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COMPUTER TECHNOLOGY IN WATER RESOURCES PLANNING

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Abstract

The possibilities of utilizing computers in water resources planning projects at various stages of the work have been studied. Particular interest has been focused on methods of preparing field data collection programmes and creating data bases suitable for evaluation with the help of computers.

It has been found that computer models tailored to solve particular planning problems can be made with a moderate amount of programming effort and an example of such a model is described. General planning models must be more schematic and require more sophisticated software. Development of models of this type is currently in progress at VBB.

Sammanfattning

Möjligheterna att använda datorer i samband med vattenresursplaneringsprojekt under olika stadier av arbetets gång har studerats. Särskilt intresse har knutits till metoder för upprättande av datainsamlingsprogram samt för skapande av databaser lämpliga för utvärdering med hjälp av dator.

Datamodeller som är skräddarsydda att lösa specifika planeringsbroblem kan göras med en måttlig arbetsinsats. Ett exempel på sådana modeller är beskrivet. Generella planeringsmodeller måste göras mer schematiska och fordrar mer sofistikerade datorprogram. Utveckling av sådana modeller äger f.n. rum på VBB.

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1. Introduction

1.1 Background

A water resources planning project principally includes three different problems: assessment of the resources, assessment of the demand and matching of resources and demand with respect to various restrictions and priorities.

Methods for assessment of resources have been developed for a long time and can be considered as the least uncertain part of a water resources study. Relevant field data includes precipitation and evaporation measurements, water quality analyses, gauge measurements of surface flows, geophysical measurements and test drilling data for aquifer evaluation, physical and biochemical measurements for evaluation of the capacity of lakes, rivers and coastal waters to receive sewage effluents, etc. Methods for evaluation of data include synthetic generation of precipitation and streamflow records, analysis of individual regulation schemes, mathematical modelling of groundwater aquifers, or even of the complete hydrologic cycle, modelling of aquatic ecosystems, etc.

Metods for the assessment of future water demands are, for obvious reasons, less reliable than those for water resources, since they are influenced by factors such as political considerations and economic development. In its roughest form, the assessment of demands consists only of an extrapolation of historic trends in one way or another. The projections may be improved considerably with the help of socio-economic, agro-economic and other studies. Nevertheless, uncertainties are bound to remain and in the planning work it is normally necessary to consider the consequences of different rates of development, a maximum and a minimum alternative, for instance.

Matching resources and demand is a multi-dimensional problem. The quantity and quality of the resources vary in time and space and so does the demand. The quality is determined by several parameters, for example the concentrations of total dissolved solids, nitrate and dissolved oxygen. The examination of all relevant information when matching resources and demand thus involves a considerable amount of work which could well be done on a computer. Below, a summary is given of some of the experience gained by VBB in this field.

1.2 Data collection and storage

In a water resources development project it is necessary for the collection of basic field data to be made in a systematic way based on a plan determined by a careful analysis of the problem and its essential features. This analysis should be formulated as a logical model of how the system studied behaves so that all important factors can be identified. Depending on the size of the problem, one can choose later on whether the model should be programmed for a computer or if it should only be used manually.

With the model as a basis one can determine the appropriate degree of resolution of desired data and exclude the collection of data which, beforehand, can be shown to be irrelevant.

The model formulation of the problem will also be helpful when storing the collected data for manual or automatic processing during the subsequent stage of the study. Even if the data is mainly evaluated by hand it would still be beneficial to have the data stored in a computer in such a way that selected data can be easily picked out and processed either manually or with simple computer programmes for statistical analysis, etc. This technique is further discussed in Chapter 3 below.

1.3 Analysis of data

Planning the utilization of available water resources entails uncertainties in several respects. The resources are not constant in time with respect to quantity and quality and accepting different degrees of reliability in the supply system may result in different planning situations. Furthermore, the future demands are not fixed but will be influenced by the economic and social development, etc.

In view of these uncertainties the water resources planning work will include the evaluation of several alternatives. A proper evaluation of, for example, the reliability of a water supply system thus includes analysis of time dependent resources, which may interact with each other, and may also vary depending on how they are utilized. Such an analysis cannot easily be performed by hand, and, in order to be able to utilize all available data as efficiently as possible, computer programmes have to be developed.

1.4 Scope of present work

Water resources planning is far from being a well-defined concept. It includes problems with a wide range of complexity and requirements on degree of resolution.

If the physical properties of a system are well assessed, it may prove desirable to model the system with all its interactions between different resources as carefully as possible. Such a model will include a large number of parameters that describe the physical behaviour of the system, and such a model is hard to generalize without making it difficult to handle. An example of such a model tailored for a particular problem is described in Chapter 2 below.

If a water resources system includes a large number of different resources and consumers, it is for practical reasons necessary to simplify the model description of how it works and only include its essential features, otherwise the model will become too costly to run. On the other hand, such a model can be made more generally applicable to this type of planning problem and easier to handle by people who know little about computer technology. A model of this type is discussed in Chapter 3 below.

2. Models tailored for particular applications

2.1 General considerations

In a water resources system where available resources are only able to meet the total demand with difficulty, if at all, an efficient utilization of the resources will significantly affect the natural water balance of the system. Depending on the way in which the resources are utilized there will thus be a wide variety of feed-back to the resources system with respect to both quantity and quality. Such a feed-back system is schematically illustrated in Figure 1.

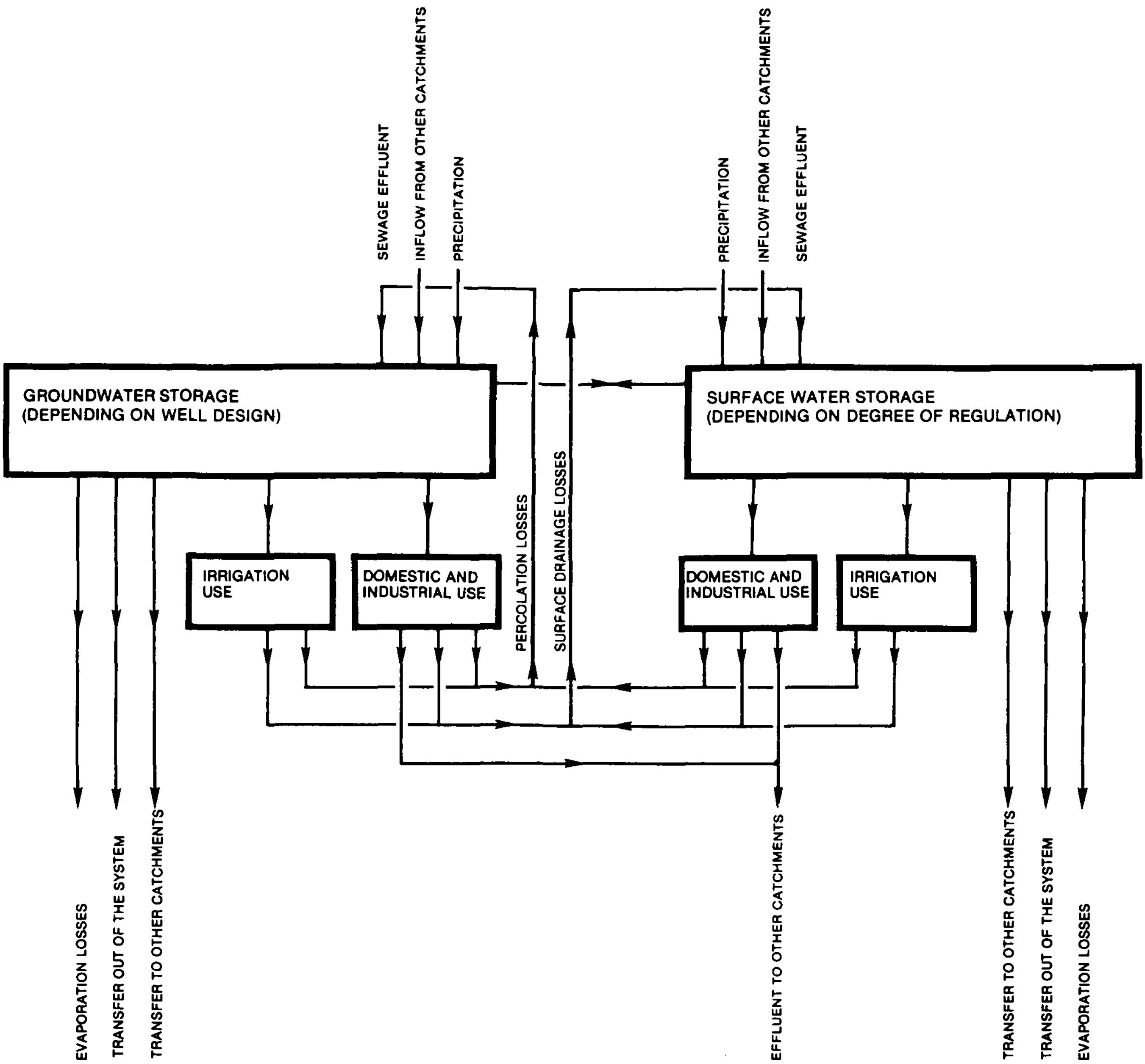


Figure 1 Definition sketch of a water resources system

If the system studied consists of several sub-areas or catchment areas, the total system to be analysed will thus consist of a corresponding number of sub-systems similar to that shown in Figure 1, which in turn may be more or less interdependent. Given that the problem also has a time-dimension, it becomes clearly apparent that the system may soon become intractable to analysis. However, if the number of resources and consumers is limited to say 20-40 each, analysis with the help of a computer model may prove efficient and successful. As an example of this an actual case study is described below.

2.2 Application to a particular water resources system

A water resources system consisting of 33 sources (8 groundwater aquifers, 24 rivers and a sewage effluent discharge) and 14 consumers (irrigation and domestic supply) was studied. The system is schematically illustrated in Figure 2. With the aid of the model the flows of water and dissolved solids through the system during a twenty year period were simulated in steps of one month. In this way it was possible to evaluate various water supply systems with respect to efficiency, reliability, and other aspects.

The input to the model in principle comprised the following data:

- Inflow of water to each resource during each time-step of the simulated period.

- Total dissolved solid concentrations of the water inflows.

- Water quantity demand from each consumer during each month of a year.

- Water quality demand from each consumer during each month of a year.

- Discharge of dissolved solids.

- Transfer capacities between resources and consumers.

- Maximum storage capacity of each resource.

- Information on the order in which the consumers are to be supplied and in which order the resources are to be utilized.

- Information on how effluent water and excess water are transported through the system.

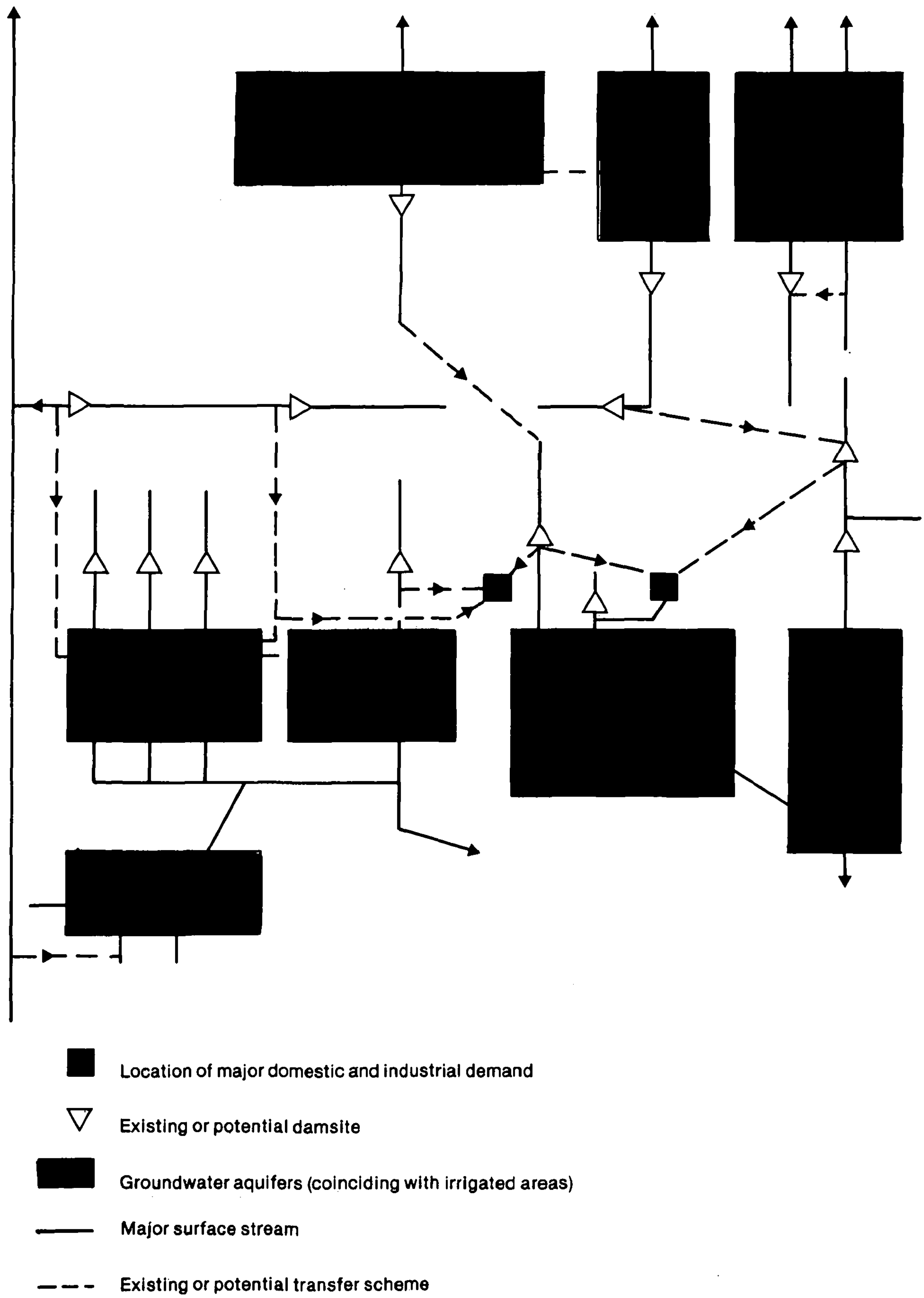


Figure 2 Water resources system studied

The output from the model comprised the following information:

1. For each time-step
- available water quantities,
- available water qualities,
- demands not possible to meet.

2. For each year
- annual transfers between resources and consumers,
- amount of water leakage from the system.

3. For the whole simulation period
- maximum monthly transfers per month between each resource and consumer,
- ditto, average transfers,
- minimum volumes in storage,
- plotted diagrams of volumes stored as a function of time (see example in Figure 3).

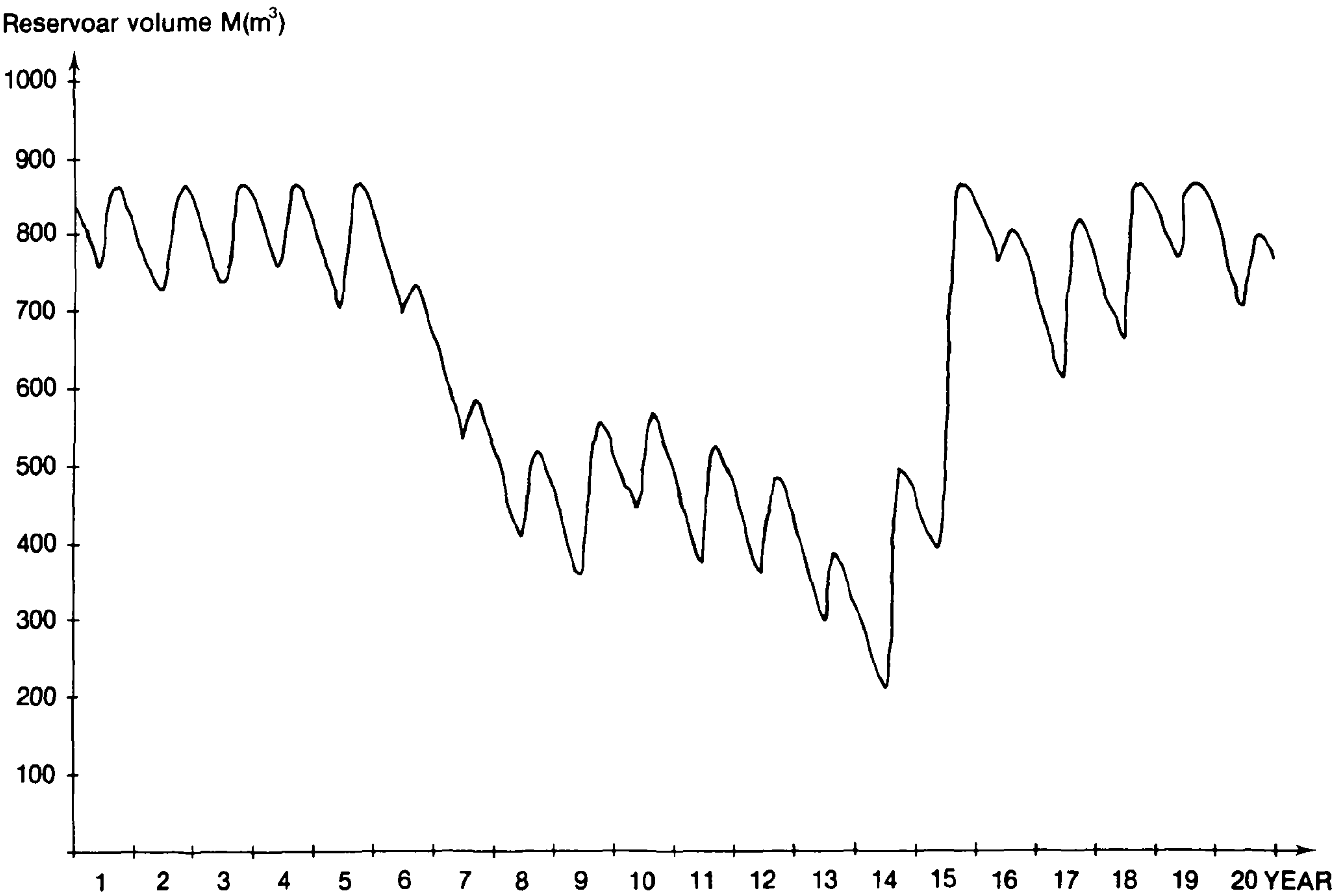


Figure 3 Computer print out of calculated stored volume in an over-year regulation dam (monthly values)

The model was used for a thorough analysis of a number of problems of importance for the water resources study in a way that would not have been possible without a computer. Among the problems met with the following can be mentioned.

How much of the surface water is timely flow that can be used directly for irrigation during the irrigation period? How much groundwater has to be extracted to maintain a reliable supply even during dry years? Would it be possible to increase the safe supply if several catchment areas were linked together?

How much water can be transferred from each catchment area to be used for domestic supply elsewhere without reducing the availability of water for irrigation and how can the availability of water be increased by surface water regulation and new groundwater wells?

How should existing and potential regulation schemes be dimensioned and operated, alone and in combination, to yield the required quantity and reliability of water supply? How should the operation schemes be modified if water deficiencies can be accepted at certain intervals?

How soon and how much will the content of total dissolved solids in the groundwater increase if irrigation with domestic sewage effluent takes place? What will the effect be on the groundwater quality if the groundwater is recycled due to heavy extraction for irrigation purposes?

How efficiently are installed facilities utilized, i.e. what is the ratio between maximum and average utilization?

2.3 Conclusions as to the usefulness of tailored models

If a systems analysis is performed at an early stage of a water resources study, and a preliminary model of the resources system is formulated, the collection of basic information may be considerably rationalized. Relevant data will be collected in a systematic way and with an appropriate degree of resolution in time and space. The risk of essential data not being collected is reduced as well as the risk of data being collected which will later prove to be irrelevant. As a result, more effort can be spent on evaluating the data collected and the analysis can be considerably refined, for example by making optimization studies with respect to various objects.

Tailored models of the type described in Clause 2.2 can be easily developed. In the case in question, formulating the model, writing the computer programme, testing the model and feeding it with input data required less than one man-month's work (excluding the collection of data). However, a computer model of this type may be difficult to apply for people who are unfamiliar with computers. Making the model easy to use and possible to apply to other water resources problems would require additional work for improvement and documentation of the programme which may not be worthwile if the model is not generally applicable.

The definite advantages of model analysis of water resources systems make it important to develop models that can be applied on a more general scale and that can be used by people who are unfamiliar with computer technology. The primary purpose is then to make the often costly data collection phase of the study as efficient as possible and to create a data base suitable for refined analysis. The development of such models is discussed in the following clauses.

3. General models

3.1 Basic requirements

A general resources model should not be restriced to pure water quantity problems but should be able to analyse the distribution and utilization of any type of resource such as water quantity, hydropower potential, capacity to assimilate pollutants, etc. A schematic illustration of a general resources problem of this type is given in Figure 4. However, for the purpose of simplicity, in the following discussion the problem is treated as a water quantity problem.

It should be possible for the model to treat systems consisting of say at least 100 catchment areas or subsystems according to Figure 1 without too much computational effort. This implies that not all the feed-back effects illustrated in Figure 1 can be included, but must be analysed separately. For example, if water is imported to a catchment area and used for irrigation, the groundwater quantity and quality resources data for that area will have to be updated and the model re-run.

It should also be easy for the model to be fed with data by people who are not familiar with computer technology. Available information may be incomplete and inaccurate in many respects but the computer programme should allow input of the data in an irregular way and then process and store it in such a way that it is amenable to analysis. This is further discussed in Clause 3.3.

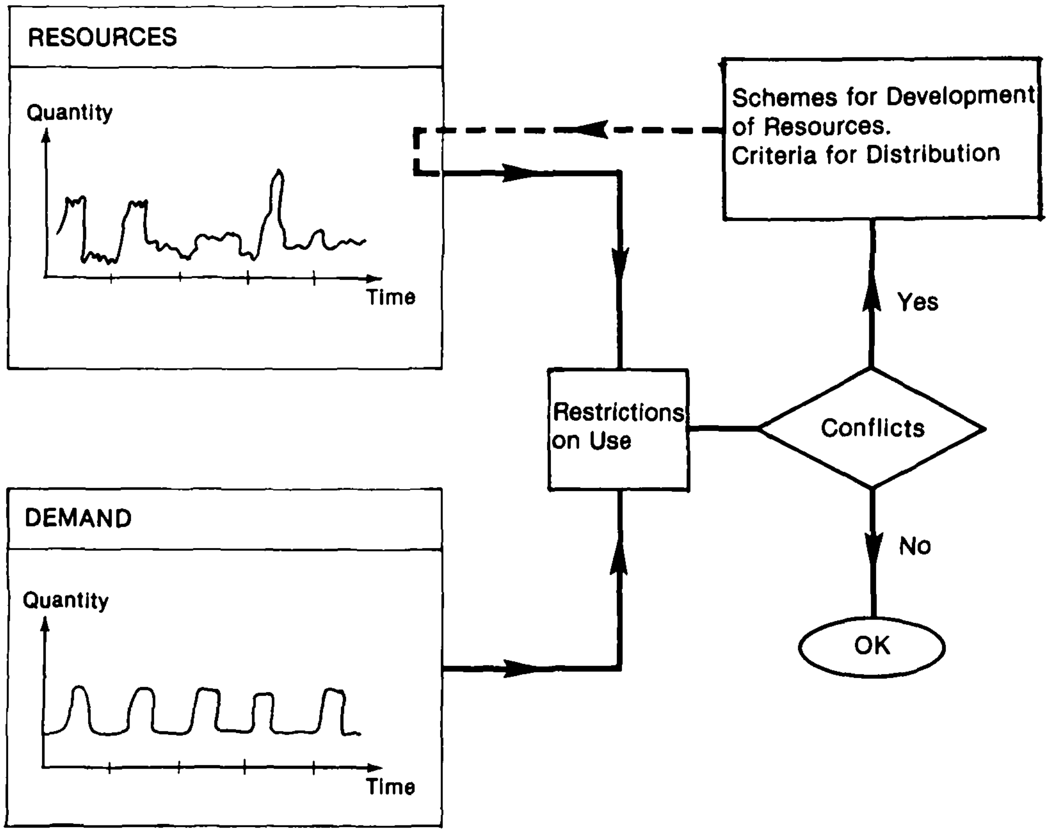


Figure 4 Definition sketch of a resources problem

The model should not be too costly to run since it may be necessary to run it many times. The model output should be as condensed as possible and preferably be presented in graphic form for easy evaluation. This is further discussed in Clause 3.4.

3.2 Model outline

The ideal modelling situation would be if the resources system as a whole could be optimized for the entire period of time with respect to a certain objective function. However, in practice such a problem would most probably be too large even for a computer, the objective function would be difficult to define and existing restrictions would be difficult to formulate mathematically. Furthermore, in a resources planning study the primary objective is not to find a solution that is in some respect optimal, but rather to assess the existence of solutions to the planning problem. It is therefore suggested that the problem be reduced in the way that is schematically illustrated in Figure 5. By disregarding various feed-back effects the method will be straight forward and by making the water distribution in two steps the computational effort will be reduced.

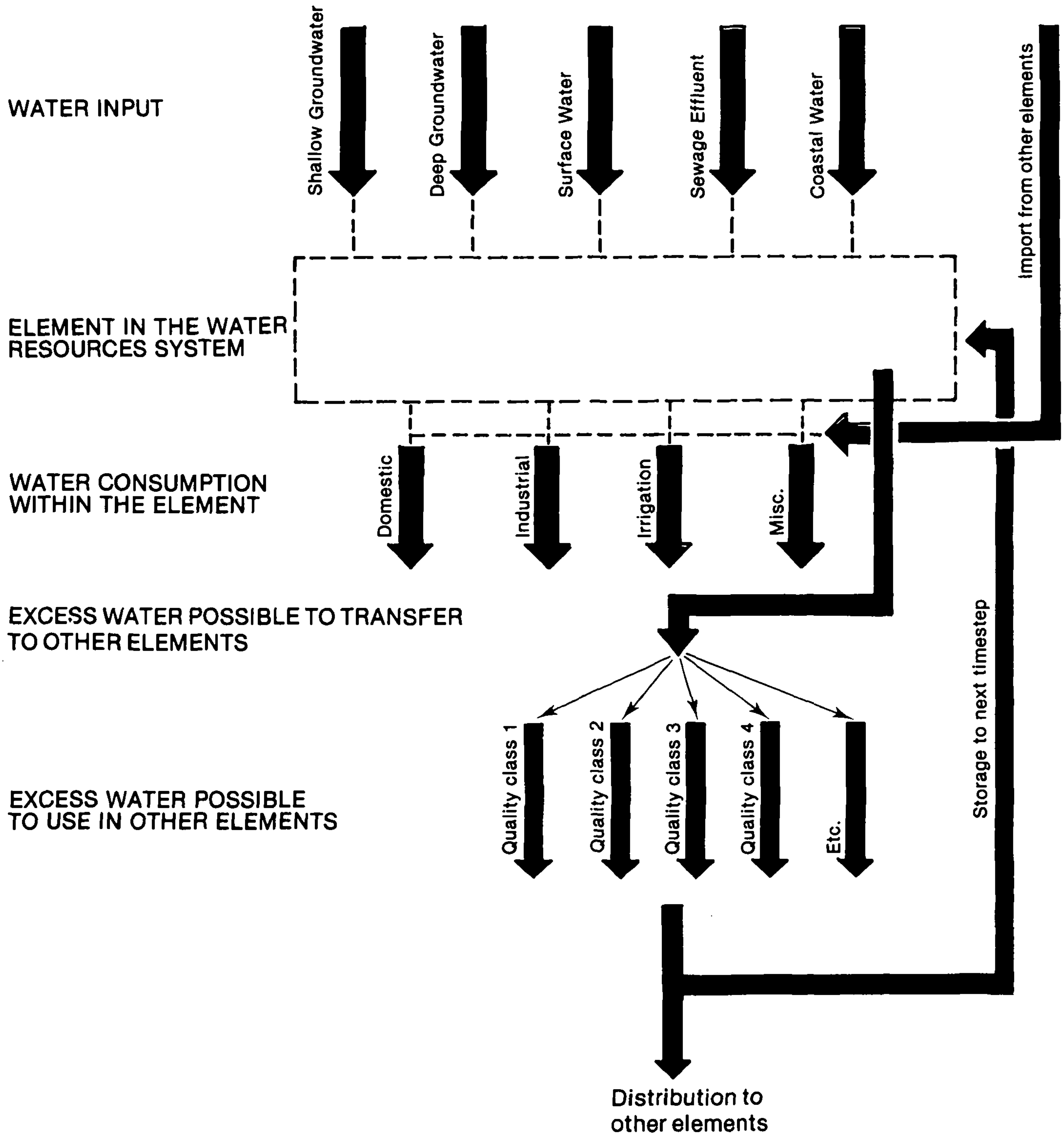


Figure 5 Definition sketch of a general water resources model

At a certain point in time the quantity and quality of available resources for each element or catchment area of the system are assessed. The resources are classified into various quality classes determined by quality demands from the consumers.

In a first step the demands for water from each quality class are met locally to the maximum possible extent. After local demands have been met, excess water is calculated as well as water demands which cannot be met locally.

After all the elements have been studied separately, remaining resources and demands are matched for the system as a whole. Successful matching can be achieved with the help of some form of flow algorithm or optimization method since the number of variables in this reduced problem is fairly limited.

After the regional distribution has been made, those water resources still remaining are carried over to the subsequent time-step (if storage facilities exist) and the whole procedure is repeated for subsequent time-steps until the end of the time period considered has been reached.

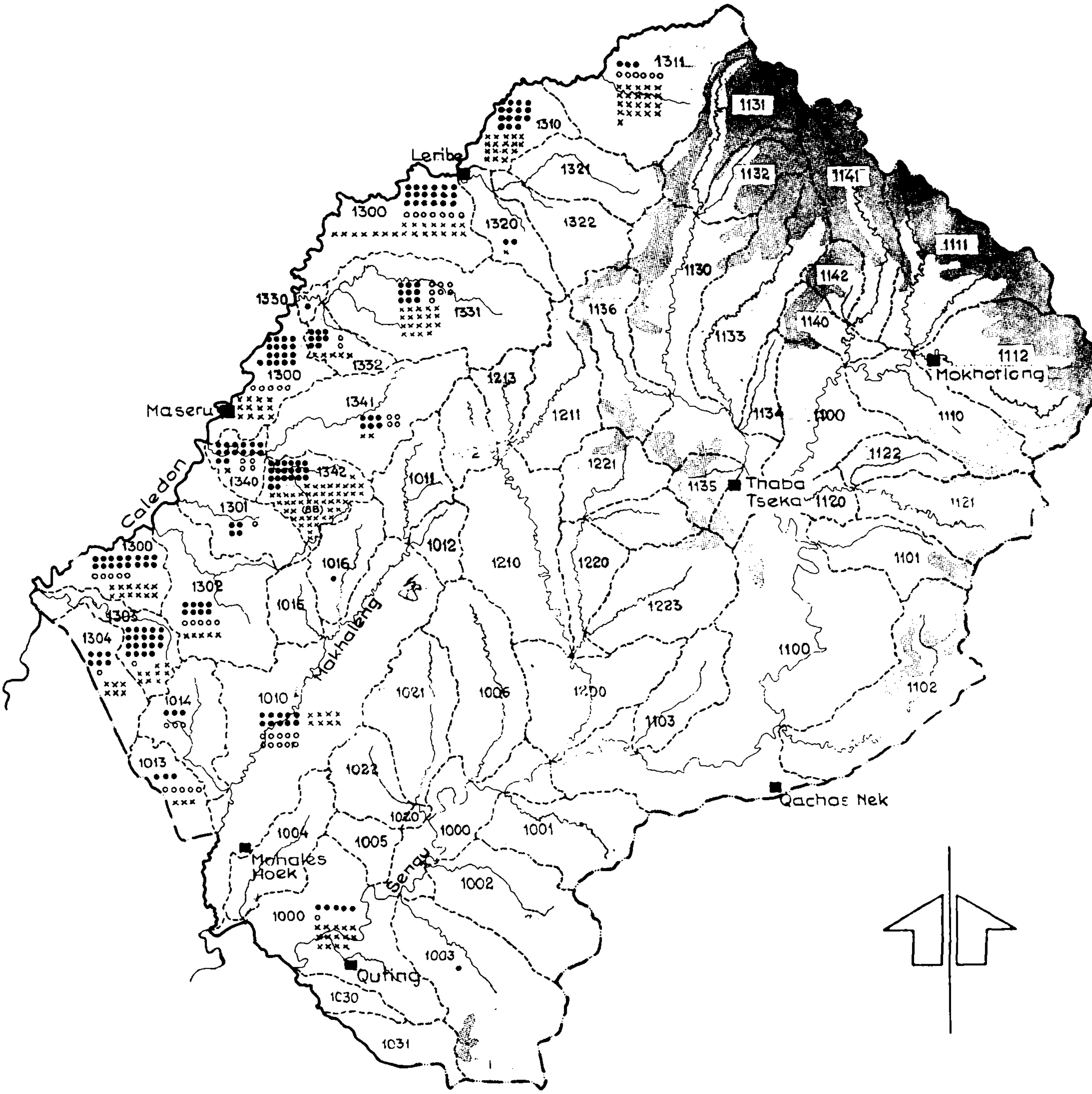
After the results of the model run have been evaluated the model may be re-run with new assumptions concerning storage facilities, demand distribution in time and space, etc., until a satisfactory solution to the planning problem has been reached.

3.3 Input data

Figure 6 shows a map of a water resources system that may be tractable to analysis with a model of the type outlined above. The system contains approximately 70 catchment areas each having shallow groundwater, deep groundwater and/or surface water resources varying in time.

In each catchment there may be domestic, industrial, and/or irrigation demands. (Hydropower demands may also have to be taken into consideration but will require separate treatment in the model since they do not actually entail any consumption of water. For the sake of simplicity, no further consideration is given to them in this paper.)

For a model analysis the following data must be fed in for each element:



------ Catchment area boundary

1140 Catchment No

● Yielding borehole

o Dry borehole

× Borehole with unknown yield

Figure 6 Water resources system tractable for analysis with a general model

- coordinates defining the location of the element,
- available water quantities in the form of time series for each type of source. The series may contain for example one value, a one-year record or a full record, provided that instructions have been given previously on how to treat the record,
- available water qualities in the same way as for water quantities for each quality parameter considered. These data are then used in the programme to classify the resources into quality classes with respect to quality demands,
- storage facilities and stored volumes at the start of the calculations,
- water quantity demands for each consumer in the form of time series in the same way as for quantity resources,
- water quality demands in the form of quality class requirements for each consumer,
- transfer capacities between sources and consumers across catchment area boundaries,
- destinations for excess water from each catchment area.

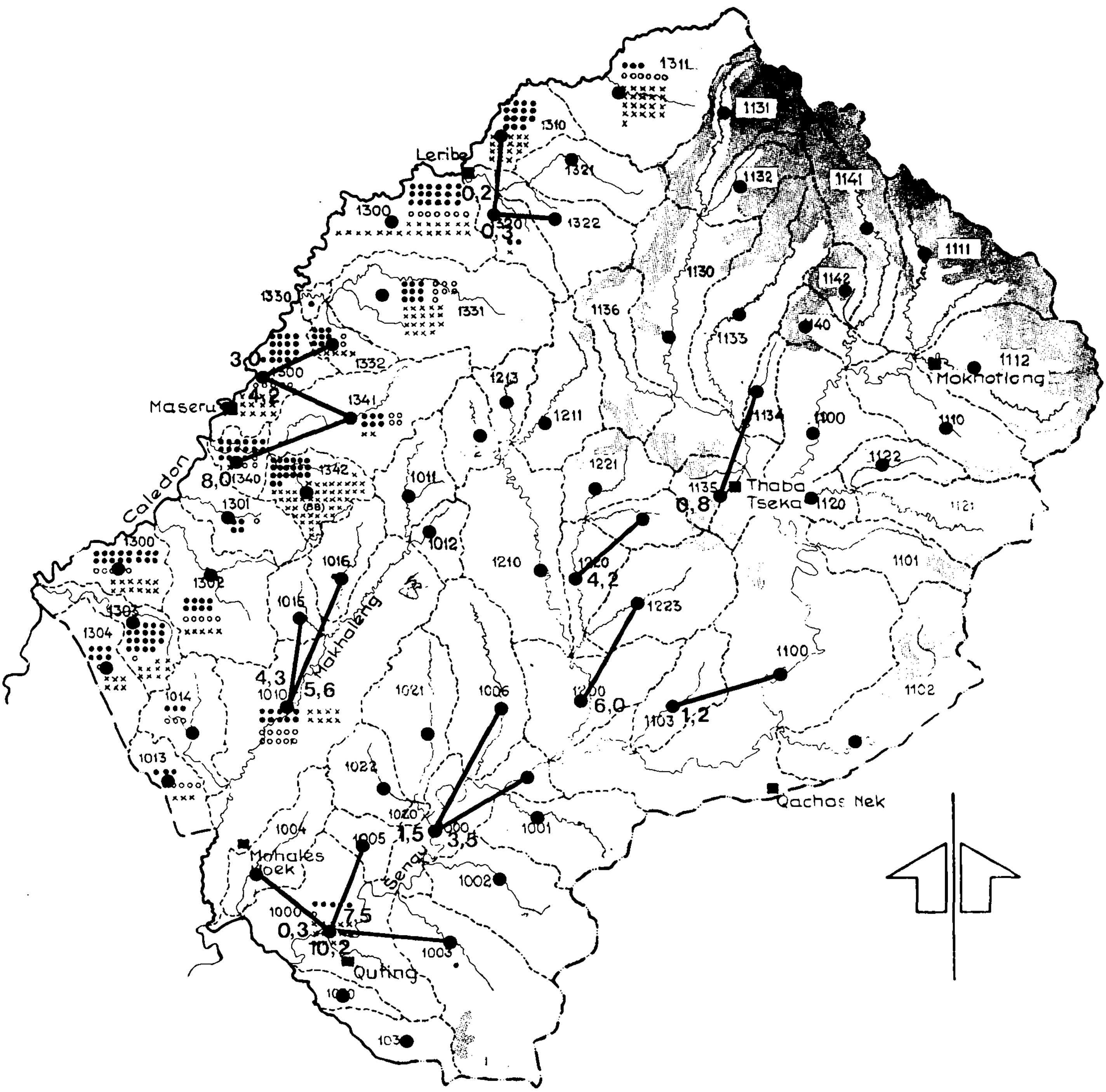
3.4 Model output

The model output should be presented in such a form that it can be easily used for evaluation without further processing. The data should therefore preferably be given in graphical form.

The transfer of water between catchment areas can, for example, be presented in the form of flow charts as in Figure 7, where sources, consumers and transferred amounts of water are given. Separate maps can be produced for average transfers, maximum transfers, etc.

In the event that regulation schemes play an important role in the supply system, computer outputs like Figure 3 may be valuable.

The graphical output should be supplemented with tables, etc., but this output should be kept at a minimum. The most important information concerns conflicts and excess resources and must be given to guide the search for an efficient solution to the resources problem.



● Coordinate defining location of a catchment area

1,2 Transfer for domestic supply (figure shows location of consumer)

4,3 Transfer for irrigation

Figure 7 Outline of model output

4. Conclusions

In water resources studies computers and computer models serve as efficient tools at various stages of the study. The preparation of field data collection programmes and the storing of collected data can be made in an efficient way if a preliminary model study of the system under consideration is performed at an early stage of the project. A computer can be used to store the data systematically. After the data have been collected and stored, computer models with various degrees of sophistication can bring about an efficient utilization of the data. The models may be tailored to solve particular problems with a moderate programming effort. General models including a more sophisticated software can be used for various planning problems including optimization studies. A continuous development of such models takes place at VBB.