X_r = 0,\ 0{,}1A_r,\ 0{,}2A_r, \ldots, A_r$ and $= F^* - F^o$.

For the non-linear case it is possible to use $E = f(X_r)$.

For the linear case it is possible to use $\Delta E_{mn} = \dfrac{\int^{A_r} Y(X_r)\,dX_r}{A_r}$.

If we construct the function $E = f(X_r)$ as a function of size of some resource which was used by a given sector in point i, and we have these characteristics for many sectors, then it is possible to compare the effect per person which could be obtainable in different sectors of regional economies. It seems that labour resources could be considered as a more general kind of resource.

Here one must analyze the situation with regional labour resources. If the labour resources are unlimited in the region under analysis one needs to analyze the sectoral reaction functions and to choose those which are positive (we do not consider here the necessity of using a free labour force, since this will be the subject of a special part of common study).

If the labour resources are limited then one must solve the special task of the optimal distribution of these resources.

For this purpose the following task of non-linearization can be formulated:

$$\sum_Z E_Z(L_Z) \rightarrow \max \qquad (5)$$

subject to:

$$\sum_Z L_Z = L^{max} \qquad (6)$$

for all Z

$$0 \leq L_Z^{min} \leq L_Z \leq L_Z^{min} \qquad (7)$$

where

Z = index of sectors which are the competitors in the point (region) under analysis

L_Z = number of labour resources which are used in sector Z according to an optimal solution

L^{max} = maximum available resources in the point (region) under consideration,

L_Z^{min}, L_Z^{max} = minimum and maximum labour resources which can be used in sector Z in the point (region) under consideration

$E_Z(L_Z)$ = reaction function (effect) which shows a variation of sectoral expenditures which depend on the number of labour resources used in the point under analysis (e.g., size of enterprise X_r)

From the above mentioned it is clear that for the practical solution of tasks (5)-(7) one must analyse the variation of regional effect as a function of one more important resource. The reason for this conclusion is the following:

a) in the case when many resources were estimated as being limited, the practical resolution of the tasks (5)-(7) becomes difficult; and

b) the reaction functions for different kinds of resources are not additive.

It seems that for the majority of possible, practical cases, labour resources could be adopted as being more important and would offer the possibility of resolving the task of the choice of directions of the regional development and to set the level of regional activities. In its turn, this would allow us to start an investigation of the production and services location (second level in Figure 1).

To finish a short analysis of the situation with regional labour resources, it should be pointed out that the fixation of the number of used labour resources on different levels and the calculation of the correspondent total effect of regional activities will give a basis for estimating the interregional effect of migration.

For the local (non-transportable) resources it is very important to know if there exists a limitation of growth of the future regional activities or not. In the latter case one has to add to the system of equations (5)-(7) the conditions when using limited local resources (e.g. water resources).

For the so-called global resources one need not introduce some restrictions into the model because this kind of resource is practically obtainable elsewhere in the required amounts (this group includes such resources as fuel, energy, etc.).

It is useful to stress here that this level of analysis requires only a generalized economical and other information, which will need only common data for the region as a whole (e.g. the price for land, energy, etc., the maximum possible water consumption, etc.).

2. As seen from Figure 1 <u>the second set of problems</u> are tied with the solution of the problem of sectors which include not only sectors of regional specialization (economic base sectors) but are also auxiliaries and service sectors.

To solve this problem more easily one needs to follow the sequence of analysis which can be as follows:

A. To start with the location of sectors of regional specialization. Within this group of sectors it would perhaps be better to start with agriculture. The solution of this task provides one with marginal costs of land in different parts of the region under analysis which are needed for the location of all other sectors.

It seems that the allocation of public service sectors which are the sectors of interregional specialization (for example, recreation centers, tourism, health care, etc.) may be analyzed after agriculture. The reason for this is that the location of these sectors can introduce additional restrictions for the location of industrial enterprises.

Following the analysis of the location of all the main industrial sectors it is possible to go to the next stage:

B. Modelling the growth and location of transportation systems: after calculating the growth of the main sectors within the region one should analyze the development of the intra-regional railroad and highway systems.

Water supply system. For this block it is a matter of importance to know the intraregional water demand. From the above mentioned it is clear that after the solution of the intraregional allocation of all sectors of specialization, the first two consumers of water are defined: agridulture and industry. The third main consumer--population--is not yet considered (on a given iteration). Therefore at this phase of analysis one needs to use the population settlements data (and corresponding water consumption) from the previous iteration, or to use some expertise (on the first iteration).

One of the problems of this phase of analysis consists of the following: for modeling the construction industry, or the transportation system, etc., one needs all information about the growth and location of all other kinds of activities. However, in any sequence of analysis one has no complete results and can obtain only part of the data from the model. For the other sectors, the results of the previous stage of analysis, or some initial fixed data (for the first iteration) can be used.

If one considers this approach (using the data obtained from the previous iteration or expertise) as a general one, it is easier to obtain approximate final results. For example, as is seen from Figure 1, water supply modeling is separated from water pollution modeling (stage four). This means that at the next iteration using the water supply model one needs to use the latest results from the water pollution model.

An additional problem here is how to obtain all economic estimations for each subregion. This detailedness of data is necessary for all calculations and is one of the requirements for the output of each model at this phase. The problem becomes more complicated if one takes into account that the boundaries dividing the region into districts for agriculture are not the same as for industry, water supply economies and so on. We will avoid here an analysis of this problem but must only stress that the division of a region into water supply districts has an auxiliary character and depends on the location of industrial and agricultural centers and the concentration of towns.

Insofar as an intraregional analysis requires dividing the region into 40-50 districts, the water supply model must provide the opportunity to obtain corresponding economic estimations (this does not mean that for a few districts the cost of the water supply must be different in all cases) because one water supply region (with a constant water cost) could embrace several districts.

3. On the third level of analysis such different kinds of problems as forecasting population growth and regional migration, balance of income and expenditures, etc., are included. All these problems are, however, very closely related to the number of people in the region and their wage and salary levels.

Though the future local population growth of the region depends relatively little on the regional economic activities and is influence more by the natural population growth, the transition to labour resources is closely related to the knowledge of regional migration and in order to define the latter one needs to know the future regional economic growth.

Knowing the future regional population growth expectancies, and using current data concerning the existing regional wage level, and the final consumption as a basis and prognosis of change of the regional wage level (as a result of the analysis of the second phase of the problem) it is possible to complete this stage of analysis by the elaboration of the regional balance of income and expenditures.

4. The fourth stage of analysis includes the problem of human settlements and services and the water and air pollution models. The sequence of analysis of the former problem seems now to be arbitrary with some preference given to urban problems because the solution of the majority of these are impossible without including the suburbs and neighboring rural regions.

When a system of settlements and relative services is defined one obtains a full set of data for pollution problem analysis: data on population, regional economic growth, the location of all kinds of activities, on the existing regional and future settlements, etc. All these data give full information with regard to pollution problem investigation.

After the completion of phase four the next iteration can be launched which must shorten the gap between the solution of the differnt subsystems and will finally bring these gaps within assigned limits.

As clearly seen from the above mentioned, the draft of the full system of models proved to be very complicated. Therefore one needs to thoroughly examine the possibilities of minimizing the number of iterations and this is particularly important for the solution of water supply and pollution problems.

II. SOME REQUIREMENTS FOR THE WATER SUPPLY SYSTEM

Below are formulated some requirements for the water supply system which are fully defined by an applied common approach to the problem of regional economy growth modeling.

For the sake of convenience it would be best to pick out the more important points of these requirements.

Size of the Water Supply Sub-Model

In order to be able to make an intraregional economic analysis one requires a very detailed presentation of the intra-regional problems. It appears that the majority of cases would be embraced if one divides the region into 40-50 sub-regions. The water supply model must be correspondingly detailed if it is to provide one with full data about the cost of the water supply.

Dividing the Region

For the solution of the tasks concerning the location of industry and agriculture, one needs a special division of the region into sub-regions. These two regional divisions have priority over the regional division from the water supply point of view. The problem of the adjustment of water and other kinds of regional division may be subject of a special analysis. Without going into more detail at this point, we should stress here that the division of a region for the solution of water supply problems must be much more detailed than for industry and agriculture because one needs to be able to obtain the characteristics of the water supply for any task of industry and agriculture location.

Number of Rivers

For the sake of the communities it would be better to include in the model the possibility to analyze two separate rivers with the option of transfering part of their run-off. The time changes of these run-offs can be considered as correlated figures.

Time Horizon

To achieve any significant change in the regional economy one needs no less than a 5 year time horizon. On the other hand, when the horizon of the future regional growth analysis is more than 20-25 years, we have a situation of full uncertainty. At the same time if one includes in this calculation a discount rate of a more or less significant level (0,08 - 0,12) then a near to zero economic influence of the events, which will take place after 20-25 years becomes very clear. Therefore the more appropriate time horizon for regional analysis is within the 20-25 year horizon.

The dynamics of regional growth are very important and it is desirable to cover the period 0 to 20 years taking into consideration the situation of each year (at least for the beginning of this period).

Measurement Units

If it is enough to describe regional water supply expenses using the prices for one m^3 of water consumption for a very aggregated analysis, then for an intraregional analysis one should have much more information. Intraregional analyses have no sense if such problems as water withdrawal, water discharge, the level of guarantee for water supply, etc. are not adequately considered as to preciseness of the main problem solution. Taking into account all of the above-mentioned we propose to use the following units for all the economic and technical estimations:

- 1 m^3 of water consumption: as a unit for economical measurement for the region as a whole, as well as for each sub-region; the dollar (ruble, etc) per 1 m^3 of water consumption could serve as the unit for calculation of the first stage (for the choice of regional specialization) and for the allocation of products between sub-regions; this unit is also used when the limits for the region as a whole and each sub-region are introduced, etc.;
- 1 m^3 of water withdrawal and discharge: as units for the description of the limits of a region and sub-regions, verification of the water demand and supply balance, etc. (e.g. mainly for all technical calculations).

Seasonal Variation of Consumption

Each consumer has its own character of water demand change. Heavy industry has a small seasonal change of deman while the communal sector and mainly the agricultural sector have a clear peak summer demand.

The irregularity of water demand is a very important factor for the choice of water supply capacities. Thefore for each consumer, the necessity of a seasonal figure of water demand must be foreseen. This allows one to summarize seasonal demands, to calculate the yearly peak of water demand and to choose adequate water storage. The last must be chosen taking into account the sanitation and navigation needs.

Water Supply Guarantee

The problem of choice of the optimal water supply guarantee level is very sophisticated and important and requires special investigation (and a model). Within the IRD system of models framework only an approximate decision of this problem is enough. If we suppose that for each group of consumers there exists data about the optimal water supply guarantee level, and that we know the growth of each kind of regional activity, then it is possible to calculate an average regional or sub-regional guarantee as follows:

$$\hat{q}_i = \frac{\Sigma_i A_i \cdot b_i \cdot q_i}{\Sigma A_i \cdot b_i} \quad (8)$$

where

$\hat{q}_i$ = average guarantee

A_i = annual output of sector i (or number of population, or volume of services, etc.)

b_i = water consumption per unit of product i (or per person; for the communal sector, per unit of service, etc.)

q_i = assigned (optimal) level of guarantee for sector i.

Definition of Economic Indexes

Taking into account the difficulties encountered when making calculations over a 20 year period, we can expect that in practice many of the regional analysis tasks could be solved as a sequence of static problems (e.g. a consecutive analysis of a time section would be fulfilled). In this case it is necessary to reach a situation where the economic indexes of the water supply for one year reflects, as much as possible, the future dynamics of cost change. With respect to this problem it would be useful to replace annual data by average indexes, which are calculated as follows:

$$Z = \frac{\sum_{t=1}^{T} (K_t + C_t) B_t}{\sum_{t=1}^{T} A_t \cdot B_t} \qquad (9)$$

where

Z = average data for the period of T years which correspond to the beginning of the period

T = duration of the period under analysis

K_t = capital investment of the year T

C_t = current expenses of the year T

B_t = discount coefficient

Changing the beginning of the analyzed period from the first to the last year (and relatively changing the last year of the period) it is possible to calculate the indexes for static analyses which would reflect the expenses of the posterior period.

Water Pollution

It is clear from the description of the system of models (the subsystem "Water Pollution") is separated from the "Water Supply" model. This was done with the aim of making the practical solution of the problem easier.

The coordination between the water supply and water pollution blocks could be done with the help of a comparison of marginal costs of water supply and water pollution, with the marginal effect of increasing regional activities.

III. WATER SUPPLY MODEL - INPUT/OUTPUT

Input Information

All input information could be divided into two parts: available data at the initial stage of calculation and available data in the process of calculation (after the first iteration).

- Start of Calculation:

The following information seems to be available:

a) characteristics of all possible kinds of regional specialization (sectors of industry, agriculture, and services): water consumption, withdrawal and discharge, seasonal change in water consumption, guarantee of water consumption which is required by every sector of regional economics; level of existing water supply and growth of communal water supply;

b) available data on run-off water, distributed over time, from the region located up-stream, and the water flow to the region down-stream;

c) approximate water consumption and withdrawal (if required) for the region as a whole with a division into four aggregate parts: industry, agriculture, services and communal consumption; and

d) approximate subregional water consumption and withdrawal which could be calculated, for example, proportionally to the existing consumption.

- Process of Calculation:

The data which are included in points a) and b) are constant during all calculations. The data included in points c) and d) are precise from iteration to iteration.

Output Information

There are two kinds of output information: at the initial stage of calculation one needs only rough estimations which must be improved during the calculation process.

- Start of Calculation:

Here the following data for the <u>region</u> as a whole are necessary:

a) average price per 1 m^3 of water consumption;

b) available maximum of water consumption;

c) available maximum of water withdrawal (if this is necessary for a particular region; and

d) the total expenses for the water supply.

For every subregion one needs the following data:

a) price per 1 m^3 of water consumption

b) available maximum of water consumption for each subregion or some limitation for a few of these;

c) available maximum of water withdrawal for each subregion or several subregions (if necessary).

- Process of Calculation:

In the process of calculation the regional and subregional informations which are included in points a), b), c) and d) become more precise.

In addition, the next stage of information is required following the first iteration:

a) regional marginal cost of water supply which corresponds to the subregion which has the cheapest cost and unlimited resources (on a given study of calculations);

b) dependence of the expenses of each subregional water supply from the volume of water consumed in this region; and

c) guarantee for the water supply for the region as a whole and for each subregion.

IV. SEQUENCE OF CALCULATIONS AND INFORMATION FLOWS

The main idea here is not to fulfill more than all the calculations need but to introduce alongside the "large" cycle, a "small" cycle of calculations.

If the large cycle consists of the intercommunicative calculations which are included in all the systems (one full iteration), then the small cycle embraces only part of the scheme which was shown in Figure 1.

It seems that the water supply model will work mainly within a small cycle which includes the analysis of the first two phases of the scheme: specialization and the problem of activity location.

Insofar as the initial data is concerned, to start the calculation, it must be prepared beyond the system of models; the goal of the small cycle would be to obtain a balance solution which gives the best possible results under acceptable restrictions and under acceptable resource costs. The scheme of information flows during this small cycle is shown on Figure 2. As one sees from this figure, the external information for this cycle can be divided into two parts:

a) external information from the high (national) level of analysis (dual estimates, external capital investments); and
b) information from the 3rd and 4th phase of the proposed scheme (labour resources, etc.).

The former information flow remains unchangeable throughout the calculations. This could be changed if the scenario approach is realized: for example, the problem of influence on regional development by changing the system of marginal costs of products or by variating the external capital investments are investigated.

The latter information flow remains unchangeable during only once cycle. Within this cycle, however, one needs to use lagged (one iteration before) information,when some results from the 3rd and 4th phase of the scheme are required.

The information which varies within the cycle is the following:

- for resources: cost of land, energy and water;
- for kinds of specialization: characteristics of costs per unit as a function of the regional production volume;

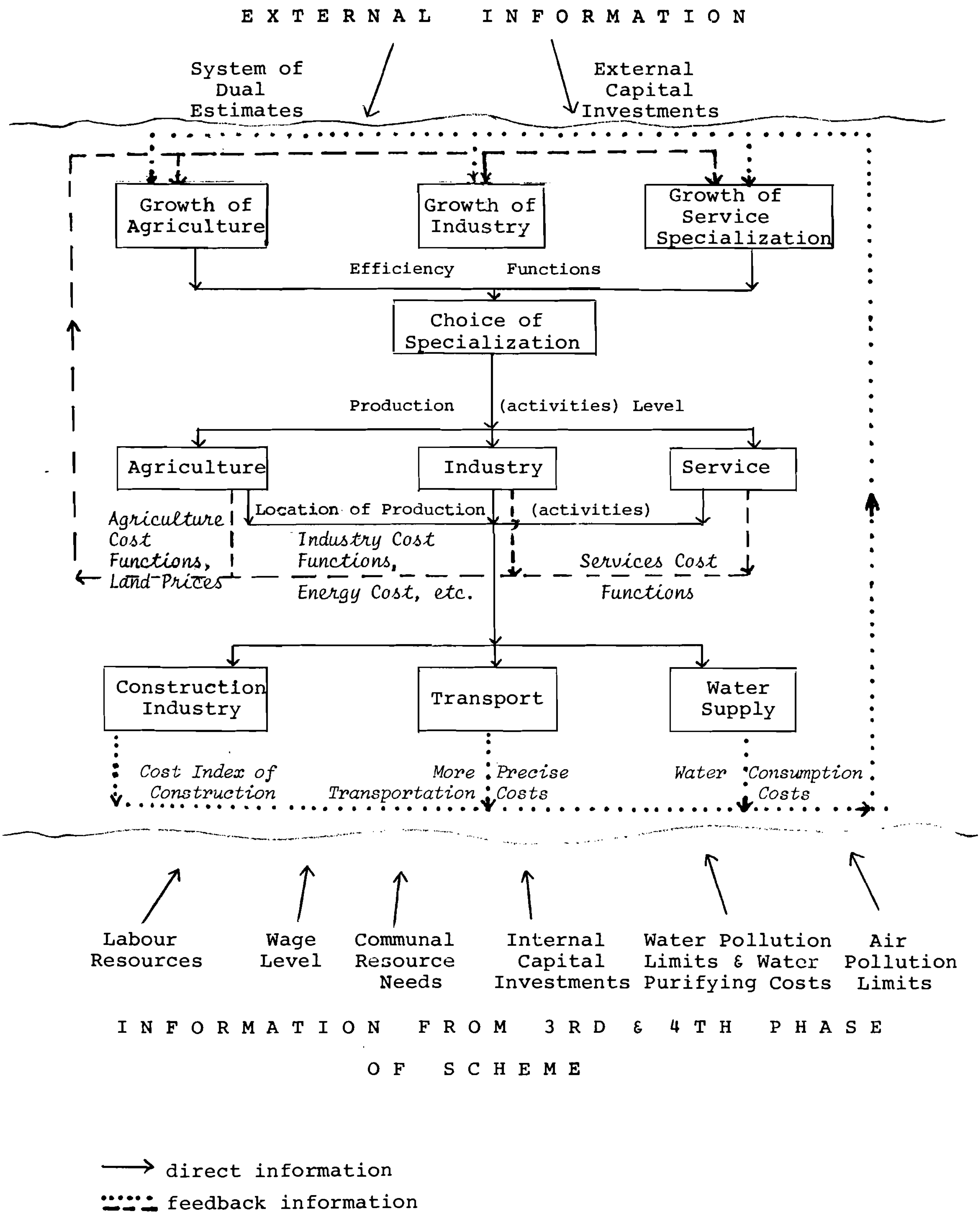

Figure 2. Main information flows (on a small cycle)

- for the construction industry: average index of regional costs of construction work (this could be important if the costs of construction differ significantly from one subregion to another); and
- for the transportation system: costs of the shipment of goods within the region.

Using more precise information it would be feasible to choose better directions and the level of the region's specialization activities growth and then be in a position to better solve the problem of the location of intraregional activities.

In order to finish the current cycle of calculations one could use the solution in which the difference in the costs of all resources[2] on the current and previous study of calculations is not more than that given in a previously established figure.

Upon finishing the small cycle, the next stage of calculation can be launched: the coordination of achieved results with the requirements and limitations which exist in the 3rd and 4th phase of the scheme. One of the directions for coordination is: investigation of intercommunication with the subsystem "Water Pollution".

The general idea here is to analyse the marginal costs of water in the subsystem "Water Supply", the costs of water-purifying in the subsystem "Water Pollution", to compare these and then to find the feasibility of decreasing regional expenses for water supply and water purifying. Upon receiving new points of equilibrium and the correspondent total dual estimates of each subregion it will be necessary to use them for a reconsideration of the regional specialization problem.

CONCLUSIONS

This guideline formulates the requirements for the regional water supply subsystem elaboration. The brief description of these shows clearly that to satisfy them in a simplified form (specially reduced) the requirements for the submodel "Water Supply" still remain very sophisticated and could not be included in any additional problem which are usual for special water supply models. Therefore the reader of the guideline must evaluate these requirements in context with the full system of IRD models taking into account the necessity of the practical realization of the whole system (but not only a part of it).