



Integrated Water Demand/Supply Management in Southwestern Skane: A Preliminary Analysis

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IIASA Working Paper

WP-82-022

March 1982



Strzepek, K.M. and Kindler, J. (1982) Integrated Water Demand/Supply Management in Southwestern Skane: A Preliminary Analysis. IIASA Working Paper. WP-82-022 Copyright © 1982 by the author(s). <http://pure.iiasa.ac.at/1993/>

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**INTEGRATED WATER DEMAND/SUPPLY
MANAGEMENT IN SOUTHWESTERN SKÅNE:
A PRELIMINARY ANALYSIS**

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March 1982
WP-82-22

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PREFACE

Water resource systems have been an important part of resource and environment related research at IIASA since its inception. As demands for water increase relative to supply, the intensity and efficiency of water resource management must be developed further. This in turn requires an increase in the degree of detail and sophistication of the analysis, including economic, social and environmental evaluation of water resource development alternatives aided by application of mathematical modeling techniques, to generate inputs for planning, design, and operational decisions.

This paper is a brief summary of a study of water resources management problems in South Western Skåne, Sweden, carried out in the years 1978-1981 by the Resources and Environment Area (REN) of IIASA in collaboration with the Department of Water Resources Engineering of the Lund Institute of Technology/University of Lund (LTH), Sweden. The study was initiated and pursued with the support of the Swedish National Environment Board, whose encouragement and financial assistance is gratefully acknowledged. The methodological work implemented within the framework of this study was generously supported by a grant from the Stiftung Volkswagenwerk, Hannover, Federal Republic of Germany.

Soon after initiation of the joint REN/LTH investigations, the Regional Development Task (RD) of IIASA engaged itself in a case study of economic and demographic, land-use and related problems for the same region of Sweden. This work was pursued by the RD task in collaboration with the Southwest Skåne Municipal Board, as part of the Board's ongoing work concerning physical and public transport planning for the metropolitan region of Malmö and its neighboring municipalities. Because of the obvious relation between the studies pursued by the REN area and the RD

task , both groups interacted intensively throughout the whole duration of their work. Moreover, it was agreed that analysis of "alternative futures" of water resource systems in South Western Skåne will take full advantage of the results of the RD studies concerning overall development prospects for the region, in particular projections of land-use patterns.

This paper on regional water management in South Western Skåne provides an overall description of the joint REN/ LTH effort, with particular emphasis on the MITSIM-2 simulation model developed for integrated analysis of water demand and supply management.

Although the MITSIM-2 application reported herein is of a preliminary nature, in the near future this model will be used for the analysis of a more complete representation of the South Western Skåne water resource system with input data embodying results of the land-use projections developed by the Regional Development Task of IIASA.

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ACKNOWLEDGEMENTS

The authors would like to thank all the members of the Resources and Environment Area that contributed to the South Western Skåne Case study, in particular Robert Anderson , Susan Arthur, Lennart de Mare, Donald Erlenkotter, Tsuyoshi Hashimoto , and Norio Okada, as well as the other IIASA staff that contributed directly to this work Åke Andersson, Geoffery Roy, Folke Snickars, Ingolf Stahl, and H. Peyton Young.

ABSTRACT

The water management system in South-Western Skåne features different water supply sources (surface and groundwater), municipal water demand zones, and several agricultural water users. In the future the Bolmen Lake scheme will be made operational. The major question now is what are the advantages and disadvantages of integrating all sub-regional solutions into a regional water resources system (particularly in terms of increased reliability).

River Basins are the main feature of the sub-regional water resource systems in South Western Skåne. A simulation model, MITSIM-2, was developed to analyze the hydrologic performance of these systems. Using this model and water use projections based upon projections of the future demo-economic structure of South Western Skåne, an preliminary analysis of a regionally integrated water supply system was performed. This analysis examined the ability of the regionally integrated system to satisfy the water requirements of South Western Skane under different development scenarios.

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1. Background to Water Management in South Western Skåne

The southernmost tip of Sweden, the province of Skåne, is one of the few areas in that country which is relatively short of water resources. At the same time, the province plays an important role in the Swedish economy. It is an industrialized area specializing in the processing of food and beverages and in the manufacturing of chemical, rubber and non-metallic mineral products. Moreover, it has the most productive agricultural sector in the entire country. Skåne consists of two counties, Kristianstad County and Malmöhus county, (see Figure 1.). Malmöhus County, located in the southwestern part of Skåne, has an area of about 5000 sq. km. and a clearly metropolitan character, with an average population density of about 150 inhabitants per square kilometer.

In 1978, the International Institute for Applied Systems Analysis (IIASA) in collaboration with the Lund Institute of Technology (LTH) initiated a study of water resources management problems in Malmöhus County supported by the Swedish National Environment Protection Board. Many of these problems are typical of water resources management issues in other countries. Consider first a brief historical review of water resources development in this region.

Until the late 1940's the region's municipal water supply for household and industrial use was almost exclusively based on local groundwater resources, primarily the Alnarp aquifer with a safe yield capacity of about 20 million m³/year. In the post-war years, however, the economy of the region started to develop rapidly and its urban centers witnessed rapid growth, especially in the municipalities of Malmö and Helsingborg. An example of this rate of growth is that during the years 1951-1970 the

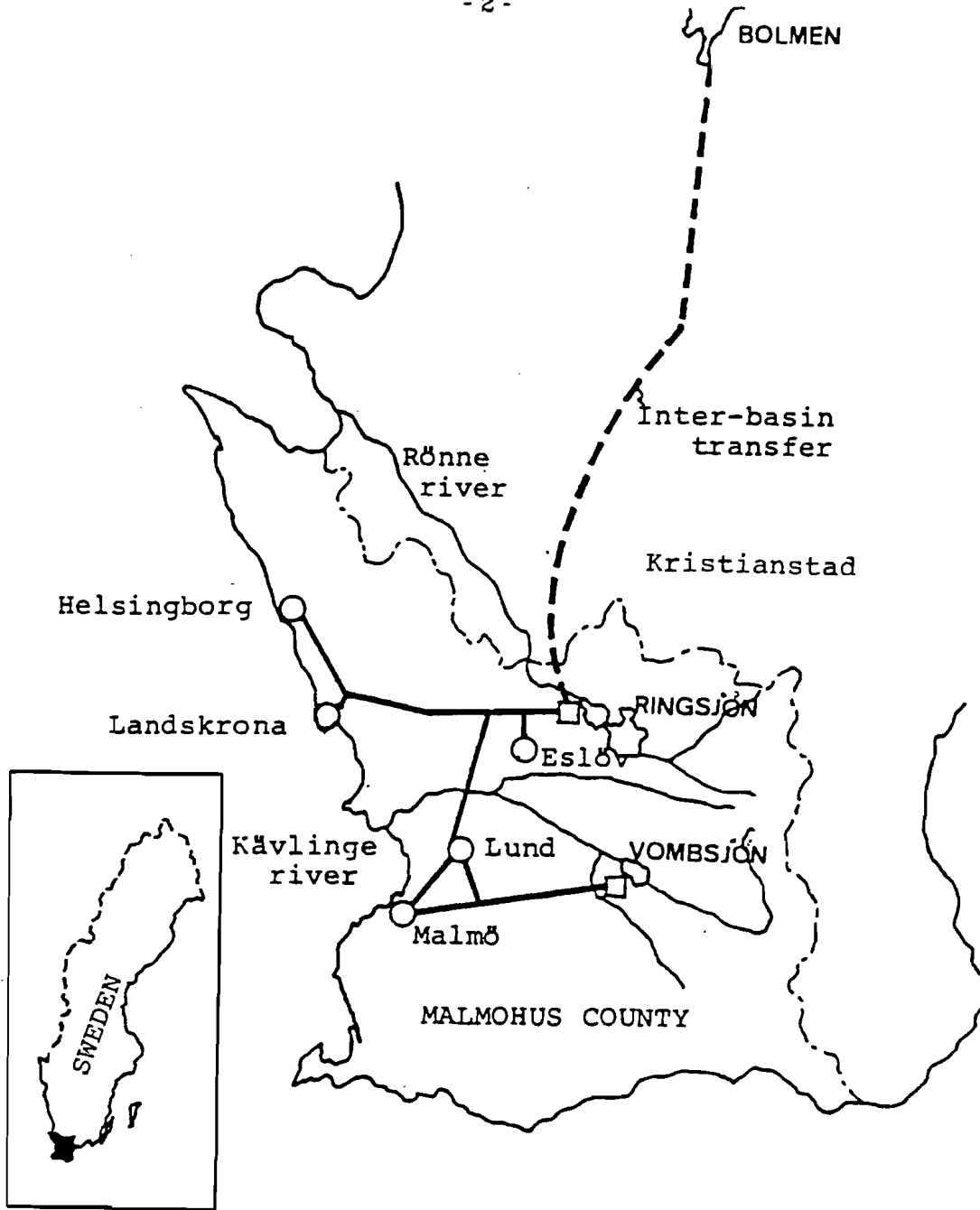


Figure 1. Region of Skåne

population of Malmö municipality grew from about 200,000 to 264,000 inhabitants, an average annual growth rate of close to 2%.

In 1948, a regional municipal water supply system was introduced with the completion of the Vomb Lake (Vombsjön) Project. The lake was converted into a storage reservoir with a projected annual yield of 47 million m^3 , supplying water through a pipeline system to Malmö and five surrounding municipalities. This lessened the reliance on groundwater resources, although groundwater continued to be used along with the new surface water supply from the Vomb. At the same time, the northern

municipalities of the region, especially Helsingborg, began to experience occasional water shortages. In 1963, the regional municipal water supply system was expanded with completion of the Ring Lake (Ringsjön) Project. Ring Lake was used as a storage reservoir with a projected annual yield of 35 million m³. Water withdrawn from Ring Lake was supplied by a pipeline system to Helsingborg and to three other municipalities in the northern part of Malmöhus County.

In the mid-1960's the economy of the region was booming and the number of inhabitants in urban centers was increasing. A general concern had emerged--would lack of availability of water hamper further growth of the regional economy? As an outgrowth of this concern, forecasts of future water use in southwestern Skåne were carried out in 1965 by local authorities with the aid of some governmental agencies (SOU, 1965). An assessment of future industrial water use was carried out in collaboration with the Federation of Swedish Industries. The conclusion was that industrial water use in western Skåne would double between 1960 and 1980, and treble by the year 2000. The forecast of household and general purpose water usage was based on analysis of such factors as population growth and its distribution, structure of the housing market, per capita demand and the industrial structure of the region. A significant increase of population in southwestern Skåne was anticipated and the previous trend of intensive migration toward the city centers, calling for construction of more multi-family houses in the three largest cities of the region (Malmö, Helsingborg, Lund), was expected to continue. The forecast made in 1965 was based on the assumption that current attitudes toward water use and water-pricing schemes would remain unchanged. The forecast clearly indicated the need for additional expansion of the municipal water supply system. As a result, attention turned to Bolmen Lake situated about 150 km north of the Skåne region. This lake is a practically unlimited source of water--it is very large compared to the total municipal water use in southwestern Skåne, which in 1965 was of the order of 70 million m³/year. In 1966, the five largest municipalities of southwestern Skåne formed the Sydsvatten Association to carry out a project to transfer water from Bolmen Lake to Skåne. In 1973, following seven years of legislative activity, Sydsvatten was granted permission to withdraw up to 195 million m³ of water annually from Bolmen Lake. Completion of the project was scheduled for 1979.

The decision to set the transfer capacity from Bolmen Lake 195 million m³/year, an amount almost three times larger than the total municipal water use in southwestern Skåne at the end of the 1960's, was based only in part on the 1965 forecast. This water transfer project called for constructing a long tunnel (approximately 80 km) through the hills separating Bolmen from Skåne, and the diameter of the tunnel had to be compatible with the requirements of the modern drilling equipment which would be used. The least-cost diameter of the tunnel corresponded to a flow rate of about 6 m³/sec, which is about 195 million m³/year of transfer capacity. It was recognized by all concerned that the full potential of the Bolmen Project would probably not be utilized before the middle of the 21st century.

It was in the early seventies that a chain of events began. First, municipal water use comprised of domestic and industrial uses stopped growing. As for the industrial component, this was due to failure to anticipate the effects of the environmental legislation of the late 1960's. These laws led Swedish industrial users to install new water-recycling equipment to cut the cost of complying with water quality requirements, and with the incidental effect of dramatically reducing water withdrawals. By 1976 the actual industrial water use was equal to about half of that forecast in 1965, in spite of a substantial increase in industrial production over the same period.

In addition to this, the household component of municipal water use became virtually level. Population growth was much slower than expected and population trends changed in the early 1970's. Unlike the earlier intensive migration toward city centers, the phenomenon of urban sprawl emerged-- people started moving from urban centers to surrounding areas within commuting distance. This new migration pattern markedly influenced housing construction and consequently influenced household water use. Since 1970 the number of new multi-family houses in the three largest cities of the region rapidly declined, contrary to the expectations of the 1965 forecast. At the same time, demand for single-family houses increased. Because an unexpectedly high percentage of the population moved to single-family houses, and because per capita water usage in single-family houses is lower than in multi-family houses (residents of single-family houses, with individual meters, are more sensitive to water price than are residents of multi-family houses for which one meter serves the entire structure), total household usage stopped growing in the region.

In 1973, as a result of these developments (which were still in a preliminary stage) the 1965 forecast was revised. The results of this revision were postponement of completion of the Bolmen Project until 1981 and some modification of the project design. Otherwise, preparations continued for project implementation.

There seem to be good reasons that the first signals of a significant deviation from the 1965 forecast for municipal water use in the region had little impact on decisions concerning development of a new source of supply. It happened that these signals coincided with six years (1970-1975) of abnormally dry summers in southwestern Skåne. With very low precipitation there were problems with filling the Vomb and Ring reservoirs, and occasional shortages of municipal water were observed in some parts of the region. At the same time, however, there was an event of much greater significance. Local farmers began to withdraw considerable amounts of water for irrigation purposes. They realized that supplementary irrigation could help maintain high productivity and the quality of crops. General availability of low-cost and easily handled irrigation equipment, as well as the availability of free water for irrigation, provided additional inducement to irrigate. It should be emphasized that none of the earlier forecasts of water use in southwestern Skåne had seriously considered supplementary irrigation.

The water problems of the very dry early 1970's also inflicted occasional conflicts between municipal and irrigation water uses. It is well known that water resource problems transcend the arbitrary political or administrative boundaries. Evidence of this in southwestern Skåne is that the municipal water supply projects--Vomb, Ring, as well as Bolmen--have been, or are being, implemented by associations established by the municipalities benefiting from the projects. These associations were concerned only with municipal water and therefore their regulatory arrangements (e.g. decision rules for operation of Vombsjön and Ringsjön) deal only with municipal water. This proved to be insufficient, especially with the emergence of a new water user, irrigation, and the overall shortage of water supply.

The Vomb and Ring projects were partly connected in 1974 as a move toward regional coordination. This increased the operational flexibility of the existing municipal water supply system to such an extent that completion of the Bolmen Project was once again postponed, this time until 1985. However, preparations for project implementation still continued.

In 1975 construction of the Bolmen tunnel was initiated, which to a large extent, is being financed by the local population through additional water use charges, wastewater disposal charges and municipal taxes. In 1978 when the joint IIASA/LTH project began, the demand for municipal water was at roughly the 1970 level and the last three years had relatively wet summers, so there was no evidence of any substantial growth in irrigation water use.

A more detailed description of the socio-economic and water resources situation in South Western Skåne was produced as part of the IIASA/LTH study, (Andersson et al, 1979).

2. IIASA'S Case Study of South-Western Skåne: An Overview

Since regional water management planning covers an extremely broad spectrum of different problems and issues, it was decided in 1978 to concentrate research efforts on a few selected topics which, on the one hand are of great practical importance, and on the other, present several challenges of a methodological nature. These topics can be summarized as (1) criteria of choice among alternative courses of action, (2) conflict over resource allocation and use, (3) uncertainty and risk in water management planning, and (4) institutional framework of regional water management.

Water problems of South-Western Skåne served as a source of inspiration for the research program undertaken by the Resources and Environment Area (REN) of IIASA. Identification of these problems--as a matter of fact quite typical for water resources management in many other countries--has been accomplished in close contact with the Swedish decision-makers and planners actually responsible for their solution.

Following is the brief description of REN's investigations carried out within the framework of the South Western Skåne study. All of these investigations focused on four topics mentioned above, with the emphasis shifting among them depending on the character of the problem brought under analysis.

2.1. Water demands

The first group of investigations was oriented towards a better understanding of demand for municipal and irrigation water. Since South Western Skåne consists of 20 municipalities, one of the major questions was how to account for differences among them in the total gross and total per capita municipal water use. Because of inadequacies in data bases made available to the project team (e.g. water use yearbooks comprise water production instead of metered water use data), statistical estimation of demand relationships proved to be difficult (Hashimoto and de Mare, 1980). The study, however, did provide some insight into the problem. The industrial activities (based on municipal water supply) were found to be most important in explaining differences among municipalities in the total per capita water use. In 1980 another attempt was made toward better understanding of the problem (Hanke and de Mare, 1981). This analysis was based on pooled, time series, cross section water demand samples from representative districts of Malmö (Malmö makes up 1/3 of the regional population). The analysis allowed the development of a model and estimates of price elasticities for residential (single family houses) water demand in Malmö.

The second study was concerned with estimation of potential water demand for supplementary irrigation in South Western Skåne. The problem is not only relevant to Skåne, but it is of crucial importance in many other regions where agricultural production is vulnerable to the annual variability of hydro-meteorological conditions during the growing season.

The study was concerned with two aspects of the problem -- effects of supplementary irrigation on the probability distribution of total water inputs to crop production over the irrigation season (Arthur, 1980 and Anderson, 1981) and relationship between changes in these probability distributions and the economic benefits, as measured by increases in expected farm income (Anderson, 1980)

2.2. Water Supply

A methodology to provide time-series of streamflow data for the Kävlinge and Ronne River Basins was developed by Kindler and Feluch, 1981. It was found that monthly precipitation data at Lund could be used to reconstruct missing monthly streamflow values throughout the basins. Using this information a 75 year time series of monthly streamflow was generated for various inflow and interflow locations in the basin.

Groundwater provides an important part of the water supply of South Western Skåne. With the increase of irrigation and fertilization present groundwater supplies are vulnerable to nitrate pollution. A study was undertaken to investigate this problem, (Golubev, et al, 1979).

A study was performed on the effect of changes of water quality to the Ring and Vomb distribution system, especially with the possible addition of soft water from the Bolmen project, (Kos, 1981).

2.3. Conflict Resolution

There are two sources of conflict in regional water management: the many objectives which are used to evaluate management plans and disagreements among the actors in the decision making process, (Cohon et al.,1981). Both of these sources of conflict do exist in South Western Skåne.

As far as the first source is concerned, in addition to economic efficiency, objectives that have been identified as important in South Western Skåne for analysis of alternative allocation schemes include distributional (equity) effects, environmental quality, and risk considerations involving robustness, reliability, and other measures of system performance. Robustness defined as the systems ability to perform under different future events other than originally expected at a relatively small incremental cost, has been studied by Hashimoto (1980). In this study, the concept of robustness is explored and an operational robustness criterion for the evaluating of alternative water supply/demand systems is developed.

An interactive procedure for multiobjective analysis of water resources allocation (Kindler et al.,1980) was developed for estimating trade-offs among conflicting objectives, some of them being of a non-commensurable character. The procedure was applied for the analysis of water allocation to seven conflicting uses in the Kävlinge River System in South Western Skåne. In this category of investigations, the problem of water resources allocation was formulated as a two-level multiobjective program which reflects a decentralized institutional framework of the region (Hashimoto, 1980). Both the upper and the lower level problems were solved using the reference objective method developed at IIASA (Wierzbicki, 1979a,1979b)

Our concern with the second source of conflicts, namely disagreements among the actors in the decision making process, is represented by two studies motivated by the Skåne situation, where a group of municipalities is developing a joint water supply system. A typical form of conflict derived from implementing such a project is the problem of allocating costs among participants (Young, et al., 1980).

In this study, certain basic principles that cost allocation methods should satisfy, have been developed, based on consideration of equity, common sense and the need to provide incentives for the participants to cooperate. In the light of these principles, a comparison has been made between the methods most commonly used in cost allocation practice, for example the separable cost/remaining benefit method, and several allocation concepts based on cooperative game theory. From this comparative analysis, there has emerged one method (the weak least core) that seems particularly well-suited to solving cost allocation problems of the type encountered in Sweden. This study led also to an IIASA Executive Report (ER-5,1981) providing a practical introduction to cooperative game theory as applied in water resources management. The study also served as a base for implementation of a gaming experiment involving real decision-makers in Sweden, with results indicating considerable interest in the principles and procedure developed at IIASA,(Stahl,1980).

2.4. Demand and Supply Uncertainty

Water resources planning is characterized by uncertainties, both on the demand and the supply side, and by long lead times for project development. Demand uncertainty can involve not just random variations about some estimated future mean demand, but also abrupt structural shifts in the evolution of demand. These shifts, which typically are not even considered among the range of forecast outcomes, are appropriately designated as "surprises". When project lead times are long, the possibility of being "surprised" between initiation and completion of the project can be significant.

Study of the implications of surprises for water resources planning has been motivated particularly by the Skåne case study, where water usage suddenly ceased increasing according to the original forecast after work had been initiated on a large project to increase supply, (Erlenkotter, Sethi, and Okada, 1981)

A model was developed to analyze the implications of a "surprise". A tentative conclusion drawn from applying the model is that even a small probability of a surprise in each year could have made desirable a significant delay in the project commitment time. The model is being expanded to consider flexibility in the form of reducing the project lead time for some additional cost or abandoning the project if a surprise occurs.

3. Demand/Supply Integration: Planning for Regional Water Resource Management.

As pointed out earlier, the water management system in South-Western Skåne features different water supply sources (surface and groundwater), municipal water demand zones, and several agricultural water users. The southern part of the system is based mostly on water supplies from the Vomb Lake and the Alnarp aquifer. The northern part of the system is based on water supplies from the Ring Lake and several local groundwater sources. In the future the Bolmen Lake scheme will be made operational--it will be able to supply practically unlimited amounts of water to South Western Skåne. The major question is now what are the advantages and disadvantages of integrating all sub-regional solutions into a regional water resources system (particularly in terms of increased reliability).

In the following sections of this paper, mostly planning decisions, either of a long-term or a short-term character, are discussed. At this point, two clarifying comments should be made. First, operational aspects of the systems' performance must be taken into account in all planning decisions; however, this is not the same as day-to-day operational decision-making in water management. Second, distinction between time horizons associated with long-term vs. short-term planning should be explicitly recognized. The long-term planning decisions are usually of a strategic character--they refer to a rather distant future since long lead-times are necessary for implementation of the major water resources projects. On the other hand, short-term decisions are of a more tactical nature. There is simply no time to wait for implementation of the long-term measures, and the water resources manager must react to the changing situation by introduction of new water use policies,

addition of relatively small physical facilities increasing systems' reliability, changing operation rules of existing facilities, etc.

The problem facing South Western Skåne are of two levels. At the regional level it is a planning problem. The major portion of the region's water resources originates from the two river basins, Kävlinge and Rönne. At the river basin level the problem is operational in nature. To address the problem of regional demand/supply integration, a multi level approach was taken. The river basin was chosen as the basis for hydrologic analysis and the operational features necessary to be accurately represented were included in the analysis. The sub-regional river basins were then combined to analyze regional demand/supply integration for long-term planning. The core of the analysis was a river basin simulation model which is described in the next section of this paper.

3.1. River Basin Simulation Model: MITSIM-2

A river basin simulation model was developed by the Water Resources and Environmental Engineering Division of the Department of Civil Engineering at the Massachusetts Institute of Technology (MIT). This model, MITSIM-1, provides a detailed simulation of both the physical and economic performance of the river basin system including multipurpose, multiobjective, surface water projects as well as groundwater projects. The model was designed for planning purposes and is described and in Lenton and Strzepek (1977) and its application in Strzepek and Lenton (1978).

To address the complex operational aspects of water management in South Western Skåne a new model, MITSIM-2, was developed at IIASA in collaboration with MIT (Strzepek, 1981a). This model is an extension of MITSIM-1, retaining its basic structure, but not incorporating any economic analysis. Modifications were made to provide an adequate representation of the detailed operational features of the sub-regional river basin systems.

3.1.1. Measure of System Performance

The physical performance of a water resource system is measured by the level of water flow at different points in the system. In water resource systems the problem that faces the analyst is that the inputs to the system, (precipitation, streamflow, irrigation water use, etc ...) possess natural variability and thus system response will exhibit variability. With variability in the system performance it is difficult for one measure to represent system performance.

There are two measures of performance used in this study. The "reliability" of the supply of Municipal and Industrial (M&I) water and the "mean deficit". Reliability is defined as the frequency with which the supply of water for M&I use attains the target M&I supply.

Reliability does not sufficiently describe the performance of the system when the target is not met. However, for this study a second measure of performance, the mean deficit from the M&I target is presented. This provides some insight into the degree to which the system is failing.

3.2. Use of MITSIM-2 for Analysis of the South Western Skåne Water Supply System

The objective in using simulation modeling in this study is to analyze the performance of the water resource system of South Western Skåne under various water demand scenarios. As was mentioned above there are presently two major sub-regional M&I water supply systems in South Western Skåne, Vombsjön and Ringsjön. These systems are operated separately, but are weakly linked through the city of Lund. There is the possibility to totally integrate the two system into one jointly operated regional system. In addition there is the option to import water to the regional system by means of the Bolmen Project. The goal of this analysis is to study the effect of natural variability in hydrologic phenomena and the variability of demand on the performance of the "regionally integrated water resource system." This analysis is carried out to provide a preliminary analysis of the performance of a regionally integrated system.

To apply MITSIM-2, it is first necessary to conceptualize the water resource system of South Western Skåne into a series of water supply and use nodes linked by arcs. For this analysis of the integrated system, the spatial distribution of the demand is not relevant, therefore all M&I demand is represented as one node. This conceptualization is shown in Figure 2 for the regional integrated system.

With the conceptualization of the system and the data on precipitation, streamflow, irrigation requirements and M&I use, it is possible to simulate the performance of the water resource system.

3.2.1. Data , Procedures and Scenario Generation

The length of the simulation runs that were performed was 75 years. The precipitation data were historic daily values from Lund from 1900-1974 aggregated to monthly values. Due to the small size of the basin the precipitation was assumed to be homogeneous over the basin on a monthly time scale. This allows the Lund data to be used for all points in the basin.

The 75 year precipitation record at Lund was the driving function for several other stochastic inputs to the simulation runs. Arthur(1980) developed a model to simulate farmers irrigation practices as a function of daily precipitation. With this model it was possible to determine the monthly water requirements for the different crops grown in South Western Skåne on a per hectare basis for each month of the 75 years. This data was then combined with information on the cropping pattern at the various irrigation nodes in the basin to determine the monthly water requirements for supplementary irrigation for the entire 75 year period. If the cropping pattern or amount of land under irrigation changes, it is possible to calculate a new time series of water requirements, by multiplying the water per unit crop area values by the new areas. These monthly water requirements are then fed into the model as input.

Streamflow data for the two basins exists for approximately the last 25 years. A statistical analysis was performed to examine the correlation between monthly precipitation at Lund and streamflow at several points in the two basins. It was found that monthly precipitation data at Lund

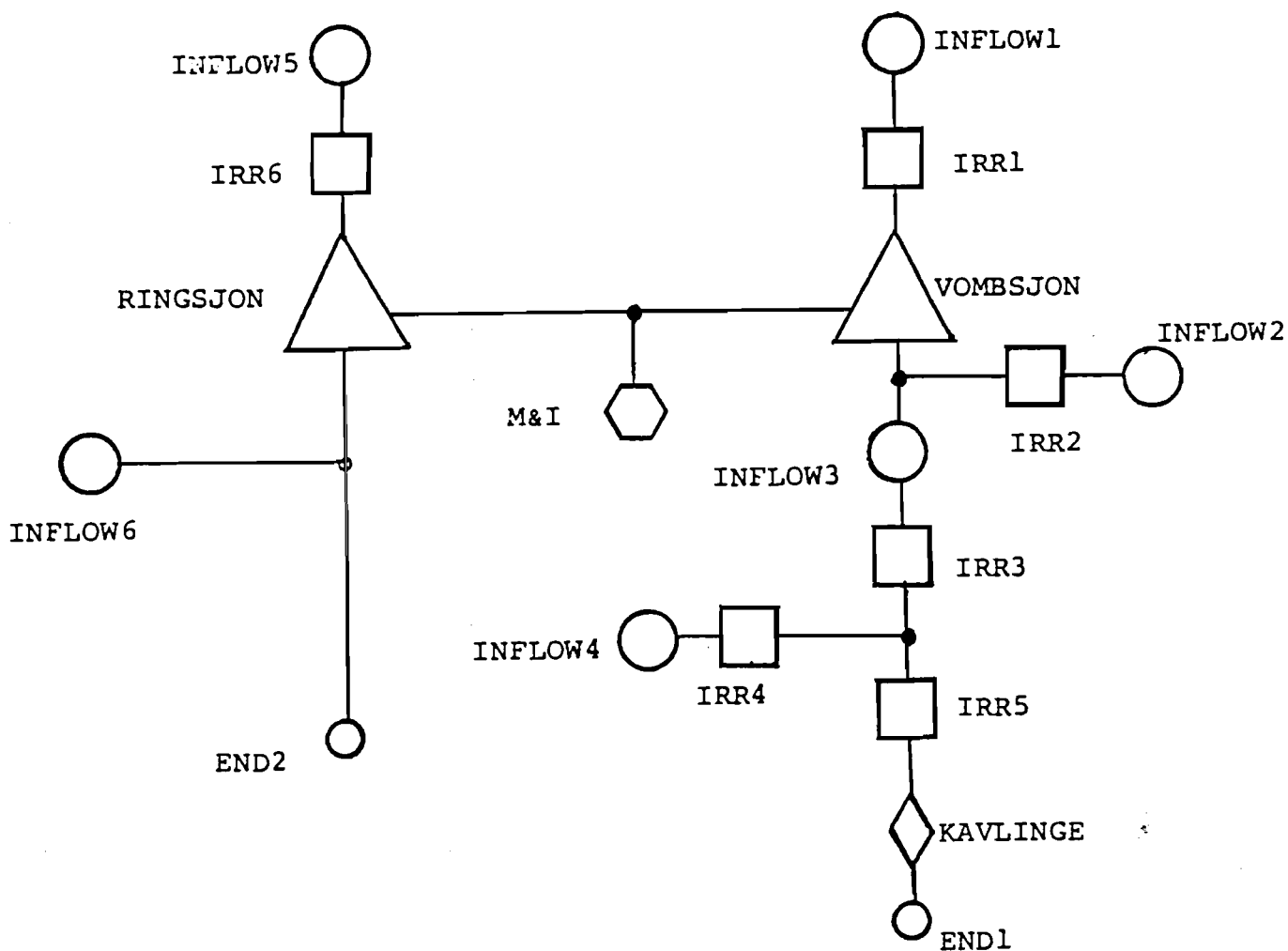


Figure 2. Integrated Regional System

could be used to reconstruct missing monthly streamflow values throughout the basins. Using this information a 75 year time series of monthly streamflow was generated for various inflow and interflow locations in the basin, (Kindler and Feluch, 1981).

By using the 75 year historic record of precipitation at Lund to generate the irrigation requirements and the streamflow it was possible to obtain a consistent set of data to analyze the interaction of a complex water resource system. Since one of the important interactions to be analyzed is the conflict between M&I and irrigation water uses it was

important to preserve the temporal correlation between precipitation, streamflow, and irrigation requirements which is important to expose a lack of water resources during times of drought.

For this analysis groundwater is considered to have a long time response and not greatly effected by short term fluctuations in precipitation on a regional scale. Therefore groundwater is considered as a constant source of water for M&I use and is not considered in the simulation analysis .

The nature of this analysis is to examine the reliability of the regionally integrated water supply system of South Western Skåne under various water use scenarios. The system examined is that shown in Figure 2. For this analysis the two reservoirs, Ringsjön and Vombsjön, are operated jointly to meet the given aggregate M&I requirements at node M&I. The reservoirs operate based on the available storage in each reservoir as described in Strzepek (1981a). There are two major water use scenarios brought under investigation. The first scenario assumes no irrigation in the basin and the second assumes irrigation withdrawals to be at the potential maximum as forecast by the Malmöhus County Board(Fahlstedt,1978).

The objective of this study was to provide a preliminary analysis of the problems facing water planner in South Western Skåne and to show the applicability of the simulation approach and MITSIM-2 in particular to provide information for water management decisions that must be made. In this regard there is no attempt in this study to predict future M&I water requirements. Instead , a parametric analysis of M&I water use was made . By examining a wide range of water use scenarios ,from no irrigation with low M&I use to full potential irrigation with high M&I use, the ability of the model to provide useful information for decision makers and planner was tested.

3.3. Preliminary Results

Two series of runs of the model were made for the each of the irrigation scenarios in the basin. Each run in the series was performed with a different target for the annual M&I water use. Monthly M&I water use targets were obtained by assuming that water use is uniform over the year .With this assumption the monthly targets are defined as a percentage of annual target calculated by the ratio of the number of days in the month to the total number of days in the year.

Although the model provides much detailed information on the performance of the system , only some aggregate indicators of system performance that may be of interest to water managers for this system are presented in tables 1 and 2. These indicators are ;the mean annual supply of M&I water by the system ,the reliability of the annual and monthly M&I water use target, and the magnitude of the monthly and annual deficit if the target supply is not met .

The results of the system's performance to each level of M&I target water use as described by the aggregate performance indicator are presented in tabular form below. Table 1 present the results for the no irrigation scenario and Table 2 provides the results for the potential maximum irrigation scenario. These tables provide useful information about

Table 1. System Performance with No Irrigation Scenario

Annual M&I Target MCM	Mean Annual M&I Supply MCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Monthly Reliability (%)											
		Mean Monthly Deficit (MCM)											
25.	25.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
50.	49.98	100.	100.	100.	100.	100.	100.	100.	100.	100.	99.	100.	100.
		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	.04.	0.
60.	59.9	100.	100.	100.	100.	100.	100.	100.	100.	100.	97.	100.	100.
		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	.08	0.
75.	74.3.	100.	100.	100.	100.	100.	100.	99.	98.	95.	96.	99.	100.
		0.	0.	0.	0.	0.	0.	.08	.11	.24	.19	.06	0.
82.	80.7	100.	100.	100.	100.	100.	99.	97.	95.	87.	93.	97.	100.
		0.	0.	0.	0.	0.	.02	.10	.25	.52	.28	.10	0.
90.	87.5	100.	100.	97.	100.	100.	99.	95.	91.	77.	88.	96.	99.
		0.	0.	.02	0.	0.	.08	.24	.39	1.02	.58	.16	.01
100.	95.1	100.	99.	96.	100.	99.	97.	93.	80.	67.	79.	91.	99.
		0.	.02	.10	0.	.04	.11	.43	.93	1.95	.97	.32	.02
120.	109.3	99.	96.	95.	99.	99.	92.	79.	67.	57.	75.	84.	93.
		.08	.15	.22	.04	.11	.30	1.39	2.58	3.38	1.71	.60	.14
150.	124.5	97.	95.	92.	97.	92.	76.	64.	45.	25.	48.	72.	84.
		.21	.40	.46	.19	.41	1.66	3.52	5.33	7.21	3.97	1.37	.83
200.	140.9	92.	89.	83.	88.	77.	53.	37.	13.	3.	23.	60.	71.
		.57	.93	1.40	1.04	2.16	5.29	8.29	12.13	13.74	8.33	3.20	2.06

the response of the system to various M&I water use targets. With this data a decisionmaker or planner can compare the performance of the system under the two irrigation scenarios and examine the effects of irrigation development on the ability of surface water to supply different levels of M&I water use. This is the type of information that is helpful in deciding the adequacy of the system to meet present and future demands.

This study made no attempt to project future water use in South Western Skåne, but analyzed water supply reliability by parametrically varying the M&I water supply target on an aggregate level.

As discussed above the RD Task of IIASA has undertaken a project to project future demo-economic and land use patterns in Skåne. Drawing upon the work of Hashimoto and de Mare (1980), Hanke and de Mare (1981) and Snickars (1981), a model for M&I water use in South Western

Table 2. System Performance with Potential Maximum Irrigation Scenario

Annual M&I Target MCM	Mean Annual M&I Supply MCM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Monthly Reliability (%)											
		Mean Monthly Deficit (MCM)											
25.	25.	100.	100.	100.	100.	100.	100.	100.	100.	100.	97.	100.	100.
		0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	.05	0.
50.	49.5	100.	100.	100.	100.	100.	100.	99.	97.	92.	95.	99.	100.
		0.	0.	0.	0.	0.	0.	.00	.08	.26	.17	.03	0.
60.	58.9	100.	100.	100.	100.	100.	100.	97.	93.	84.	93.	99.	100.
		0.	0.	0.	0.	0.	0.	.07	.22	.51	.29	.05	0.
75.	71.7	100.	100.	100.	100.	100.	97.	95.	81.	68.	87.	96.	100.
		0.	0.	0.	0.	0.	.11	.30	.72	1.52	.50	.13	0.
82.	77.2	100.	100.	99.	100.	99.	97.	92.	71.	64.	81.	96.	100.
		0.	0.	.00	0.	.01	.15	.41	1.30	2.03	.72	.15	0.
90.	83.1	100.	99.	97.	100.	99.	96.	85.	68.	57.	75.	92.	97.
		0.	.03	.04	0.	.05	.22	.70	2.04	2.47	1.13	.24	.02
100.	90.1	99.	99.	96.	100.	99.	95.	77.	63.	51.	75.	89.	97.
		.03	.04	.10	0.	.11	.33	1.45	2.87	3.34	1.43	.37	.05
120.	102.4	99.	96.	96.	99.	97.	80.	67.	55.	35.	60.	81.	92.
		.09	.17	.22	.04	.14	1.02	3.01	3.90	5.35	2.70	.71	.24
150.	115.8	96.	95.	92.	97.	89.	67.	51.	32.	16.	37.	68.	84.
		.23	.40	.46	.20	.79	2.97	5.00	7.63	8.98	4.95	1.72	.83
200.	131.7	92.	89.	83.	88.	73.	47.	23.	9.	0.	20.	59.	71.
		.57	.93	1.40	1.05	2.85	7.20	10.90	13.90	15.13	8.96	3.39	2.06

Skåne was developed (Strzepek, 1981b). This model uses the detailed projections of population and economic structure of Skåne from the RD work together with the data and results from the other REN studies to provide projections for water use in 11 demo-economic sectors.

The results from this water use model representing all the municipalities connected to the Vomb/Ring system as a lumped demand point are presented in Figure 3.

The three curves in Figure 3. represent the water use projections for the three different demo-economic scenarios examined by the RD project. The Industrial Scenario assumes that substantial growth will occur in the industrial sector of South Western Skåne. The Public Scenario assumes that pronounced growth will take place in the public sector with some growth in the Industrial sector as well. Finally, the Basic Scenario assumes more moderate growth in both the public and industrial sectors than in either of the other two scenarios, (Snickars, 1981).

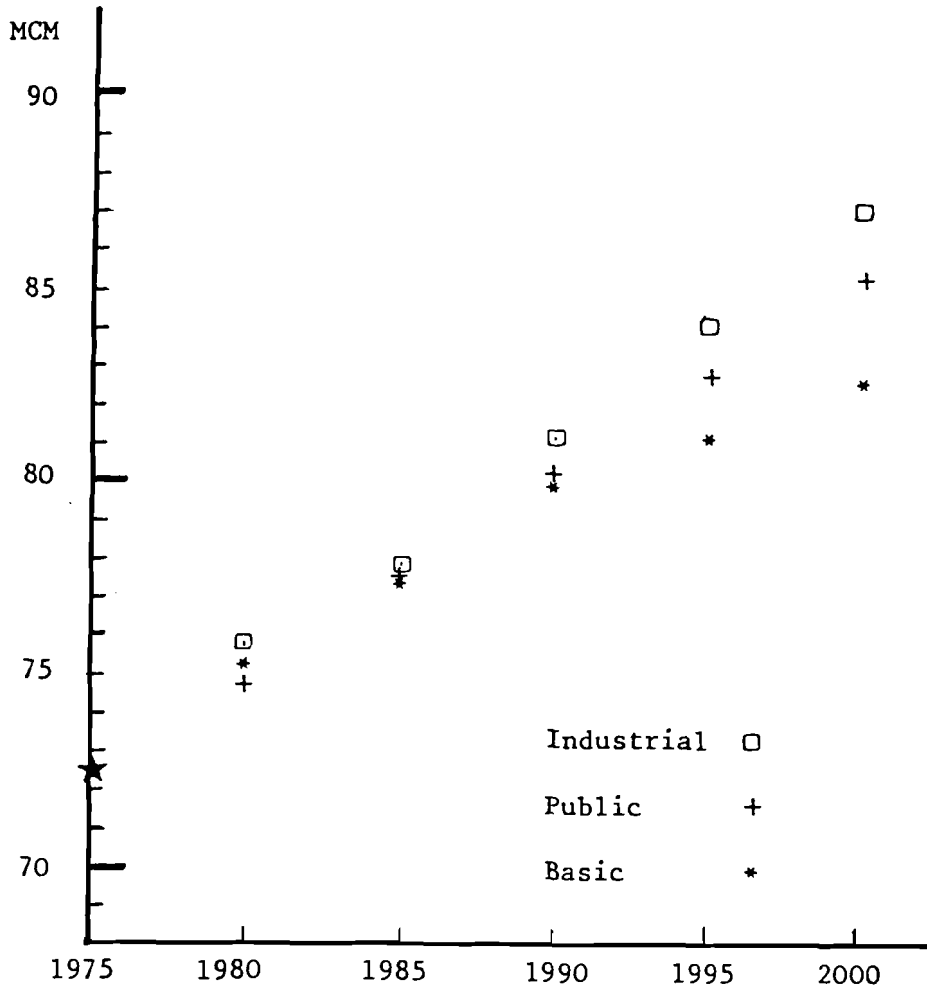


Figure 3. Projected M&I Water Use In South Western Skåne

The values presented in Figure 3. are for total M&I water demand. This demand must be supplied by some combination of surface and groundwater sources. As mentioned in the overview section, a substantial amount of M&I water in Skåne is supplied by groundwater, from both a deep highly reliable source, Alnarp Acquifer, and local shallow sources. There are some doubts whether the long term reliability of the shallow sources can be assured due to various forms of groundwater pollution. However, the Alnarp Acquifer can be consider a extremely high reliable source into the next century, (de Mare, 1981). From 1950 through 1980

the average yearly withdrawal has been approximately 15 million cubic meters (MCM), with the safe yield estimated at about 20 MCM/year. In recent years the amount withdrawn from Alnarp has decreased due to high pumping costs.

With the data presented above, some preliminary conclusions can be derived about the ability of the regionally integrated water supply system to meet the M&I water requirements up to the year 2000. From Figure 3 regional estimates of water requirements can be obtained, assumptions can be made about the amount of this requirement provided by groundwater and the remaining requirements must be met by surface water. Table 2 and 3 provide results about performance of the regional surface water supply system to various levels of M&I water requirements for different irrigation scenarios. This information provides some preliminary insights into the ability of a regionally integrated system to meet future water requirements of South Western Skåne.

4. Summary and Reflections

This paper is a preliminary effort to integrate all the work of the REN Area on Regional Water Management in South Western Skåne together with the work carried out by the RD Task on demo-economic structure of Skåne. The analysis of demand/supply integration for regional water management was accomplished through the use of a river basin simulation model. This approach adequately represented the operational aspects of the river basin, but allowed for long term planning of regional demand/supply integration. Some preliminary insights to long term planning issues were presented.

Since the paper refers to regional water management planning, it is appropriate to also briefly review the notion of a regional development. This term refers to a relatively small spatial subdivision of the national territory which represents a regional order for economic and social policy purposes. According to Hamilton (1978), the development of a region means socio-economic and cultural modernization involving structural shifts in activity and associated societal organizations from the lower stages to the higher stages of society. While water resources projects have had very significant impacts on regional economic development and population distribution in the past, they are usually not the major factor in accomplishing these objectives in the modern industrial societies. These projects should rather be viewed as one of several ingredients necessary to secure and encourage regional development supporting whatever regional policy a particular nation adopts.

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