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INTERREGIONAL WATER TRANSFERS

Problems and Prospects

Editors
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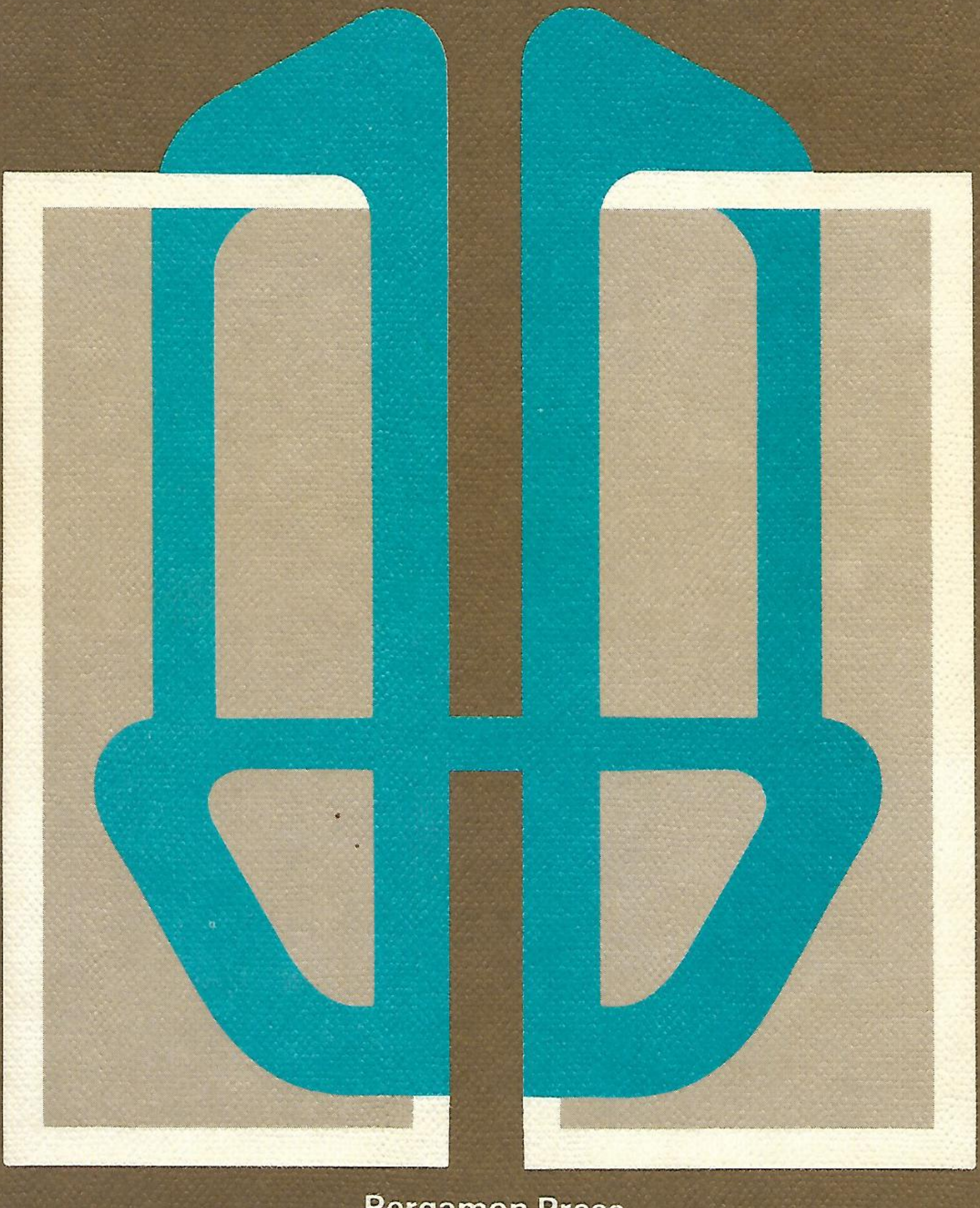

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Preface

The total amount of water available globally, if used more efficiently, can meet vastly higher human needs. Current estimates indicate that the total volume of water on earth is $1.4x10^9$ km^3, 97.3 percent of which is ocean water, and, therefore cannot be used by man except for fisheries and navigation. Only 2.7 percent is fresh water, 77.2 percent of which is stored in polar ice-caps and glaciers, 22.4 percent as ground water and soil moisture (about two-third lies deeper than 750 metres below the surface), 0.35 percent in lakes and swamps, 0.04 percent in the atmosphere and less than 0.01 percent is in streams. In other words, nearly 90 percent of fresh water is stored in ice-caps, glaciers and as deep ground water, and as such is not easily accessible. For all practical purposes, it is surface water in rivers, streams and lakes, amounting to less than half of 1 percent of available freshwater, that constitutes the basic available supply for man, even though ground water has been heavily developed in certain parts of the world.

With the continual increase in the world population, more and more water is becoming necessary for domestic, industrial, agricultural and other purposes. Furthermore, it has been observed that as the standard of living increases, water use per capita goes up as well. Thus, mankind is going to need more and more water in the future, both due to increases in population and standard of living.

The major user of water, however, is agriculture. It has been estimated that agriculture accounts for 80 percent of all water consumption in the world: the corresponding figure for the United States is slightly above 40 percent. It takes approximately 1,000 tons of water to grow one ton of grain and 2,000 tons to grow one ton of rice. In addition, animal husbandry and fisheries require abundant water.

In 1975, according to the Food and Agricultural Organization of the United Nations, the total area irrigated in the world amounted to 223 million hectares, of which 93 million hectares was in developing countries. Some 15 per cent of the world's cropland is irrigated, but it yields from 30 to 40 per cent of all agricultural production. The amount of water used by irrigated crops is nearly 1,300,000 million cubic metres, but because of losses in storage, conveyance and use, the total amount used increases to almost 3,000,000 million cubic metres.

It is estimated that by 1990 the total area irrigated in the world will increase to 223 million hectares, of which 119 million hectares will be in developing countries. Expanding and maintaining irrigated areas to 1990 is going to be a challenging task, and its magnitude can be judged by the following requirements for the developing market economy countries only:

22.5 million hectares of new irrigation;

45 million hectares of irrigation improvement;

78.2 million hectares of drainage improvement, including 52.4 million hectares on irrigated land;

438,000 million m^3 of additional water; and $97,800 million of investment at 1975 prices.

Increased agricultural activities in marginal areas have often overexploited water availability. In many areas, more groundwater is being withdrawn than can be replenished naturally, thus contributing to major management and environmental problems.

As more and more water becomes necessary for agricultural, industrial and other purposes, certain regions of the world have already started to face shortages, so much so that it is becoming one of the major constraints for further socioeconomic development. Accordingly, it is necessary to explore alternatives to alleviate this rapidly developing critical situation. One possibility is to transfer water over long distances from surplus to deficit areas. Already many projects exist which divert water from one region to another.

In order to study the different aspects of interregional water transfer, Resources and Environment Area of the International Institute for Applied Systems Analysis (IIASA) Laxenburg, Austria, convened a Task Force meeting of international experts from Canada, India, Mexico, Soviet Union and the United States. This meeting was held at IIASA during October 11-14, 1977. It discussed not only the experiences of different countries in interregional water transfers, but also their geophysical, environmental and economic implications. The papers included in this volume are the results of that meeting. The only new addition has been a comprehensive bibliography on the subject.

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Interregional Water Transfers

GENADY GOLUBEV* and ASIT K. BISWAS**

A Task Force, comprising well-known international experts, met at the International Institute of Applied Systems Analysis (IIASA), Laxenburg, Austria, during 11–14 October, 1977, to discuss and review current status of interregional water transfers (IWT) in the world, and to make some recommendations about possible future directions of work. Specialists on IWT from Canada, India, Mexico, Soviet Union and the United States attended the meeting under the chairmanship of Professor Genady Golubev of IIASA; Dr. Asit K. Biswas of Canada was the General Rapporteur.

In his opening address, Dr. Roger Levien, Director of IIASA, briefly described the current research of the Institute, and stressed the importance of IWT within the framework of the existing research activities in the area of water.

The Chairman of the meeting, Professor Golubev, then set the scene for the 4-day meeting by raising some principal questions with regard to IWT projects. He pointed out five major considerations. These were:

(1) The size of IWT projects has been growing exponentially with respect to time. Now the largest ones can transfer up to 10 km^3/yr. Projects for the next 20–30 years are of the next order of magnitude.

(2) Some groups of problems arise because of the growing size of IWT projects: (a) water demand/supply relationships as a starting point for IWT; (b) uncertainty; (c) efficiency; (d) links with other major problems (energy, resources, capital investment, food, etc.); (e) impacts; and (f) other, non-conventional ways of water supply.

(3) In the USSR and the USA, IWT projects have stemmed from: (a) serious demand/supply situations in southern USSR and south-western USA; (b) decrease of river run-off due to human activity; and (c) deterioration of hydrologic regimes of lakes and seas.

(4) The IWT problem consists of three main blocks: technology, socio-economic, and environment. They are subdivided into sub-blocks of a lower level. There is a strong interrelation not only *within* the main blocks but also *between* them.

(5) As a general rule, as the size of IWT projects increases, the complexity increases as well. Uncertainty is in turn connected with complexity and is also growing. Comparison of the curve of uncertainty and the curve of efficiency as functions of the projects' size has been demonstrated. With these considerations in mind, it can be concluded that there is a certain size limitation above which uncertainty is greater than efficiency, and very big IWT projects are not appropriate for the time-being. With the progress of science the critical size of projects will increase.

Dr. Asit K. Biswas, Director of Biswas & Associates, Ottawa, Canada, provided an overview of the interregional water transfer projects in North America. He pointed out that three

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factors must be analyzed before IWT could be considered. These are availability of water, both in terms of space and time, nature of demand functions and current efficiency of water use. In many parts of North America, especially in northern Canada and parts of Mexico, adequate data on surface and groundwater supplies do not exist. In many other parts of Canada, the United States and Mexico data are available only for a short period of time and hence reliable forecasts of water availability on a probabilistic basis are difficult to make. The situation is much worse when water demands are considered. Demand functions are difficult to construct, and in the context of water planning demands are often synonymous with requirements. Finally, efficiency of water use is very low in certain sectors, especially in agriculture. On a global basis, 80% of total water used is for agriculture: the corresponding figure for the United States is about 40%. Currently, 223 million ha of land are irrigated in the world, 93 million ha of which are in developing countries. Irrigated crops currently require 1.3 million million m^3 of water, but because of losses in distribution systems, 3 million million m^3 of water have to be withdrawn. The efficiency of global irrigation is even much less since there is a universal tendency to over-irrigate. Thus, in most cases, before major IWT schemes can be considered, it would make better sense to improve the water use efficiency of present systems.

The most ambitious IWT plan in North America was the North American Water and Power Alliance (NAWAPA), first proposed in 1964. The general approach of this scheme was to distribute the surplus water of the high precipitation areas of the north-western part of the North America to water scarce areas of Canada, the United States and Mexico. The immensity of the plan stirred the imagination of many engineers and economists, and within the 5 years of NAWAPA being proposed, a whole series of IWT schemes was put forward to redistribute the waters of North America.

However, as these new massive diversion schemes were being proposed, a new era dawned in North America. Toward the end of the 1960s, environmental considerations became increasingly more important, and this culminated in the development of a completely new process – that of environmental impact assessment – within the overall planning framework. Politically, environmentalists became a major force, and they opposed construction of massive water development projects on environmental and ecological grounds. The growth of environmental awareness, to a large extent, contributed to the decline of interest in IWT in Canada and the United States. At the present time, it is hard to foresee the construction of any new major IWT in Canada and the United States before the end of this century.

Prof. G. Voropaev, Director of the Water Problems Institute, Moscow, reviewed the Soviet experiences in IWT. The long-term economic planning in the USSR foresees considerable growth of water demands. By the end of the present century, water demands will exceed the present level by two to three times. The existing resources will not be enough to meet the growing water demands in the southern parts of the USSR. To meet these demands, it is necessary to undertake complex measures that will include the following:

(1) the improvement of the technology of the water use and the substitution of water-consuming industries by less consuming ones;

(2) fuller use and the increase of water supply from local water resources by run-off regulation;

(3) the territorial redistribution of water resources by redirecting run-off of the northern rivers to the southern side.

The most important matter in solving the problem of water needs of the national economy will be the territorial redistribution of water resources. The choice of the alternatives and the sequence in taking measures on the territorial redistribution are possible only by indepth study of the problem. Such a study will provide predictions of the long-term impacts on ecological, physio-geographical, and socio-economical processes by water redistribution measures. It is critical to realize the interrelations between these processes in order to understand their regional estimation, to study the dynamics of their development, and to see the global aspects of the problem. Studies of this kind have already been initiated in the USSR. Their methodological foundation is based on the systems approach to the problem.

The complexity of this problem solution is also conditioned by a number of specific factors such as a wide range of climatic changes over the vast territory of the USSR, extremely uneven distribution of surface and groundwater resources, the existence of large water bodies (seas) in the south, synchronous or asynchronous river run-off oscillations over big territories of the country, water demands in various regions, etc.

At the same time in the USSR there are a number of objective prerequisites for successful solution of this problem, two of which are: general state planning of the whole economic and social life of the society and people's property of land and water resources; and the high economic power of the country and large experience in conducting large-scale water projects on irrigation, hydroenergetics and water transport.

H. Garduño of the Comisión del Plan Nacional Hidráulico, Mexico City, described the current plans for large-scale transfers within the master water plan for Mexico. Water resources planning in Mexico is carried on by the National Water Plan Commission (NWPC), from the Agriculture and Water Resources Ministry. In a 5-year period, a special planning process was designed and the National Water Plan (NWP) 1975 was completed.

The methodology consists of an iterative process with both national and regional approaches. Each iteration starts with alternative socio-economic scenarios and its main results are national and regional objectives, goals, policies and programs for each basic (e.g. irrigation, flood control, etc.) and supportive activity (e.g. research, water inventories, etc.).

It is within this context that the need for water transfers appears. In Mexico, a country of 200 million ha, with a population of 60 million in 1975 and a mean annual run-off of 410 km^3, agricultural soil, water and population are unevenly distributed and they do not coincide geographically. The total irrigated area is 5 million ha, 900,000 of which lie in the northwestern regions, where there still is a surface of 1.5 million ha of good idle land. Eighty per cent of this surface is located in the northern part, while the rivers which are still uncontrolled lie in the south. To irrigate about 900,000 new ha by the turn of the century, a combination of aquifer mining during 10 years and water transfers to irrigate new lands and to rescue the lands irrigated with mined groundwater will be developed. The system will include the construction of eight dams, conduits of 1500 km and some 600 Wh per year of energy to raise the water 500 m.

The NWPC is presently working on linking some models it has developed during the last 3 years so that, once a national goal is set up by the government (e.g. food self-sufficiency) the evaluation procedures help to decide which projects are better to achieve that goal.

The other water transfer project for the near future is needed to supply water for Mexico with a present population of more than 10 million. The supply will have to increase from 42 m^3/sec to 110 m^3/sec in the year 2000, with pumping heads of more than 1000 m to reach the Mexican capital at 2240 m above sea level. The huge investments needed, and the population estimates (by the year 2000, 30 million) make it clear that higher efficiency is needed in water use and that effective decentralization measures should be taken to reach a more balanced regional development in the country.

Robin R. Reynolds, Deputy Director of the California Department of Water Resources, Sacramento, reviewed the Californian experience in the operation of IWT projects.

Using California and California's State Water Project as an example, the phases in the history of the development and use of water resources were reviewed. Several of the examples of systems analysis used in the planning and operation of the Project were reviewed, especially those relating to operations in the Sacramento–San Joaquin Delta where there is intense technical and political controversy. The operation scheme using off-peak power also was described. In addition, a possible ultimate pattern of water development for a nation or a large international region was discussed. It was suggested that some insight into the characteristics of one such possibility of an ultimate phase can be gained by considering the characteristics of a large power grid system. On this basis, the characteristics of a water grid were described. The most significant characteristics are large interbasin and interregional aqueducts and a central coordination and management.

Mr. K.S. Murthy of the Central Water Commission of the Government of India, New Delhi, India, reviewed the current status and future plans of IWT in India, a country that has a geographical area of over 800 million acres. The cropped area is about 400 million acres. Current irrigation covers nearly 100 million acres. The ultimate irrigation potential is estimated at over 200 million acres.

India lies in the tropical and sub-tropical region. Rainfall is confined to the monsoon months of June–September (nearly 90%). It is erratic – not dependable in most parts of the country. Agriculture is the main occupation of the people – over 70% are engaged in it. It contributes over 50% of the GNP but successful agriculture is not possible in most areas of the country without irrigation.

Since Independence (1947) the country has embarked on a massive irrigation development program. Over 70 million rupees have been spent so far. Current annual investment is over 10 billion rupees. One third of the country suffers from drought. Large sums of money are spent in relief works. To provide permanent relief, studies and investigations are now in progress for big irrigation projects for these areas. These involve interregional interbasin transfer of water. Obviously, drought areas have no waters of their own.

Under the Constitution of India, "water" is under state jurisdiction. The Central Government acts as a coordinator and provides technical and financial assistance, and in certain cases helps in construction as well. Inter-State agreements are necessary for interbasin and interregional water transfers, which take time. Proposals are under consideration to give the Centre greater authority in this matter.

Inter-linking of rivers has been under consideration for quite a few years – north to south, east to west, etc. This has generated a lot of passion and arguments. Current studies envisage interregional water transfer taking note of local needs and sentiments. But at the same time these are being so designed as to fit into an over-all national water grid at a future date. The main elements of such transfers are high-lift storage and long-distance movement.

Agronomic and economic aspects are equally important, especially for high-lift water uses. Political considerations should be given due consideration and public opinion is important for construction of these schemes. Once public opinion develops to support the schemes, the task becomes easier to accomplish.

Interregional water transfers are going to be crucial in the coming years. They are the answer to the "Two Faces of Water – Floods and Droughts". International cooperation, especially in the fields of shared knowledge and experience, can play a vital role in this field.

Professor Charles W. Howe of the Department of Economics, University of Colorado, Boulder, Colorado, reviewed the history of IWT in the USA, which is similar to other countries in its progression from smaller to larger projects. The high costs, uncertain environmental effects, and opposition from areas of origin led to reduced interest in IWT until the energy crisis of 1973. Some interest has arisen from potential energy industry demands such as shale oil production and coal gasification. Other current interest arises from "rescue operations" for regions dependent on fossil groundwater.

Six issues warrant discussion. (1) Agriculture is generally the largest user of proposed transfers but represents the lowest valued uses, reducing benefit–cost ratios. At the same time, low agricultural values imply the possibility of satisfying new demands with present sources of agriculture water rather than from IWT. (2) Limited world markets study the price effects of large expansions of irrigated production. (3) Possibilities of increasing use efficiency of existing supplies as a substitute for IWT or to defer the need for IWT construction must be studied. (4) The extent of energy recovery in IWTs which require pumping is important to economic feasibility. (5) Externalities in the exporting region such as foregone uses and increased salinity concentrations must be taken into account. (6) There is a tendency toward premature construction of IWTs. Several case studies (Arizona and Mexico) have shown that deferring IWT projects would not be costly to the importing region and would greatly reduce the present value of construction costs. These last two points relate closely to the major points of Professor Fisher.

Professor Anthony Fisher of the University of California, Berkeley, reviewed some theoretical and measurement problems in economic assessment of IWT projects. With recent increases in the size of proposed IWTs, careful consideration of their economics becomes particularly important. A number of proposals and propositions concerning the theory and measurement of the costs and benefits of an IWT were suggested. They can be stated briefly as follows:

(1) Commonly used methods of measuring the conventional economic impact, including input–output analysis, are not entirely adequate, in that they do not allow sufficiently for induced changes in the structure of the economies of the impacted regions, do not trace these changes through time, and do not relate them to maximizing behavior by economic agents. An econometric modeling approach may be used to accomplish these objectives.

(2) Calculations of the benefits and costs of an IWT ordinarily ignore its effects on the environment, yet these are likely to be substantial. The standard decision criterion can be modified to include the costs of environmental effects. Where the costs cannot be estimated, a technique was suggested for comparing an IWT to an alternative means of producing water, that still accounts for both conventional economic and environmental effects of each. Briefly, if both the economic and the environmental costs (even where these cannot be measured in money terms) are lower for one of the alternatives, it is said to *dominate*.

(3) It is possible that the environmental effects of an IWT may be both irreversible and uncertain. Where, however, the uncertainty diminishes over time, as better information about the effects and their costs becomes available, there is a kind of additional cost to proceeding "too soon" with the project. This represents a further modification of the standard benefit–cost criterion.

Discussion of the paper was brief, limited mainly to technical questions about part (3). The one important point of substance had to do with the practicality of the finding in part (3). That is, would it be practical to estimate the additional cost to proceeding "too soon"? Fisher's answer was, probably not; but the finding is still relevant, since it puts the burden of proof on marginal projects. A project that exhibits the characteristics of part (3) should not be undertaken (on economic efficiency grounds) if its expected present value is just barely positive.

Professor Leonard Ortolano of Stanford University, USA, discussed environmental assessments in water resources planning, with special reference to the United States. As a result of laws and regulations promulgated early in the 1970s, environmental assessments are required for studies carried out by the federal agencies responsible to water resources planning in the United States; a wide variety of impacts on both the natural and "social" environment are included in these assessments. The paper summarizes the nature of these impacts as well as the various methods being used for impact identification, prediction and evaluation. Documentation from case studies and mail questionnaire surveys is presented to support the notion that issues related to assessment methods *per se* are not the critical ones in ensuring that environmental factors receive adequate consideration in planning. Rather, the key issues relate to the ways in which the results from applying environmental assessment methods are used in water resources planning and decision making. An "iterative, open-planning process" is presented as providing a mechanism for assuring that environmental assessments are used in the formulation and ranking of alternative actions; such a process is now being used by the US Army Corps of Engineers, one of the principal water resources agencies in the United States. The discussion of the paper indicated that the use of an iterative, open-planning process in no way detracts from the efforts of economists to evaluate environmental effects in monetary terms and thereby increase the extent to which alternatives are evaluated on a rigorous, systematic basis.

Professor G. Golubev reviewed environmental issues of big IWT projects. With the increase of the size of IWT projects the complexity of environmental assessment is growing as well. It stems from the fact that the number of components and links in a geoecosystem are increasingly nonlinearly as a function of projects' size. Correspondingly, the greater the size, the greater the uncertainty in evaluation of environmental impacts. Above a certain size, uncertainty would be so high that it would not be feasible to carry out a project. Possibly it is true of very big IWT projects regarding present knowledge of environmental assessment. One of the approaches to decrease uncertainty may be the dividing of a complex project into parts.

A case study of environmental issues of big IWT projects has been done by the author using one of the proposals for reallocation of water in the USSR. (The mouth of the Ob River, Ural Mountains, Pechora River, Severnaya Dvina River, Volga River, Central Asia and Don River.) All this long way was divided by reaches. Environmental problems concerning IWT were expressed in the form of trees of consequences, or networks. The main problems have been discussed for each reach (Arctic Sea problem, change of regime in rivers, change of adjacent territories, impoundments and related effects, improvement of hydrologic regime of the Azov Sea, development of irrigation and related problems, etc.). The approach is regarded as being useful both for the first steps in the project's assessment and for better management of scientific studies for environmental forecast of IWT projects.

CONCLUSIONS AND RECOMMENDATIONS

The Task Force agreed on several conclusions. These are the following:

(1) Interregional water transfers are and will be one of the ways to increase water supply. However, they should not be regarded as the only means available to an end: rather it should be considered as one of several alternatives available to optimize water use. If, having analyzed

all these alternatives, IWT appears as a promising solution, it should be considered within the planning framework. The timing of an IWT project should be elaborated having in mind other alternatives of water supply.

(2) To assess a large IWT project it is not sufficient to apply conventional methods of an economic evaluation and much more broad, complex approach is required.

(3) The environmental and ecological costs of IWT could be many, and these should be carefully analyzed and evaluated. Adequate counter-measures must be taken to reduce such costs to a minimum. The least solved question within the IWT problem is a methodology to assess environmental costs of IWT's and to forecast their impacts on nature.

(4) Similarly, social costs of such schemes should also be evaluated.

(5) The feasibility of IWT varies from country to country and region to region. In other words, it is site-specific. Whereas it is unlikely that new IWT schemes could be developed in the United States and Canada because of economic, environmental and political reasons, at least within the next two decades, it seems that they are viable under certain situations in countries like the Soviet Union, India or Mexico.

The Task Force made the following recommendations:

(1) The papers prepared for the Task Force meeting should be published as soon as possible, since these provide an authoritative account of the present status of IWT in the world on an interdisciplinary basis. No such comparable work is currently available. It was agreed that Professor Genady Golubev and Dr. Asit K. Biswas will edit the proceedings, which would be published in both the English and Russian languages.

(2) IWT should be considered within the over-all context of other non-conventional means of water development like weather modification, iceberg towing, desalination, use of very large crude carriers (VLCC) to transport fresh waters, etc. An over-all state-of-the-art report, critically reviewing the present developments in such areas, is both necessary and desirable.

(3) Within the context of IIASA's present program on water demand modeling, IWT should be considered as one of several other alternatives, wherever desirable and feasible. Attempts should be made to develop general guide-lines for IWT and these then should be incorporated within a methodological context.

(4) IIASA can play a catalytic role in IWT, and the Institute can play a major role in terms of information exchange, on a global basis, in this field.

(5) It was suggested that another meeting be held in about 2 years' time. As far as there is no developed methodology to assess and forecast environmental implications of current and proposed IWT schemes, future meeting should consider this issue. Critical state-of-the-art reviews on the subject would be desirable.

If necessary, small *ad hoc* teams should be set up – comprising IIASA and external specialists – on specific sub-topics.

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Interregional Water Transfers as an Interdisciplinary Problem

GENADY GOLUBEV* and OLEG VASILIEV*

Interregional water transfer is a fairly popular and important topic. For example in the Soviet Union, about 100 institutes are working on the problem of reallocating water resources of the country. Recently, the same issue was also discussed in the United States. There are large water transfers projects in India and Mexico, and plans, projects and even some construction are already underway in Australia, Pakistan, Hungary, Sudan, Egypt, Canada and other countries.

The topic of water transfers is not a new one. Water diversions are known from former times in the States of Ur, Rome and by the Incas. In the last century, especially in the last few decades, many water transfers have been carried out. In Tables 1 and 2, some features of the big water transfer schemes in the US and USSR are given. Some of the values are perhaps out-of-date, as some projects continue to develop (i.e. Karacum Canal). The total amount of reallocated water in the USSR, is now about 50 km^3/yr. The same order of magnitude is characteristic of the US.

Throughout the history of water transfers, their sizes (such as water discharge, length of canal, etc.) have grown exponentially. At the beginning of this century, water discharges from the largest transfer schemes were about 0.5 or 1 km^3/yr. They are currently of the next order of magnitude (see Tables 1 and 2, compiled by the authors) and new projects of another order of magnitude are proposed. The situation is represented graphically in Fig. 1.

Some groups of problems arise because of the growing size of water transfer projects, for example:

(1) water demand/supply relations as a starting point for decision making concerning water transfers;

(2) uncertainty of large interregional water transfer (IWT) projects and control of them;

(3) efficiency (not only expressed in terms of money);

(4) links with other major problems of global or universal interest (energy, resources, food, capital investments, etc.);

(5) consequences and impacts (both short-term and long-term ones); and

(6) other water supply alternatives to IWT.

Let us look into some of these questions.

Water demand/supply relations in a number of regions or countries are rather unfavorable. Table 3 gives an idea of water resources for a year of low flow (75% probability) in comparison with water demands for eight major rivers of the southern European part of the USSR.[1] It is obvious that every fourth year the situation is rather strained and if we take into account constant growth of water demand, especially the projected considerable increase of irrigated lands, the supply/demand difference would be more unfavorable.

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Table 1. Some water transfers in the USA

Name of the project	State	Direction of the transfer	Amount of transferred water in km^3/yr	Total length in km		Water reservoirs		Total capacity of hydropower stations in 10^3kWt	Additional data
				Canals	Tunnels	Number	Total volume in km^3		
Colorado Big Thompson (1938 - 1959)	Colorado	Colorado River, Rocky Mts, South Platte River basin	0.4	154	55	10	1.2	180	4 pumping stations with total capacity of 30 × 10^3kWt
Central Arizona (1968 - 1985)	Arizona	Colorado River, Central Arizona	2.7	600	10	4	?		9 pumping stations with total capacity of 547 × 10^3kWt
Fryingpan - Arkansas (1962 -)	Colorado	Colorado River basin Arkansas River basin	0.1	?	42	4	0.9	200	
Central Utah (1964 -)	Utah	Between river basins in the state of Utah	0.2	190	10	6	1.3	133	
California State water project	California	Reallocation of water in state (mainly from North to South)	4.2 (1972) 5.5 (plan)	1100	?	23	8.2	630	18 pumping stations
Central Valley Project	California	Reallocation of water in the state (mainly from North to South)	9.0	?	-	19	13.8 (1972) 19.6 (plan)	1250 (1972) 1820 (plan)	
All systems of California	California	Reallocation of water in the state (mainly from North to South)	31.1	?	?	68	about 30	?	

Table 2. Principal water transfers in the USSR

Donor river	Name of canal	Water discharge km^3/yr	Length km	Principal use of water
		Interbasin transfers		
Volga	Volga - Moscow	2.3	100	Municipal and industrial
Amudaria	Karacum	7.8	760	Agricultural
Dnieper	North Crimea	8.2	400	Agricultural
Irtysh	Irtysh - Karaganda	2.2	460	Industrial
Samur	Samur - Apsheron	1.7		Agricultural and industrial
Dnieper	Dnieper - Donbass	1.2		Industrial
Volga	Volga - Ural	3.1	400	Agricultural
		Intrabasin transfers		
Naryn	Great Fergana	6.0	350	Agricultural
Syrdaria	Golodnaya Step	4.4		Agricultural
Kura	Verhnii Karabakh	3.6	170	Agricultural
Kuban	Nevinnomysskii	1.9	50	Agricultural
Don	Don Magistralnii	1.0	110	Agricultural
Terek	Tersko - Kumskii	2.7	150	Agricultural
Kura	Verhnii Shirvanskii	2.4	120	Agricultural

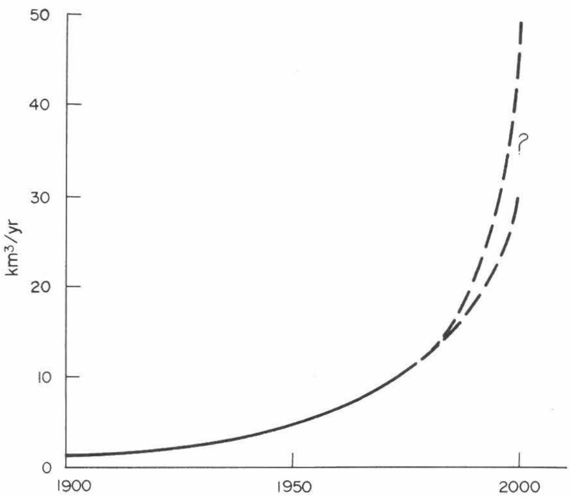

Fig. 1. Size of water transfer projects as a function of time.

In the US, the water resources of the western and southwestern areas are considerably below those of the rest of the country. Table 4 gives an idea of resources and demand differences for this part of the US (data taken from Howe and Easter[2]). Tables 3 and 4 can not be compared directly; to the values in Table 4 on-stream use and sanitary run-off should be added, thus increasing the water demand 30 or 40% (these values have been obtained from Soviet data). According to Table 4, with corrections, the situation is quite strained. Note that water surplus in the Pacific Northwest is fictitious, as hydropower stations there require a greater proportion of on-stream use of water.

Table 3. Comparison of water supply and water demand for major rivers of the southern European part of the USSR for a low flow year (75 % level of probability), km^3/yr *(after*

River Basin	Supply (river run-off plus underground water)	Demand							Surplus (+) or Deficit (-)
		Consumptive use					Instream uses (sanitation, navigation, electrical power generation, etc.)	Total water demand	
		Irrigation and other agricultural needs	Municipal and industrial	Fish-breeding	Evaporation from water reservoirs	Total consumptive use			
Volga	221.5	15.6	4.4	2.9	19.2	42.1	168.0	210.1	+11.4
Dnieper	45.4	14.7	6.7	0.6	3.2	25.2	16.0	41.2	+4.2
Kura	25.5	13.9	0.8	0.7	2.5	17.9	5.5	23.4	+2.1
Don	21.7	6.0	2.0	0.7	2.0	10.7	21.0	31.7	-10.0
Kuban	12.0	7.2	0.4	2.3	0.2	10.1	2.0	12.1	-0.1
Terek and Sulak	15.4	6.4	0.7	1.9	0.0	9.0	4.5	13.5	+1.9
Dniester	8.3	2.6	0.8	0.4	0.2	4.0	2.5	6.5	+1.8
Ural	5.3	1.1	1.1	0.8	0.9	3.9	5.5	9.4	-4.1

Table 4. Comparison of water supply and water demand for the western part of the USA, 1965 (Howe and Easter[2])

Water use region	run-off		Consumptive use				Surplus (+) or deficit (-) as to:	
	Average	90% of probability	Irrigation and other agricultural needs	Municipal and industrial	Conveyance losses	Total	Average Run-off	Low run-off ($P=90\%$)
Western Gulf	60	23.4	18.7	1.7	4.6	25.0	+35	-1.6
Colorado	23	12.4	11.1	0.4	4.2	15.7	+7	-3.3
Great Basin	14	5.5	5.0	0.1	1.8	6.9	+7	-1.4
Pacific North West	288	203.9	13.7	0.4	9.7	23.8	+264	+180.1
South Pacific	85	38.6	18.6	2.0	5.8	26.4	+59	+12.2

Deficit or strain situation with water in arid parts of both countries is superimposed by the trend of decrease of natural river run-off due to man's activity. From the point of view of the hydrological cycle, consumptive use of water occurs through evaporation, hence consumptive use increase means an increase in evaporation and decrease of run-off. Table 5 shows the corresponding data for the main rivers of the USSR.[3] The natural run-off of large Siberian and northern rivers has not changed and is not expected to change noticeably. As for the rivers in the south, however, the run-off decreased by 8% in 1970 and is expected to decrease another 30% by the year 2000. In some of the rivers, up to 80 or 90% of the water will be utilized.

Table 5. Decrease of river run-off in the USSR due to man's activity

River	Mean natural water resources		Decrease of annual run-off					
			1970		1981 - 1986		1991 - 2000	
	in the basin km^3/yr	at the mouth km^3/yr	km^3/yr	%	km^3/yr	%	km^3/yr	%
Volga	254	239	16	6	26	10	36	14
Ural	11.4	11.2	1.6	14	2.6	23	3.0	26
Terek	11.5	8.3	2.0	17	5.0	44	9.0	78
Kura	24.2	18.0	0.5	2	4.5	19	14.0	58
Don	27.9	27.9	5.1	18	8.5	30	12.6	45
Kuban	13.4	11.1	2.2	16	5.2	39	8.0	60
Dniester	9.3	9.3	1.3	14	3.0	32	3.5	38
Dnieper	53.5	53.5	10.7	20	13.8	26	18.0	34
Amudaria	77.1	41.0	5.0	12	24.0	59	39.0	95
Syrdaria	33.5	13.0	4.0	31	6.0	46	12.0	92
Ob	384	384	8.2	2	13.0	4	16.5	5
Zapadnaya Dvina	18.4	18.4	0.02	1	0.04	1	0.04	1
Severnaya Dvina	107	107	0.05	1	0.09	1	0.11	1
Pechora	128	128	0.002	0	0.005	0	0.007	0
Enisey	555	555	2.10	1	4.8	1	6.1	1
Lena	525	525	0.30	1	1.00	1	1.70	1
Amur	312	312	0.36	1	1.20	1	2.20	1
Total	2544	2462	54.5	2	118.9	5	183.1	7
For rivers of the Southern slope	516	432	42.4	8	97.6	19	155.1	30

Another water problem within the framework of IWT is the deterioration of lakes, internal seas, and estuaries.

As shown in Fig. 2, the main results of man's activity at a river level are:

(1) decrease of run-off due to increase of consumptive use of water;

(2) an increase in salt content and pollution due to agricultural and industrial activity;

(3) direct effect of reservoirs and dams.

At a lake/sea level it leads to increase of salt content and pollution, a decrease of lake level, and deterioration of conditions for aquatic ecosystems. These effects are typical and they are seen in the Great Lakes, San Francisco Bay, Gulf of California, Caspian Sea, Aral Sea, etc.

The decrease of inflow to the internal seas of the USSR is shown in Table 6.[3]

Due to the decrease of the natural inflow to the Azov Sea, the average salinity rose from 10–11 parts pro mille to over 12.5 parts pro mille;[4] this led to a considerable decrease of fish production, which indicates the need for fresh water to maintain the natural conditions of the ecosystem. The current fish catch of the Azov (6 tons/km^2) and Caspian Seas (5 tons/km^2) yields about 200 million roubles per year.[4]

Table 6. Decrease of surface water inflow to the internal seas of the USSR due to man's activity

Sea	Natural inflow	Decrease of inflow					
		1970		1981–1985		1991–2000	
	km^3/yr	km^3/yr	%	km^3/yr	%	km^3/yr	%
Caspian	295	22	8	44	15	74	25
Aral	54.0	9.0	17	30	56	51	94
Azov	41.1	7.7	19	14	34	21	51

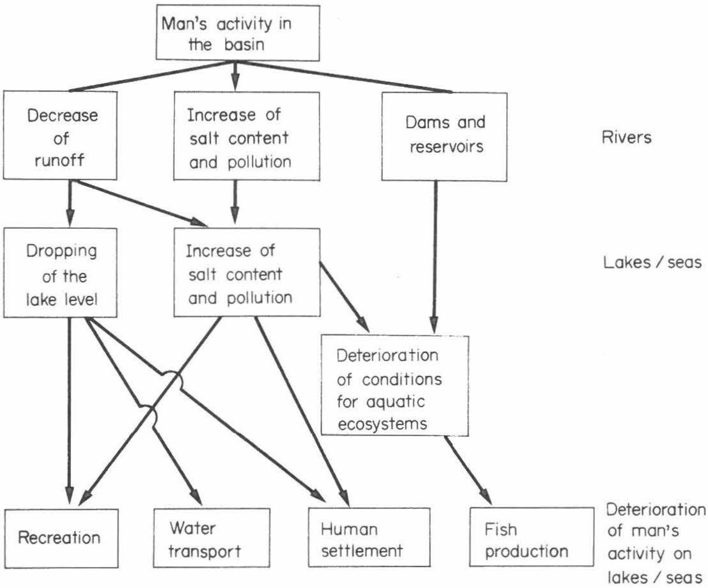

Fig. 2. Conceptual scheme of man's influence on lakes and internal seas.

The water level of the Caspian Sea dropped (due to natural causes) in the 1930s; this lead to a loss of about 15 or 18 thousand square kilometers of the fish productive area. The water level should increase now, unless a decrease of inflow due to man's activity develops. The water level is currently about −28.5 m a.s.l., and a drop of 0.8 or 1 should be regarded as catastrophic, as the area of highly productive shallow waters would diminish considerably and salinity in the northern part would change.[4] To improve the hydrologic regime, additional fresh water is required.

Therefore, between the arid regions of North America and Eurasia, there are a number of common features from the viewpoint of the demand/supply of water:

(1) a deficit of water exists in certain years and will continue to increase; moreover, the greatest consumptive use for water is irrigation;

(2) natural river run-off is declining due to man's activity; and

(3) a considerable amount of fresh water is required to maintain or improve ecological conditions of lakes and seas.

For the near future the southern slope of the USSR would require from 97 km^3/yr for a normal flow, to 120 km^3/yr for a low flow year (95% probability).[5] There are various strategies for the solution of this problem, and between them are situated IWT's. Interregional water transfers are appealing because of the great amount of water produced, which drastically changes the water situation. Large IWT's should be studied within a framework of strategic water management planning, at a continental or subcontinental level with the planning horizon not shorter than the years 2000 or 2030.

What is the problem structure of IWT? There are three main blocks: technology, socio-economy and environment. If there were three persons or three institutions responsible for a project and representing these three blocks, their objectives would all be different. The objective of the technology block would be to carry out the project and maintain its operation. The other two blocks would be constraints. The objective of the socio-economy block would be to maximize a society's net benefit from a IWT; the benefit should not be expressed only in terms of money. The other two blocks would be constraints. The environment block's objective would be to ensure optimal conditions of the environment. As we do not usually know what these optimal conditions are, the objective would be to minimize disturbance in nature. The other two blocks would be constraints.

Thus, even at the highest level of the problem, a strong interrelation exists and the problem is of a systems nature.

The history of IWT projects reflects this structure. First, only technological engineering schemes were discussed and studied. Then, economic issues were incorporated. The next step should now be an integration of environmental issues and, therefore, the examination of the problem is in its present form.

Each block can be divided into sub-blocks, which are in turn also divided. Tentative division of the problem showing only the first and second levels is given in Fig. 3. Interrelations between blocks and sub-blocks are not shown and will be discussed later. Let us briefly discuss the sub-blocks in order to present some questions.

Technique – This means how to carry out and operate a new system.

Technology progress – Interregional water transfer projects would be designed to serve for approximately 100 yr. Hydrologic constructions of 1880 are now archaic. The rate of technology progress is increasing. The questions which then arise are: (a) How to take it into account? (b) Is it possible? and (c) Is it necessary?

Water use – Structure and amount of water use would change because of (a) IWT proper, and both its direct and indirect influence, (b) shifts in economy, (c) technology progress.

Resource consumption – These are manpower, capital investments, energy, materials, etc. to carry out the projects. It may be a very complicated strong subject for consideration, especially when it is necessary to choose between various large programs, only one of which would be the IWT.

Economic efficiency – This is obviously an important part of the overall problem and an important criterion in considering a project. Howe and Easter[2] successfully based their analysis of IWT efficiency on the following inequalities:

$$(DB_M + SB_M) + (DB_T + SB_T) > (DC_x + SC_x) + SC_c + TC,$$

$$TC + [(DC_x + SC_x) - (DB_T + SB_T)] < TC_A.$$

Let the benefits from the actual use of water be called direct benefits (DB), and the costs of giving up the direct use of water (i.e. benefits forgone) be called direct costs (DC). Benefits and

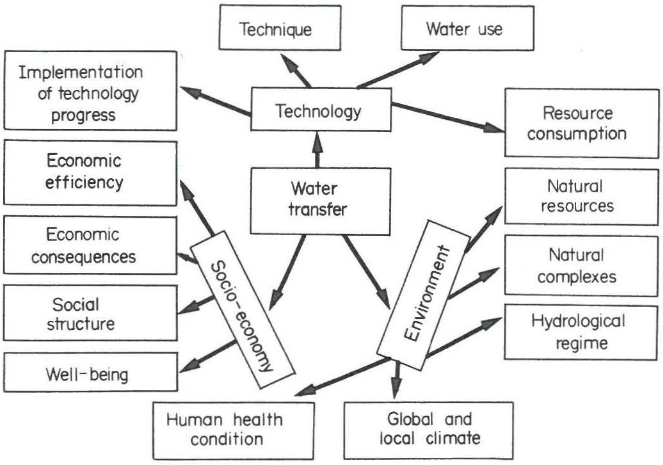

Fig. 3. Structure problem of water transfers.

> costs in market-related activities as seen from a national viewpoint will be referred to as secondary (SB, SC). TC represents the costs of the physical transfer system, and T_A the cost of the best alternative. Subscript *x*'s refer to parties in regions exporting water, *M*'s to those in regions importing water, *T*'s to affect parties in regions through which the transferred water will pass, and *c*'s to parties in regions whose outputs are competitive with those of the water-importing region (pp. 20–21).

And further,

> The first condition states that the increment to net incomes in the importing and transit regions must exceed the loss of incomes in the exporting region and in other regions where activities are displaced by the expansion of water-related activities in the importing region plus the costs of the physical transfer system, all properly capitalized on the basis of consistent time period. The second condition states that the cost of the physical water transfer scheme (including the net opportunity cost of the water) must be less than the cost of the best alternative for supplying the same amount of water to the importing regions. This comparison presupposes the prior optimum sizing of the projects (p. 21).

Is it, however, enough to measure the economic efficiency of a huge project just using this "conventional" technique? How does one evaluate long-term consequences? How does one take into account non-measurable values, including environmental values, and account for uncertainty?

Economic consequences – These are closely connected with matters of efficiency. The following questions arise: What are direct, secondary, and tertiary consequences, and what are they at a regional, national, and international level?

Social structure –– This would be greatly influenced by an IWT project both during its construction and operation. Many feed-back loops from the social structure and its change can be created, and influence various blocks of the problem.

Well-being – An overall objective of a water transfer project is to improve the people's well-being. How are we to understand the term of well-being? The meaning might be quite different.

Political and judicial issues of IWT are also quite important in a number of countries. However, this topic is mostly institutional and does not stem from the proper sense of the problem. For this reason, it has been omitted from the overall problem structure of IWT's. Practically speaking, the first steps of IWT projects are sometimes taken in these areas.

Natural resources – A large IWT project influences both renewable and non-renewable natural resources. Part of the resources can be used for construction (timber, mineral resources, etc.). Thereafter follow short-term impacts, such as the inundation of ore or oil fields, loss of areas with fertile soils, change of water quality due to new water reservoirs, etc. These are followed by long-term consequences, i.e. biological changes which include forest productivity, etc. The question is: how then, to assess an influence of projects on natural resources?

Hydrologic regime, climate and natural complexes – These are blocks describing the corresponding processes in the hydrosphere and atmosphere, and in the interface between the hydrosphere, atmosphere, lithosphere and biosphere. These blocks are another face of "Natural Resources", the latter being in many cases an economic aspect of the former. There are many questions to consider. An indispensable part of a IWT scheme is a water reservoir. Its creation means losses of the best lands, deterioration of water quality, etc. Reallocation of water means change of water circulation in the atmosphere, that is, a change of climate – but to what extent? A natural complex (geoecosystem) consists of hundreds and thousands of interrelated elements. A change in one of its components or groups would lead to many other changes in a geoecosystem. Assessing the project, it is very important in evaluating environmental natural features. This brings up the question: how to measure them and how to compare non-commensurable phenomena. We must also determine a way to predict environmental changes in both quick impacts and long-term cumulative responses, and those which may be disregarded.

Human health –- It is well known that human health is a product of both natural and social factors. Changes in both groups of factors would lead to impacts in human health.

Sub-blocks discussed here can be disaggregated. There are many relations between partial issues concerning the IWT problem. The whole problem can be represented as a trihedral pyramid, each side of which is one of the main blocks (technology, socio-economy, environment). Each block ramifies according to the level of aggregation of the problem, and these ramifications have many links both within the same main block, as well as with other blocks (sides). Hence, the problem is really interdisciplinary.

One of the authors has tried to single out the most important relations between the sub-blocks, and to evaluate the intensity of them. The results are shown in the matrix (Table 7).

Two principal conclusions can be drawn from this matrix: (1) there is a strong interrelationship within each of the main three blocks; (2) the relationship between the blocks is no less strong. Thus, to use an expert evaluation approach as a tool to develop and assess an IWT project, it is necessary to organize experts' work not only within the same field, but to implement from the very beginning an interlinkage between various fields.

The problem of assessment of large IWT projects is very complicated – we do not have examples of developed methodology. Another question arises and may be discussed during our meeting, but can hardly be answered: is there a developed methodology for other large projects? A certain amount of experience was gained, for example, during elaboration of the Alaskan Pipeline Project. By the term methodology, we understand here an elaborated system of techniques applied to each IWT project rather than a loose set of approaches. Other questions to put forward for discussion are: (a) What method of assessment can be used? (expert evaluation? simulation games? optimization models? simulation models? others?);

Table 7. Interactions between various factors in assessment of water transfer projects

Action \ Impact			Technology				Socio-economy				Environment				
			1	2	3	4	5	6	7	8	9	10	11	12	13
Technology	1	Transfer technique			+ +	+ + +	+ + +				+	+	+ + +	+ + +	+ +
	2	Technology progress	+		+ +		+ +	+							
	3	Water use	+	+			+ + +	+ +	+		+		+ +	+ + +	+
	4	Resource consumption	+ +	+			+ + +	+ +		+					+ +
Socio-economy	5	Economic efficiency	+ + +	+ +	+ + +	+ + +		+ +	+ +	+ + +				+ +	+ +
	6	Economic consequences		+	+ +	+	+ +		+ +	+ +	+				+
	7	Social structure			+ +	+									
	8	Well-being	+ +	+	+ +	+	+		+ +		+ +			+	+
Economy	9	Human health	+		+ +					+ +					
	10	Climate									+		+ + +	+ +	+
	11	Hydrologic regime	+ +		+		+ +				+			+ +	+
	12	Geoecosystems					+ +						+ +		+ +
	13	Natural resources	+ +			+ +	+ +	+					+	+ + +	

(b) Do steps in a project's development correspond to a certain method? (c) What is an approach to integrate various disciplines in an assessment? (d) How is it organized?

The list of questions can be expanded. After all, there are two goals of this meeting: (1) to discuss our knowledge of the IWT problem; and (2) to clarify questions for further studies of this very complicated problem.

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PART I: Survey of Proposed Projects on Interregional Water Transfers

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North American Water Transfers: An Overview

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INTRODUCTION

Interregional water transfer is not new: it has been practised from time immemorial. For example, the ancient Egyptians diverted river water over long distances several thousand years ago.[1] But its importance has increased in recent years, especially as population pressures in many arid regions of the world have made it imperative to grow more food. Agricultural production can be increased in two ways – by increasing crop yields and by bringing new land under cultivation. Both of these alternatives can only be viable, provided adequate water supply is available.

The importance of water control for crop production can be illustrated by the following facts. On a global basis, agriculture uses 80% of all water consumption: the corresponding figure for the United States is about 40%. Total irrigated area in the world is 233 million ha, out of which 93 million ha are in developing countries.[2] Irrigated land constitutes less than 10% of global cropped area, and yet it accounts for 30–40% of total agricultural production. Thus, as populations in developing countries continue to increase, and since these countries are without exception in the tropics and subtropics, water control is increasingly becoming a major requirement to boost food production. As water resources of populated regions become fully developed, interregional transfer becomes an attractive possibility – provided the environmental and social problems associated with such major projects can be resolved.

Interregional transfer is, however, one of several alternatives of non-conventional water development. There are other possibilities, among which are weather modification, desalination, iceberg towing, and the use of VLCC (very large crude carriers) to transport fresh water to water-deficient regions. None of these are universal solutions, and each must be considered in relation to problems of the region being analysed. In other words, these solutions are site-specific. Furthermore, for most of these unconventional techniques, there exist technological, legal and environmental problems many of which have yet to be solved. In many cases, economic constraints have yet to be overcome.

INTERREGIONAL WATER TRANSFER

First, what is meant by water transfer? On simplest terms, it may be defined as inter-basin diversion, that is, the artificial withdrawal of water by ditch, canal or pipeline from its source in one contributing or exporting drainage basin for use in another receiving or importing basin. Before such interregional diversion can be seriously considered, it is important that

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three factors be analysed. These are assessments of available water resources, the nature of the demand function and the efficiency of water use.

Assessment of available water resources is an important factor for any water resources development plans. Availability of water varies with space and time. Thus, before reliable forecasts of water availability can be made, it is necessary to have adequate data over a reasonable period of time. Based on such data, long-term development and management plans can be established. However, in many parts of the world, such data are not available, or if available, they are for a rather limited time horizon. This is unfortunately the case for most developing countries. Even for North America, adequate data are not always available – especially for northern Canada and many parts of Mexico. Without a comprehensive assessment of water availability, it is difficult to contemplate interregional water transfer – or any other water planning process for that matter.

Second important consideration is the assessment of water demands for various purposes. The term "demand", in the context of water management, really means requirements, and is very rarely used in its traditional economic sense. Indeed, very rarely is the concept of demand elasticity explicitly considered within the water planning process. Thus, it should be no surprise that very little is known about constructing appropriate demand functions under varying socio-economic considerations. In other words, emphasis so far has been on supply management – that is, increase in supply is considered to be virtually the only management alternative – rather than on demand management. As the demands for water for various purposes continue to increase and available sources become more and more exploited and polluted, emphasis will have to gradually shift from supply to demand management.

Efficiency of existing water use is the third important consideration. Agricultural sector is an inefficient user of water, and where most improvements could be made. Existing efficiencies of irrigation systems are so low that they do not by any means reflect the actual water requirements of crops. On a global basis, 1.3 million million m^3 of water is used for irrigating crops, but for this 3 million million m^3 of water have to be withdrawn.[3] In other words, 57% of water withdrawn is lost in the distribution system. This, however, does not mean that 43% of water reaching irrigated fields is efficiently used. Over-irrigation is not exactly an uncommon practice in both developed and developing countries. It not only means that water is wastefully used but also contributes to development of adverse environmental problems, like increase in groundwater table and salinity levels.[4] Thus, before major alternatives like interbasin transfer can be analysed, the possibility of optimization of water use by increasing efficiency should be considered. As a rule, it is cheaper to obtain more water per unit cost by improving the efficiency of water use from existing projects than from building new ones. Also, the time required to plan and to build new schemes is significantly longer: the efficiency of existing projects can be improved more quickly.

INTERREGIONAL TRANSFERS IN NORTH AMERICA

To bridge the gap between past images of development and proposals for new construction, it is important to recognize the groundwork of water diversions already established between river basins. Figure 1 illustrates this pattern aggregated for major basins in the United States. The figure shows that the walls of the Colorado basin have obviously been breached in a number of places for exporting water to surrounding regions, but the Columbia and the North Pacific, on the other hand, have remained largely self-contained and water-abundant.

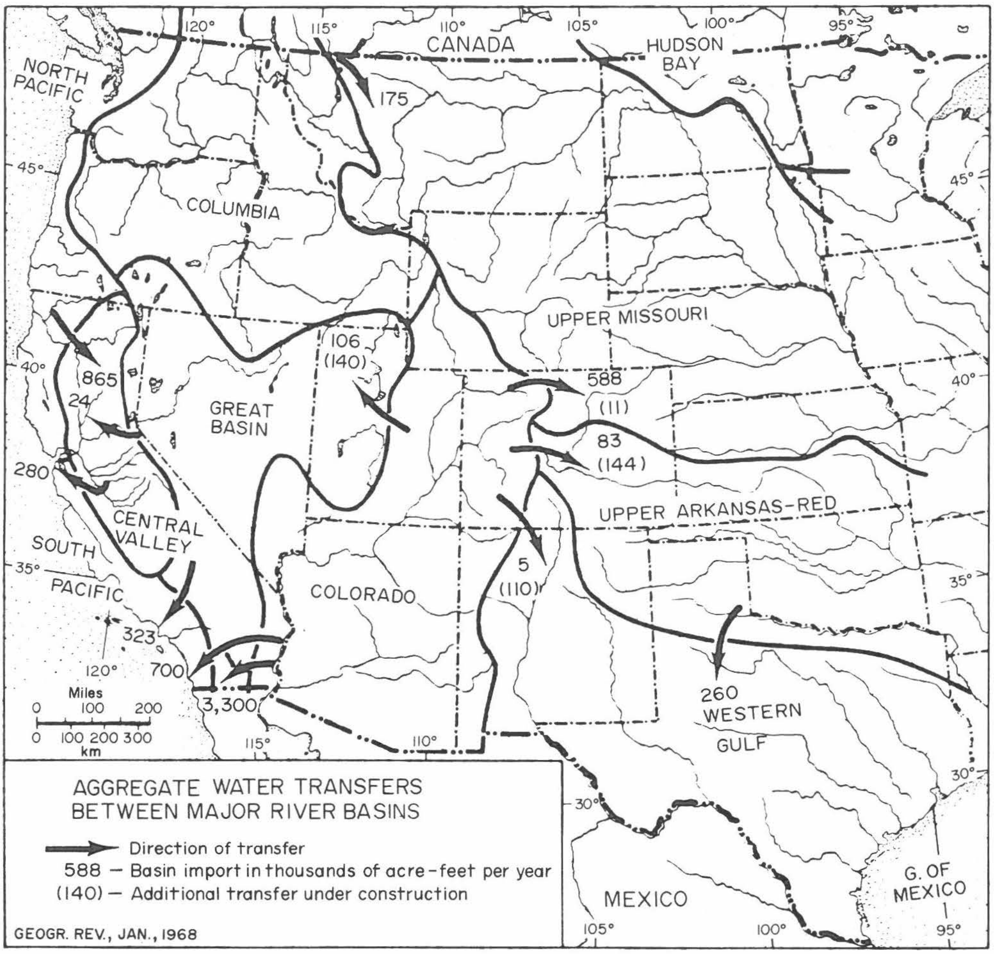

Fig. 1.

Late-developing urban centers, unable to dislodge agricultural water rights, account for most of the recent long-distance water importations. Probably one person in three in the Western United States is now served by a system which imports water from 100 or more miles away. It is quite likely that Los Angeles, Salt Lake City, Laramie, Denver and Colorado Springs would have found it impossible to each beyond their own river systems to the Colorado, if the diversions had meant crossing their state lines as well.

The same can be said for the rest of the continent. New York City takes from the Delaware; Boston from the Connecticut; Chicago from Lake Michigan into the Illinois; the province of Ontario from the Albany and Kenogami drainage of Hudson Bay into Lake Superior; British Columbia from the Nechako to the Coast at Kitimat. Their effects, of course, have sometimes been felt downstream across the boundaries.

A few select interbasin diversions will be briefly discussed herein. These have been selected primarily on the basis of their magnitude or historical importance. The experience in California or Mexico will not be discussed, since they are discussed elsewhere in this collection.

1. *Nechako–Kemano Diversion*

In 1925, the Kenny Dam on the Nechako River was completed by the Aluminum Company of Canada. The dam stores the run-off from a 5400 square mile area of the Fraser River drainage for diversion westward to the company's power plant near tidewater at Kemano. The average flow, approximately 6500 cfs at the point of diversion, is controlled by the 6.6 million acre-ft of usable storage in the reservoir. Diversion is made by means of a 10.1 mile long, 25 ft diameter tunnel leading to an underground powerhouse with a head of 2500 ft and a present installation of 707,000 kW. The average annual diversion from the reservoir is about 3300 cfs. Excess water is spilled or released to the Nechako–Fraser system.

2. *Lake St Joseph Diversion*

Flows from the Winnipeg River system of Western Ontario and Eastern Manitoba are augmented by a diversion of the run-off from a 4760 square mile area of the headwaters of the Albany River which flows north east to Hudson Bay. Water is diverted from Lake St Joseph in the Albany system southward to Lac Seul and onward down the English River and Winnipeg River to Lake Winnipeg. The diversion increases the offpeak flows on the Winnipeg River and raises power production at nine hydro plants. The diversion has averaged approximately, 2800 cfs since 1957.

3. *Long Lake and Ogoki Diversions*

In addition to the Lake St Joseph diversion, there are two other diversions of water from the headwaters of the Albany River. The Long Lake and Ogoki diversions came into being in 1939 and 1943, respectively, and re-routed Albany River water southward to Lake Superior, and hence assists Great Lakes water level control during low water years. The Long Lake diversion has averaged approximately 1400 cfs and the Ogoki diversion about 3900 cfs which taps a basin of 5800 square miles.

4. *Chicago Diversion*

Diversions of water from the Great Lakes–St Lawrence system at Chicago into the Mississippi River system have been made since 1848. Diversions reached magnitudes of slightly over 10,000 cfs in 1928 but the diversion at present is governed by United States Supreme Court decree of 12 April 1930, which provided that on and after 31 December 1938, the diversion would be limited to 1500 cfs in addition to domestic needs of the City of Chicago. The present diversion averages 3200 cfs. A new International Joint Commission (IJC) reference has been announced, authorizing a 5-year study of the effects of increasing the diversion up to a maximum of 10,000 cfs for abstraction of the water of Lake Michigan at Chicago, which will have an effect on the water levels and flow of the Great Lakes.

5. *Chamberlain Lake Diversion*

While the Chamberlain Lake diversion does not involve waters of Canadian origin it warrants comment because of its very interesting history and the role it played in pointing out the need for a joint United States–Canada commission to deal with international rivers.[5]

6. *Garrison Diversion*

The Garrison diversion is part of the Pick–Sloan Plan, a huge development plan proposal for the Missouri River Basin. The immediate purpose of the Garrison project, which is under construction, is to direct 879,000 acre-ft of water annually from the Missouri River for municipal, industrial and recreational use, and for irrigation of 250,000 acres of land. The irrigation aspect is the principle cause for concern due to the possible introduction of foreign species of fish and biota to Canadian waters, as well as wastes. Most of the land to be irrigated is on the northern side of the continental divide and drains into the northward flowing Red and Souris Rivers.

7. *Saskatchewan–Nelson Basin Study of Possible Diversions*

In 1972, the Saskatchewan–Nelson Basin Board completed a 4-year study of Canadian Prairie rivers in terms of additional supply of water by diversion or storage in one of the four largest river basins in North America (414,000 square miles). The Basin includes three major river systems, the Saskatchewan, the Red and the Winnipeg. Preliminary engineering reports identified 55 possible dams and 23 diversion projects. The design of a water demand study for the Basin has been completed and will be implemented in the near future.

8. *James Bay, Quebec*

This diversion is centered on the La Grande River, and reflects drainage basins totalling over 64,000 square miles made up of La Grande (37,800 square miles) plus parts of three other rivers: the Eastmain (by diversion of the Opinaca, a tributary), the Great Whale (flowing into southern Hudson Bay), and the Kaniapiskau–Koksoak (flowing into Ungava Bay). The first phase of the La Grande scheme, which is currently under construction, will produce in excess of 8000 MW (12,000 MW ultimate) and calls for an investment in excess of 6 billion Canadian dollars.

9. *Lake Winnipeg, Churchill and Nelson Rivers*

A two-year $2 million study was completed in 1974 to determine the effects that regulation of Lake Winnipeg, diversion from the Churchill River and development of hydro-electric potential of the Churchill River would have on water and other resources. The diversion of up to 30,000 cfs from the Churchill River has currently reached 20,000 cfs. Six out of the fourteen hydro-electric stations have been constructed at Jennep producing 168,000 kW of power. The diversion will reduce the Churchill River discharge from 40,000 cfs to 13,000 cfs. An implementation agreement covering all of the study recommendations is currently under negotiation by the Canadian Government and the Province of Manitoba.

10. *Dickey–Lincoln School Project*

This hydro-electric project has been in the planning stages since the early 1960s.[6] The project consists of two dams with generating facilities in each. A large dam at Dickey (Maine), some 15 miles upsteam of the international reach of the St John River (at the International Maine/New Brunswick border), would create a reservoir 88,000 acres in area. The total volume of the proposed reservoir is about 8 million acre-ft, of which 2.9 million acre-ft are live storage. The powerhouse at Dickey would generate 760 MW for peaking purposes, while the second dam at Lincoln School, 1.5 miles upstream of the international reach, would be used to even out fluctuations in outflow from Dickey. About 5000 acres would be flooded on tributaries in the Province of Quebec. An environmental impact study costing $750,000 is currently underway for this $500 million project.

11. *Colorado River Basin*

In 1968, as part of the Colorado River Basin Project Act, Congress prohibited federal studies of importation of water to the southwestern United States for a period of 10 years. That moratorium expires in 1978. Southwest water interest groups continue to seek studies of alternatives for importation of water from the northwest. Added pressure due to increasing droughts will undoubtedly occur when the moratorium expires.

PROPOSALS FOR INTERREGIONAL TRANSFERS

Proposals for interregional transfers have been made in the 1960s, the most ambitious of which is the North American Water and Power Alliance (NAWAPA), first proposed in 1964. The immensity of the plan stirred the imagination of many engineers and economists, and within the 5 years of NAWAPA being proposed, a whole series of interregional water transfer schemes were put forward to redistribute the waters of North America. Table 1 shows twelve such schemes which are primarily national in character. Eight major international proposals are shown in Table 2.[8] Only the major one, NAWAPA will be briefly discussed.

NAWAPA project – This $100 billion project was proposed by Ralph M. Parsons Company of Los Angeles.[9] The general idea is to collect surplus water from the high precipitation areas of the northwestern part of the North American continent and distribute it to water-scarce areas of Canada, the United States and northern Mexico. A series of dams and power stations in Alaska and northern British Columbia would collect water and provide power to pump this water up to the Rocky Mountain Trench Reservoir in southeastern British Columbia. From the Rocky Mountain Trench Reservoir, water would be lifted by pumps to the Sawtooth Reservoir on Central Idaho. From there, the water would flow by gravity to the western States. NAWAPA would initially provide 137.5 billion m^3 of water annually to seven provinces of Canada, 33 states in the United States and three northern states of Mexico. The total power generation would be 100 million kW/yr. Out of this, 30 million kW/yr would be utilized by the pumping requirements of the project. NAWAPA is a gigantic project and its environmental and social costs have yet to be determined. In the present era of environmental awareness, it is highly unlikely that such a major project will receive serious planning attention – at least for another two decades.

ISSUES INVOLVED WITH INTERREGIONAL TRANSFERS

There are a number of problems associated with (and several issues involved in) large scale transfers of water. These are discussed below under four separate headings: technical, socio-economic, political and legal, and environmental.

Table 1. Interregional transfer proposals (national)

Proposal (Author)	Year proposed	Water source	Volume of diversion in millions of acre-ft	Estimated cost in billions of $
Pacific Southwestern Water Plan (Interior Dept)	1963	north coastal California	1.2	?
Western Water Project (Pirkey)	1963	lower Columbia at Dalles	13.0	12.8
Snake - Colorado Project (Nelson)	1963	middle Snake in Idaho	2.4	1.4
Modified Snake - Colorado Project (Dunn)	1964	lower Snake in Oregon	5.0	3.6
Yellowstone - Snake - Green Project (Stetson)	1964	Yellowstone and Snake, Montana and Idaho	2.0	0.4
Undersea Coastal Aqueduct (NESCO)	1965	Klamath, Eel and Rogue, mouths	11.0	8.0
Texas Water Plan (State of Texas)	1965	eastern Texas rivers	3.3	0.5
Prime Plan (Province of Alberta)	1965	Peace and Athabaska rivers	?	?
Mexican Plan (Government of Mexico)	1965	southern east coastal region	?	?
Undersea Hose (Conner)	1967	mouth of Columbia	12.0	2.0
Beck Plan (Beck)	1967 - 1968	Missouri in Nebraska	10.0	3.5
Hudson Institute Plan (Hudson Institute)	1968	Mississippi and Arkansas	34.0	12.2

Table 2. Interregional transfer proposals (international)

Proposal (Author)	Year proposed	Water source	Volume of diversion in millions of acre-ft	Estimated cost in billions of $
Grand Canal Plan (Kierans)	1959	James Bay dyked rivers "recycled" to Great Lakes	?	?
Great Lakes - Pacific Waterways Plan (Decker)	1963	Skeena, Nechako and Fraser of B.C., Peace, Athabaska, Saskatchewan of Prairie Provinces	115.0	?
North America Water and Power Alliance, NAWAPA (Parsons)	1964	Primarily the Pacific and Arctic drainage of Alaska, Yukon and B.C.; also tributaries of James Bay	110.0 initially	100
Magnum Plan (Magnusson)	1965	Peace, Athabaska and North Saskatchewan in Alberta	25.0 at border	?
Kuiper Plan (Kuiper)	1967	Peace, Athabaska and North Saskatchewan in Alberta Nelson and Churchill in Manitoba	150.0	50
Central North American Water Project of CeNAWP (Tinney)	1967	Mackenzie, Peace, Athabaska, N. Saskatchewan, Nelson and Churchill	150.0	30 - 50
Western States Water Augmentation Concept (Smith)	1963	Primarily Liard and Mackenzie drainages	38.0 at border	75
NAWAPA + MUSHEC or Mexican - States Hydroelectric Commission	1968	NAWAPA sources + lower Mississippi and Sierra Madre, Oriental rivers of southern Mexico	158 + 129 NAWAPA MUSHEC	?

Technical

(i) The planning, design and construction of gigantic projects for transporting large bodies of water over large distances must be carried out with great care and imagination by highly qualified individuals. This is necessary because as a rule the bigger the size of such projects, the greater are the uncertainties. It may be more prudent to postpone a decision on such projects, if all investigations are not complete, or if uncertainties are enormous – rather than make decisions in a hurry. Also, such large projects can be severely affected by upstream and downstream developments, i.e. sudden failure of a hydraulic structure upstream can adversely affect the overall safety of the project.

(ii) The hydrologic and meteorologic characteristics of the drainage basins may significantly change after the completion of the project. Such changes should be adequately anticipated and considered within the planning framework.

(iii) For determining surplus water of a basin, its long-term storage requirements to take care of the time variation of run-off in the basin should be considered. Regions with a present water surplus have been understandably reluctant to permit exports which might have even a slight probability of restricting their own economic growth in the distant future. There have been controversies over diversions of the Colorado,[9] Columbia[10] and Yukon[11] rivers in the United States. However, if the population of such regions can be assured that only surplus water of their basins, calculated after taking into account their projected requirements (say, for a period of 50 years as provided in the Texas Water Plan),[12] as well as their storage requirements for taking care of the time variation of the run-off at a given location in the basin, will be diverted, the objection could perhaps be minimized.

(iv) The project should be made flexible by leaving as many options as possible open for future adjustments decisions. Large-scale transfer of water from one basin to another is, in effect, an interference with the natural water regime. For such cases, from ecological and environmental viewpoints, a cautious and conservative approach is desirable. In spite of scientific and technological developments of recent years, not much is known about the behaviour of the streams and rivers under changing flow and sediment conditions. Thus, a number of uncertainties are involved in the planning and design of such large-scale projects. It may, therefore, be desirable to make decisions on the project in various stages and the plan be kept flexible enough that only those decisions which are essential for the immediate future have to be made.

(v) Efforts should be made to determine the impact of interbasin transfer of large bodies of water on the environmental characteristics of the region. When surplus water of a river is diverted, the waste assimilative capacity of the river decreases. This may adversely affect the biological life in the downstream reaches.

(vi) Interbasin transfer routes and reservoir sitings must take into consideration earthquake-prone areas. Safety should be a significant concern of such projects.

Socio-economic

(i) Howe and Easter[13] have concluded that large-scale transfers of water are likely to cost more than they are worth to a nation, except in certain "rescue operation" cases where diverting water supplies threaten to idle immobile capital and labour. On the other hand, Wells[14] points out that the importation of water to the high plains of Texas is not economically feasible but also that the State simply cannot afford not to import water to the area. Thus, there can be great diversity of results that can be obtained from the economic analysis of such large projects. Sufficient care and effort must therefore be exercised in economic feasibility studies.

(ii) A large-scale interbasin transfer project must be justified not only in terms of the direct costs of transporting water, but also in terms of the value of services foregone by the exporting region due to the diminuition of its water supply (the opportunity cost of the diverted water).[15] Various alternatives to interbasin transfers should be investigated and that alternative which provides water to the deficient areas at the minimum cost (including special and environmental), should be selected. Alternatives might include:

(1) more efficient use of water within existing allocation patterns;
(2) reallocation of surface supplies;
(3) wastewater reduction, including desalination;
(4) improved integration of surface and groundwater supplies;
(5) management of watersheds; and,
(6) weather modification.

(iii) As an alternative to importation of water, economy in the water use should also be considered by the importing region. The philosophy of controlling water demands to eliminate or reduce further water development involves a number of factors and has been discussed by Coe[16] in detail.

(iv) The framework for the economic analysis should be properly made; not only the primary benefits, but also where possible, the secondary and tertiary benefits of the projects should be considered.

(v) Broad social objectives and benefits should be considered in the light of growing urban and industrial demands; while benefits to the agriculture sector are usually the major concern of the majority of diversion schemes, social objectives such as income redistribution, alteration in regional growth rates, reduction in unemployment and environmental protection (though not always measurable in purely economic terms) should also be considered in assessing alternative public investments *in situ* demands e.g. fish, aquatic vegetation, power, recreation and navigation should also be considered.

Political and legal

(i) In many Western States, the earliest water rights were developed simply by use and some are still unrecorded. Even in the areas where all rights have been adjudicated they are measured in quantity of water withdrawn, rather than in quantity actually consumed, which must be determined before a transfer can take place.[17]

(ii) It is more than coincidence that all transfers of water that have been effected thus far on the continent, fall within state and provincial borders. While the effects are certainly felt downstream across these borders, it is still fair to say that the present pattern of interbasin diversions strongly reflects the potential regionalization of Canada and the United States.

(iii) The foundation of Canadian–American international water law derived from the 1895 United States–Mexico dispute over the use of the Rio Grande. The United States reply is what is now referred to as the Harmon Doctrine.[18] A less stringent version of the same doctrine or principle appeared in Article II of the 1909 Boundary Waters Treaty.

(iv) Of all the difficulties associated with major interbasin transfers, the legal and political considerations are the most complex.

(v) The Supreme Court decision of *Arizona* vs *California* (373 US 566, 1963) was a landmark decision in federal–state water law. During the 10 years of litigation (1952–1963) both parties came to the conclusion that the water supply of the Colorado River was not big enough to supply the needs of both states, and therefore a supplemental source of water had to be found outside the Colorado basin.

Environmental

(i) The environmental implications of large interregional water transfer schemes are many, and these should be carefully analysed and received. A major difficulty is to assign economic values to many of the social and environmental costs stemming from such projects.[19] These should at least be subjectively evaluated.

(ii) The increase in both water-borne and water-based diseases due to major water developments, especially in the tropics and subtropics, should be carefully considered. Appropriate countermeasures should be taken to ensure that incidence of such diseases are kept to a minimum.[20]

(iii) Major interregional transfer schemes may affect the flora and fauna, and may cause irreparable damages.

(iv) Changes in micro- and macro-climate due to large-scale developments is always a possibility, especially in terms of increased evaporation and fog formation.

(v) Since the promulgation of the US National Environmental Policy Act (NEPA) of 1969 and the issuance of the Canadian Environmental Assessment Guidelines (1976), it is necessary to prepare environmental impact assessment for all significant federally funded projects. This includes, *inter alia*:

the environmental impact of the proposed action;
any adverse environmental effects which cannot be avoided should the proposal be implemented;
alternatives to the proposed action;
the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and
any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

CONCLUSIONS

Within the North American context, the following conclusions can be drawn for future large-scale interregional water transfer projects.

(1) Opposition to water exports, especially for interstate and international projects is likely to increase, especially as water becomes a scarce commodity. Logically this is hard to explain, since states and countries freely export other resources like minerals, hydrocarbons or agricultural products. In fact, for these resources, emphasis seems to be on increasing exports. Public sentiments, for some reasons, seem to be against water exports, and this is reflected within the political process. This is unlikely to change in the near future.

If the plan is self-contained within a state, its probability success is much higher.

(2) There is a tendency within the engineering and economic professions to opt for technological solutions – "soft" options are seldom seriously considered. Since water

resources development is dominated by these two professions, there is a tendency to make decisions to go ahead with technological fixes before all the alternatives are explored.

(3) The legal aspects of interstate and international transfers are quite complicated. This can be easily noticed when the number of serious disputes arising out of management of interstate and international rivers and lakes are considered. This is a global, and not exclusively North American, problem.

(4) Since the late 1960s opposition to major interregional water transfer projects has increased on environmental grounds. In the United States, it is unlikely that such schemes will be implemented within the forseeable future – at least for the next two decades.

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The Scientific Principles of Large-scale Areal Redistribution of Water Resources in the USSR

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The high rates of productive forces development in the Soviet Union have given rise to a large increase in water consumption of all branches of the national economy. Only for the past 5-year period, 1970–1975, the total withdrawal from water sources has increased by 20%. It is apparent that in the near future, water consumption rates will persist and by the end of the century they may amount to 600–700 km^3 year, exceeding the present value by 2–2.5 times. Appreciable changes in both the hydrologic regime and water quality occur because of the increase in water withdrawal and return water diversion and related construction of hydraulic structures and man's activity on watersheds. It affects adversely the ecological systems of water bodies and ecosystems at places of water use. A number of regional water problems have emerged and get increasingly complicated, and these problems will become world-wide in the course of subsequent water resources development.

The uneven distribution of river run-off, which is the main source of water resources, makes the solution of new water problems in our country exceedingly difficult. The southern areas, with up to 63–75% of the country's water consumption, have less than 15% of run-off. Adjacent and inland seas are another complicated factor: it places stringent requirements on the amount and quality of water.

Among the solutions of the above problems are: (1) all-round decrease in water consumption by improving water use technology in all branches of national economy and replacing a number of water consuming industries by waterless ones; (2) more complete use of all local water sources and enlargement of their resources by watershed management; (3) interregional water transfer by diverting part of the run-off of northern rivers to the basins of southern rivers.

The present state and perspective estimation of the scientific and technological progress in water consumption and water resources management indicate the possibility of achieving certain practical results in the way of reducing specific indices of water consumption, increasing the degree of water treatment and reuse, replacing water-demanding industries, etc. However, in many regions of the USSR, water requirements will exceed water availability. Water deficit in sourthern areas may be over 100 km^3/yr by the end of the century. To cope with these requirements in such a short period of time is possible only by undertaking a complex of measures including interregional water transfers.

The scale of construction needed for the interregional transfer of water resources in the USSR to meet the demands of the national economy at the end of the century and later may be so enormous and the impact on natural processes in major regions may be so strong and

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irreversible that now it is impossible to foresee the effect of the interregional water transfer on the environment and predict ecological and social consequences without special studies. Despite the existing valuable experience in solving large-scale water resources problems in the Soviet Union, we have no acceptable criteria for solving the newly arising problems and selecting the best project alternatives. The economic criteria established by practice and being used at present proved to be insufficient.

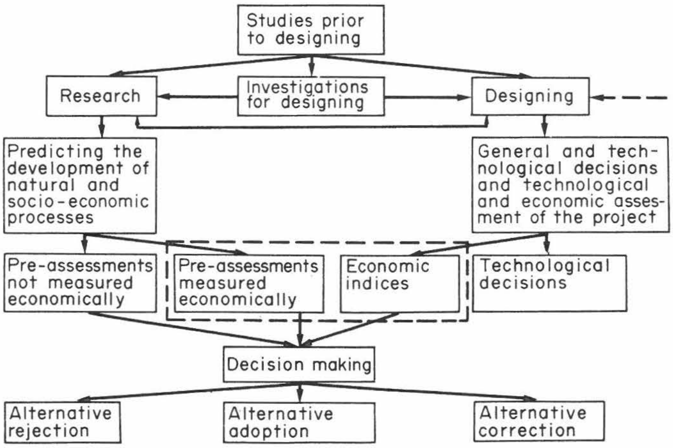

Fig. 1. The interrelationship between designing and research in solving a large-scale water resources problem.

Figure 1 shows the inter relationship between designing and research in solving a large-scale water resources problem. Interregional water transfer is such a problem. The experience of design and hydraulic structure construction convinces us that the larger the project, the more complicated are its relations with the environment and economy, and thus technological and economic assessment alone prove to be insufficient for making decisions. Therefore, special studies for predicting the development of natural and socio-economic processes, caused by water resources development, are necessary. Such studies will permit obtaining both qualitative and quantitative pre-assessments of these processes. Part of the estimates may be economically measured in indices similar to designed ones and used together with them (measures for removing negative consequences or using an additional benefit from the decision alternative under discussion may be planned). Estimates of individual processes development, which cannot be expressed in economic indices at the present state of knowledge, may appear (Fig. 1). However, these indices should be also considered in decision making; in our opinion, this is the main distinctive feature of the solution of the problem and its difficulty.

Proceeding from all accomplished designs and plans for interregional water transfer and for water supply of the national economy, and taking into account the earlier suggestions for solution of water problems, one may distinguish four quite different approaches, but each of these alternatives solves the same problem – the water supply of the national economy and the development of the country's water resources for a long-term period of over 40–50 years.

The first alternative (Fig. 2) envisages separate water supply of the European and Asian parts of the USSR. The water deficit of individual regions in the European area of the USSR should be eliminated mainly at the expense of the run-off of northern rivers of the Kara and Beloye (White) sea basins and lakes of the north west of the USSR which should be diverted

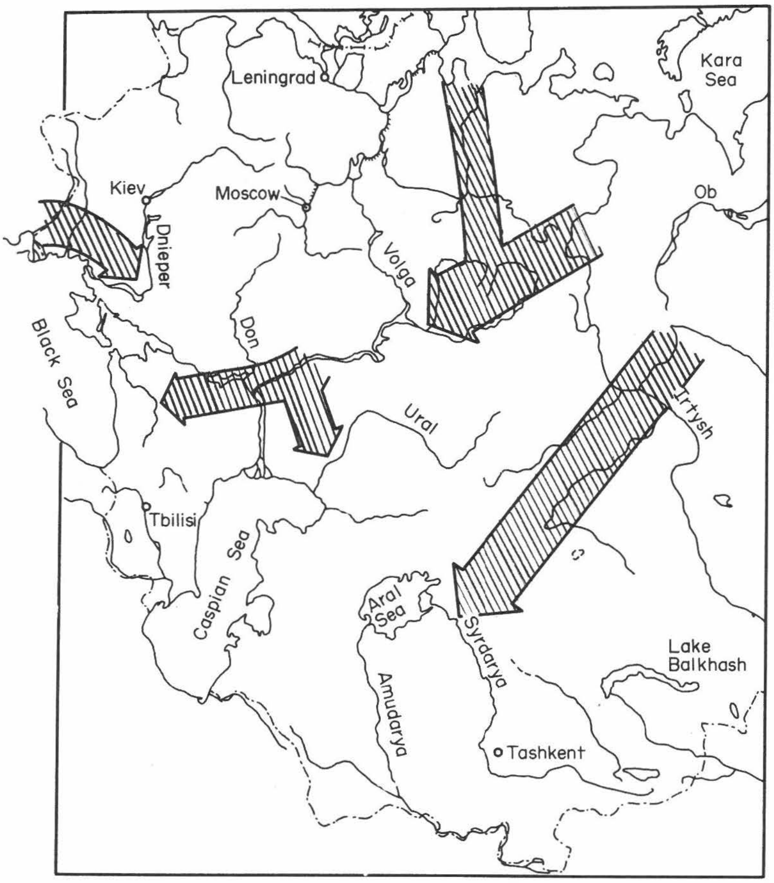

Fig. 2. Separate Euroasian alternative.

to the Volga. The diversion of the run-off of northwestern rivers and the Danube streamflow to the Dnieper basin will also contribute to the solution of the European area's water problems. In the Asian area of the USSR, the growing water requirements of Central Asia and Kazakhstan will be met mainly by the Ob River run-off.

The second alternative (Fig. 3) envisages the combined solution of water problems in the European and Asian areas of the USSR. The main idea consists in withdrawing water from the Lower Ob and transferring it through the Urals to the Pechora basin and farther to the Volga basin. The water of some northern rivers and lakes of the European area should also be diverted to the Volga. The water supply to Soviet Central Asia, Southern Kazakhstan, Middle and Lower Volga areas, Northern Caucasus, Kalmyk area and the Rostov region will be provided by the run-off of northern rivers, diverted to the Volga. The diversion of the run-off of the Danube and northwestern rivers to the Dnieper is also being contemplated.

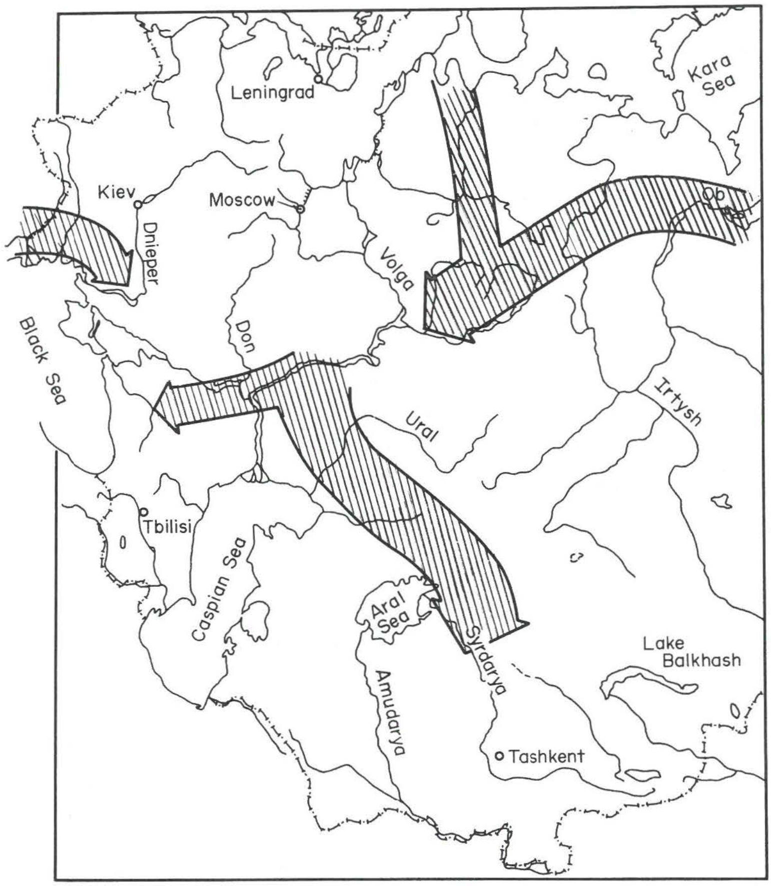

Fig. 3. Integrated Euroasian alternative.

The third alternative (Fig. 4) envisages the water supply of both the Asian and European areas of the USSR at the expense of the Volga run-off alone. In the Northern Caspian Sea a dam will be constructed, this will result in a manageable water–salt regime in this area. The Black Sea water will be transferred to the Caspian Sea. Local solutions involving the diversion of the run-off of other rivers may also be made.

The fourth alternative (Fig. 5) may be considered as a totality of all possible solutions to be made in an optimal combination within the Integrated Water-Resources System of the country. This last alternative represents the state of the nation's developed water management system and may be considered as the most general solution of water problems. The three above-mentioned alternatives may represent separate stages of the development of the Integrated Water-Resources System whose links may be formed completely in a longer period of time lasting for 30–40 years.

Now, it is possible to formulate a number of principles which will determine the general features of the Integrated Water-Resources System, its formation, stages of its development and functioning. They are as follows:

(1) The development of the Integrated Water-Resources System and the extent and quality of water resources management will depend upon the scientific and technological progress of the nation and the general state of productive forces. The rates of power systems development and river water power use are very important in this respect.

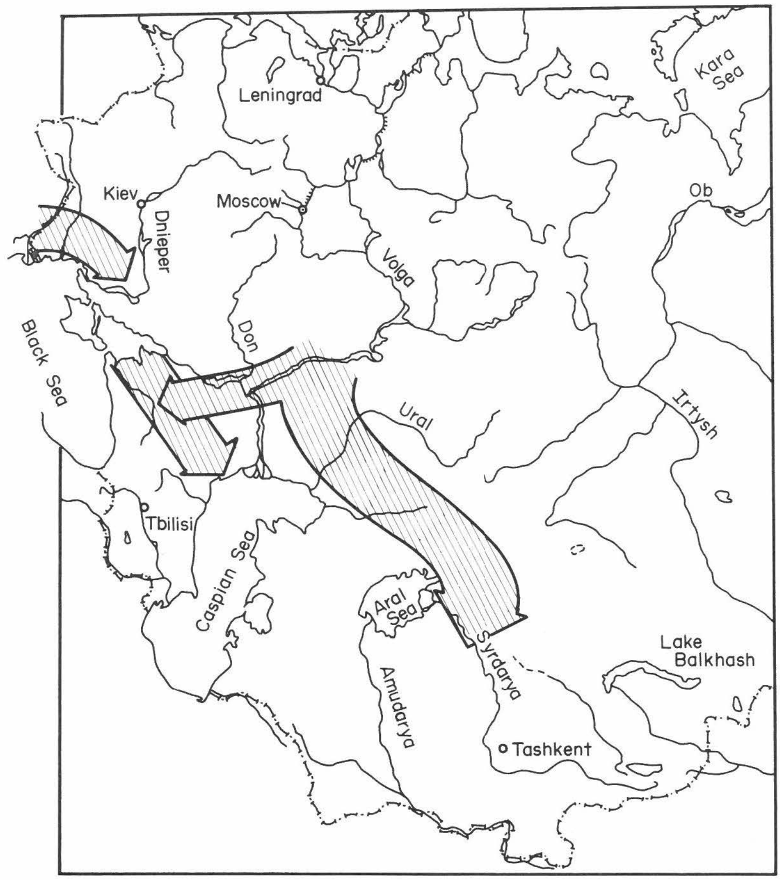

Fig. 4. Black Sea—Caspian Sea and Volga alternative.

(2) The Integrated Water-Resources System should be considered not only as a technological means of water resources management, but also as an important component of the environment, providing a basis for the formation and development of hydrologic, hydrochemical, ecological and other links.

(3) Under conditions of annual and long-term variations in water resources and water consumption, the water resources links being formed within the Integrated Water-Resources System should consider most completely the asynchronism of water resources and water consumption from various sources in different regions of this country.

(4) Proceeding from particular conditions of water resources distribution over the country's area, run-off regulation is advisable to be carried out not only by the routine method of the construction of inland water-storage reservoirs, but also by creation of regulating storages in river-mouth areas, using sea bays, sea areas and even individual small seas, for example, the Sea of Azov and the Beloye (White) Sea.

(5) It is advisable to assess any water management measure or development stage planned for the near future with regards to their place in the prospective Integrated Water-Resources System taking into account the general principles of the formation and development of the System.

(6) Selection of the next stage of development of the Integrated Water-Resources System should allow the possibility of further multi-variant development of the System. This will permit improvement in forecasting the current stage impact on the environment and economy and will allow a complex of studies for further development of the System to be carried out.

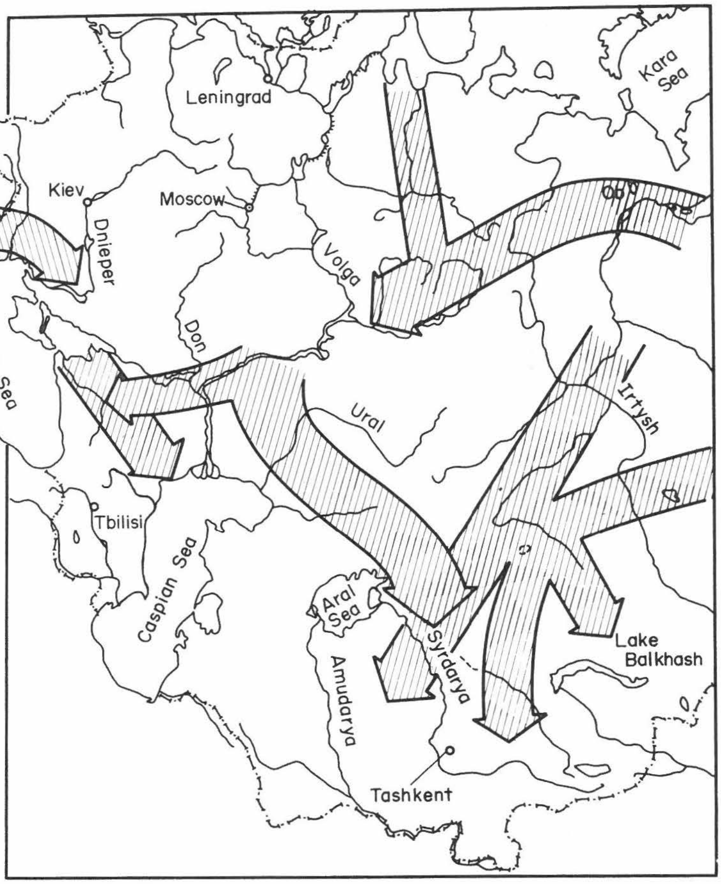

Fig. 5. The Integrated Water-Resources System.

The scope of the problem to be solved may be seen from the following figures: the total area within which run-off will be transferred amounts to 12,000,000 km^2 that is more than half the USSR area and more than all Europe, this area includes 600,000 km^2 of lakes and 1,000,000 km^2 of adjacent seas. The run-off of the area is 2200 km^3/yr or more than half the total run-off of the USSR, exceeding the run-off of the conterminous United States of America or that of India.

Each of the above mentioned alternatives provides equal water amounts, but may produce a different effect on the use of natural resources, development of productive forces, and the dynamics of environmental processes. Some of the effects are seen even now or may be clarified in the course of designing and planning, some others (and they are the majority) need special studies and prediction. For example, it is evident that the first alternative measures (separate European and Asian water diversions) may appreciably reduce the water discharge of the lower reaches of northwestern rivers in the European area and the middle reaches of the Ob in the Asian area of the USSR. The second alternative measures (the integrated Euro-asian alternative) are more preferable in this respect.

The advantages of the second alternative consist in stage-like character and smaller terms of funds freezing in the course of construction. For example, after the construction of the Volga—Aral Sea canal providing water for the Syrdarya and Amudarya basins, it will be possible to start construction operations for diversion of water from the north to the Volga basin. The water of the Pechora, Northern Dvina, northwestern rivers, and the Lower Ob may be used in various succession and amount, or the third alternative, comprising the diversion of water from the Black Sea to the Caspian Sea, may be developed. It may be evident that the transfer of large water amounts to the Volga will improve the quality of the water both in its reservoirs and the river run-off in the basin.

On the other hand, it is also evident that the transfer of the Lower Ob water over the Urals Range and permafrost areas is difficult. Diversion of water from the Black Sea to the Caspian Sea and regulation of the salt regime of the Northern Caspian area seem to be technologically complicated due to the necessity to uphold the salt regime of the Sea of Azov and due to the routing of the canal through areas with a high level of economic development.

The fourth alternative, involving an optimal combination of individual technological decisions, reasonable terms and scope of operations, may exclude some drawbacks of the other alternatives.

An appreciable advantage of this alternative is the possibility to create the Integrated Water-Resources System providing water resources management on a completely new basis, i.e. creation of regulated water bodies in river mouth areas and a possibility of manoeuvering water resources over extensive areas with allowance for the asynchronism of water resources and consumption.

Natural regulating storages in the river mouth areas of the Kara, Barents, White and Baltic sea basins (Ob and Yenisei estuaries, some bays of the White and Baltic sea) and the diversion of water from the storages to the south will preserve as much as possible the natural hydrological regime of river systems and reduce the need for reservoir construction on plains. Climatic conditions of the north would guarantee the quality of water resources. Acceptable conditions for fisheries and sea navigation would be created by regulating the water exchange between the water bodies being constructed and the seas. A similar approach to water resources regulation in the south in the basins of the Caspian Sea, Sea of Azov, and Black Sea may result in creation of storages with a regulated salt regime providing for intensive fisheries under conditions of rich biogenic run-off and heat abundance. This may be accomplished by the regulation of the Sea of Azov, Northern Caspian Sea and Black Sea's firths.

Within the Integrated Water-Resources System, the most rational management of water resources may be achieved by the diversion of water from one basin to another having different water demands.

It is known that water availability and demands within a basin may be correlated, but more often they are not. Hence, reasonable reallocation of water resources between river basins in different years should be performed.

Studying and predicting the effect of the planned measures are advisable to carry out on the basis of modelling the water resources system as a whole, and individual environmental and economic processes associated with the development and functioning of the Integrated Water-Resources System. At present, the experience in development of such major scientific problems and, the more so, modelling of such water resources systems exist neither in the USSR nor abroad. Projecting the Integrated Water-Resources System cannot be identified with any single mathematical problem due to the diversity of criteria. In this case, a series of problems connected by a chain of non-formal links inevitably arises. The selection of a solution variant must finally result in search for a certain compromise. Based on systems analysis, one should assume that the most effective way of solving such problems may be the use of a system of interrelated and subordinated mathematical models (Fig. 6).

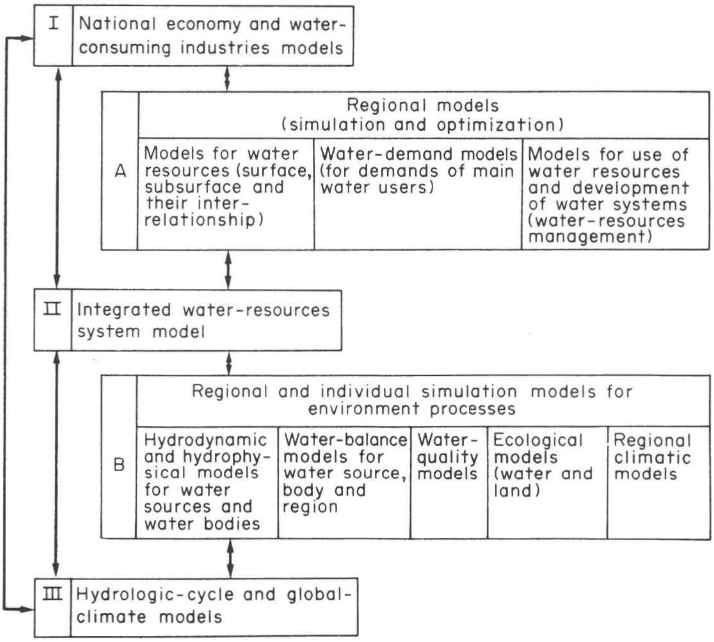

Fig. 6. A system of mathematical models for studying and estimating interregional water transfer.

A model, having input information on the location and distinctive features of the regime of water sources, location of water consuming industries, regime and requirements for water resources of all water users, and location and characteristics of water resources installations, may produce output data on the regime of water resources installations (management knots) and water bodies.

The information obtained is initial for development and solution of regional models of various environmental processes (Fig. 6, Block B) and global models (Fig. 6, Block III). On the other hand, the results may be used for correcting initial locations of water consuming units (Fig. 6, Block I) and management regimes (Fig. 6, Block A).

Proceeding from the experience gained for today and achieved level of programming, it is possible to realize the above problem, if the necessary information is available from special studies of environmental processes and a complex of design studies.

The starting point in these studies must be the prerequisites of development of water consuming industries and requirements for water resources of all branches of the national economy and water management.

Distinguishing water consuming industries from industrial branch plans through needed product balances and consideration of other demands on water will allow the formulation of the problem of locating water consuming industries and the construction of optimization models for the whole country. At present, an appreciable experience in construction of such models has been gained (Fig. 6, Block I).

Regional models (Fig. 6, Block A) are of essential importance in the system of models. Simulation models of the water resources of individual surface and subsurface water sources, models of the surface water–groundwater interrelationship are used for estimating the regularities of water resources formation and water source regimes with allowance for natural processes, and current and prospective economic activities. Water demand models reflect the regularities of formation of water demand in different branches of economy and take into account natural processes and technological development in water consumption.

Models of using water resources in separate regions and development of water systems may be optimizational. At present, an experience in numerical solution of such models exists for a number of river basins (Terek, Don, Kuban, and Syrdarya river basins). Linear and dynamic (both stochastic and deterministic) programming models are being used. Appreciable achievements in this field have been made in the USA.

The solution of problems using the Block A models allows the information on water resources, water demand and water resources management to be obtained. This information in the most aggregated form (water resources and demand of preset probability, run-off regulation parameters, economic indices of industries, etc.) is necessary for Block I models. The information from Block A models in a non-aggregate form is used in models of the Integrated Water-Resources System (Block II). In this case, indices of the dynamics of the natural water resources of river systems for a long-term period with their annual variation may be used, and water demand may be characterized by qualitatively identical indices.

In addition to the information role, Block A models should perform the correction role: they allow correcting water resources, water demand and water management parameters by iterative calculations.

Regional and partial simulation models of Block B are of particular importance in this system. They should cover a wide range of natural processes: hydrodynamic (water flow in river channels, canals, water reservoirs and hydraulic structures), hydrophysical (flow of sediments and admixtures, river bank and bed scour, the thermal regime of rivers and water bodies), hydrogeological (groundwater flow and discharge, storage of groundwater in aquifers, interrelationship of surface and groundwater and artificial structures) water balance (water balance of water sources and regions), water–salt balance (water–salt balances of soils, areas, and water bodies), water pollution and quality (quality of surface and subsurface water sources and bodies), ecological (ecology of water and land systems and their interrelationship) and climatic processes (water circulation, heat regime and evaporation).

Complicated links exist between Block B models, they are caused by links between corresponding processes. Data on location of water management installations and the regime of their operation, i.e. the regime of water courses and reservoirs and water consumption are initial for all models. It is necessary by means of Block B models to estimate a fairly large number of alternatives of functioning the Integrated Water-Resources System and make iterative corrections in the initial conditions of the models of Blocks II and I. Therefore, unification of Blocks B and A models seems to be an important matter. Typical models having a certain level of aggregation of input and output data can be constructed (the topological scheme of models will have, naturally, regional features).

The above system of models is the basis of studies in this field. Iterative calculations will allow combined estimates of various alternatives of interregional water transfers and stages of development of the water resources system and correct design solutions to be obtained. As the development of water resources systems is associated with long term construction and with even longer periods of environmental changes one must predict development of these processes for many decades in advance. In this connection, while solving the given problem, the levels of water demand at some stages, approximately for the years 1990, 2000 and 2030, closely related with national economy forecasts, are being considered.

At present, in the USSR, integrated studies on the interregional water transfer problem are being carried out. Over a hundred research organizations are taking part in these studies and the USSR Academy of Sciences guides them. The problem is treated as ecological and economical and as an inseparable part of the general problem of rational use of natural resources in the USSR. Therefore, its solution should serve not only economic objectives, but should also be a considerable contribution to the scientific substantiation and development of measures for increasing the efficiency of environmental quality management in the USSR.

The programme envisages revealing all possible main alternatives of the solution of the problem and predicting the reaction of natural processes caused by the possible interference with the water regime of regions and separate water bodies. Such an estimate must be made for all alternatives at various scales of interference and for distant future. The reversibility of biospheric changes should be estimated, the qualitative and quantitative aspects of changes from the natural and historical point of view should be determined, and the benefit and detriment of these changes for man should be evaluated.

Proceeding from the above, the following studies are planned:

(a) identify and estimate, scientifically and substantiatedly, all the ways of meeting prospective water demands (alternatives of water resources development);

(b) assess the effect of water resources development on the environment and socio-economic processes;

(c) work out the scientific principles of water provision and put forward primary tasks for planning and designing;

(d) make an all-round scientific assessment of the planned primary measures and substantiate measures for preventing and eliminating negative consequences.

The fundamental results of natural and social sciences will be used, and new developments in some branches and trends of these sciences would be achieved in solving these problems.

Particular attention is being paid to the studies of the processes of circulation of atmospheric, soil, surface and subsurface waters, and also waters of snow packs and glaciers, formation of land water quality under conditions of changing water exchange and economic activities. Based on these studies and achievements of biological sciences, it is necessary to develop methods for both quantitative and qualitative estimation of the impact of the water factor and man's economic activities on the ecological systems of land and water bodies, and therefore, all the environment. These studies are expedient to be linked with studies on the theory of climate for the purpose of a more complete and sufficiently substantiated estimate of man's impact on the environment.

Studies on scientific prediction of the development of the national economy for the distant future and prediction of scientific and technological progress in water consumption and water diversion are planned for solving the socio-economic aspects of the problem. The principles and methods of systems analysis are planned to be used widely both in posing the problem as a whole and in solving it. Methods of modelling large systems of physio-geographical and ecological processes, governed by the water factor, and modelling of the management of complex water resources systems will be used in particular.

The methodical basis of the programme is composed of present-day methods of analysis of complex systems with probabilistic and uncertain information. The objective of studies – the development of methods for water resources management allowing rational use of natural resources and environmental conservation – may be achieved only on the basis of all-round qualitative and quantitative analysis of decisions made in keeping with systems analysis principles.

The systems approach to the problem of rational use of water resources calls for development and wide application of mathematical modelling and programming. Simulation models permitting a wide range of computer runs with models of water resources systems, which cannot be treated analytically, occupy a prominent place in the studies. A water resources system as the main link in solving the problem of the provision of the national economy with water, is an interacting, hydraulically related totality of economic and ecological elements. Considering the peculiar role of water in the man–environment system, the programme of studies proceeds from the following premises:

(a) the necessity of treating water problems in their unity at a national level. Such a unity and interrelationship of regional problems with the general problem are stipulated not only by economic, but, above all, natural processes;

(b) the interrelationship of the effect of patterns of water resources use on natural processes not only in the area of planned water systems, but also in adjacent regions (heat and mass transfer of continental and oceanic waters, water circulation in the atmosphere, interrelations of ecological systems, etc.);

(c) the necessity of considering the developing water systems for a long-term period of no less than 40–50 years, several stages associated with long-range plans for development of productive forces – 1990, 2000 and 2030 being distinguished;

(d) the necessity of the development, analysis and comparison of different alternatives of productive forces development as a basis for the formation of water demand alternatives, water availability and environmental protection problems. Working out of such alternatives should consider direct and reverse links between productive forces and the water factor;

(e) the expediency of development of scientific hypotheses of water provision, founded on the scientific and technological progress and technology of water consumption, achievements in the management of water resources formation, the total potential of productive forces, and the possibility of construction of large-scale engineering projects for water resources management.

In the USSR, there is a number of objective prerequisites for successful solution of the problem of interregional water transfers for the benefit of all the people: state-wide planning of all economic and social activities, state property of land and water resources, high economic potential and vast experience in realization of large-scale water resources projects in irrigation, hydropower construction and water transport.

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Large-scale Transfers within Master Water Planning in Mexico*

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INTRODUCTION

Mexico, a country with a surface of nearly 200 million ha, has distinguished itself by an accelerated demographic growth, and an unequal spatial distribution. In 1950, the country had 26 million inhabitants, of which 60% were rural. In 1975 the population of Mexico reached 60 million, of which 40% lived in rural areas. It is estimated that by the year 2000 the total population, demanding great amounts of food from agriculture, will be from 126 to 139 million. Migration of peasants, caused by the hope of finding better living conditions in the city, will mean that by the turn of the century only 20% of the population will be rural and this will increase the size of already gigantic Mexico City and a few other large urban centers, which will require an increase in their water supply systems.

Agriculture is responsible for 95% of the total consumption of water. Although urban–industrial activities withdraw and consume small volumes of water, compared with those used for irrigation, the irregular distribution of water in the country and the increasing marginal cost of augmenting water supply systems, calls for huge investments to have adequate water supplies for our cities.

The average yearly rainfall in Mexico is 780 mm, equivalent to 1,530,000 million m^3; about one fourth of this corresponds to surface run-off, that is 410,000 million m^3.

The distribution of water resources has no direct relation to the location of the population. The southeastern area of the country, which contains 15% of the total area of Mexico and 12% of the population, has 42% of the run-off. On the other hand, the central and northern plateaus have 36% of the nation's territory, 60% of the population and only 4% of run-off.

The future need of water for irrigation and of huge water supply systems within a territory with non-uniform and non-coincident distribution of agricultural soil, water and population generate problems which will be treated in this paper. These problems, along with others such as water pollution, groundwater mining, etc., called for an integrated approach to water resources planning. A group was formed in 1972 to develop a National Water Plan, whose objective was to formulate and institute a systematic process for planning the water resources development for the rational selection of programs, projects and policies on this subject, which contribute to the attainment of the objectives of national socio-economic

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* This paper was edited with information from the Mexican National Water Plan 1975 and on-going projects of the NWPC. The part dealing with water transfers to supply Mexico City, was taken from studies of the Comisión de Aguas del Valle de México (Water Commission of the Valley of Mexico).

** Comisión del Plan Nacional Hidráulico de la Secretaria de Agricultura y Recursos Hidráulicos. (National Water Plan Commission (NWPC), Agriculture and Water Resources ministry).

development. In order to utilize foreign expertise and to make it possible for other countries with similar problems to take advantage of this effort, an arrangement was made with the United Nations Development Program and the World Bank.

A methodology was designed and a first iteration of the National Water Plan (NWP) was produced in 1975. In May 1976 the NWP Commission was created in order to update the Plan every 2 years, to constantly maintain in force its execution, to evaluate its results and to promote and coordinate research and training programs for water resources development. The NWP 1977 is presently being integrated.

METHODOLOGY, REGIONALIZATION AND SOME RESULTS OF THE NWP 1975

Methodology

The socio-economic aspects, as shown in Fig. 1, are studied at both national and regional levels, allowing in this way an identification of the objectives, policies and development goals which, along with technical factors, determine the demand for water. The supply of water resources is compared with the demand. In this way, the balances are computed, and problems derived from water shortage and lack of control or inadequate quality are identified. The alternative solutions to these problems, proposals made by different agencies related to water, and a catalogue of existing projects, are the basis to formulate and integrate, with the aid of systems analysis techniques, the programs for water resources development in each of the regions in the country.

The regional programs are integrated at national level in order to analyze the compatibility of the supply achieved through the programs with the demands derived from development, and of the financial and human requirements, with their availability. Through this analysis, some adjustments are made in goals and policies originally formulated; in this way, a cycle of the planning methodology is completed. The results of the implementation and operation of these programs set up a feedback with the socio-economic scenario, and lead to the identification of new goals.

In each cycle of the process, objectives, policies and goals for water resources development are set up. New projects are identified and recommendations are made for making studies and obtaining basic data. Finally, programs to build infrastructure works, provisions for its operation, institutional modifications, personnel training and research are formulated.

Regionalization

The hydrological watershed is the most adequate unit for planning water resources development since it groups, in natural form, the diverse groups of users and permits an integrated consideration of the effects of the management of water. For this, the country was divided into thirteen regions, formed by the main hydrological watersheds and groups of watersheds. These regions were grouped into four zones, each one including areas with similar characteristics or related in some way through the use of water. The thirteen regions were then divided into 102 socio-economically and politically homogeneous subregions. In Fig. 2, the division of the country into zones, regions, and subregions is shown.

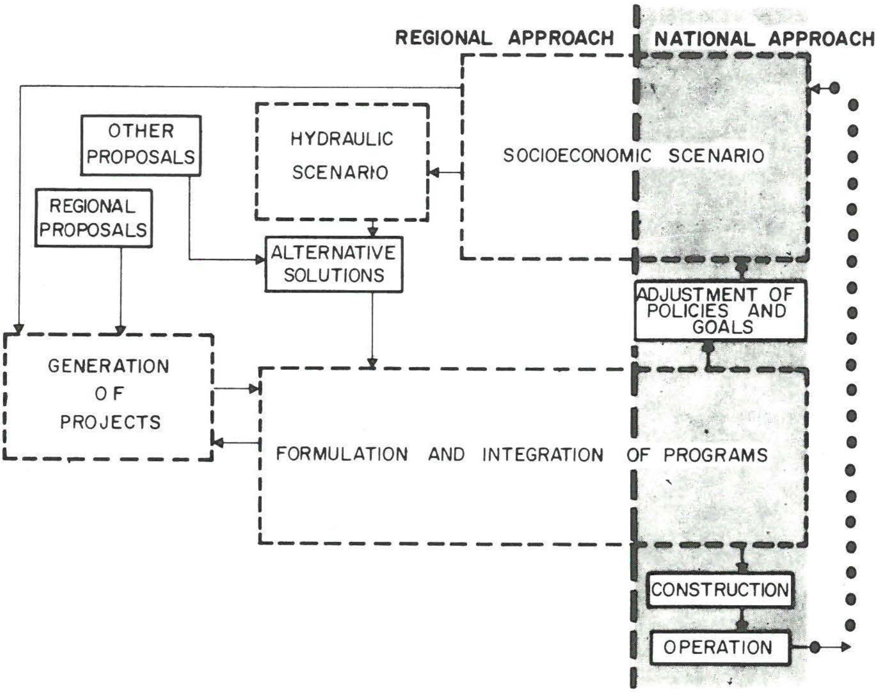

Fig. 1. Methodology of the studies of the National Water Plan.

The National Water Plan 1975

The dynamic process described above resulted in the NWP 1975 report, which was divided into three parts, as shown in Fig. 3. The first part is composed of the socio-economic and physical frameworks as well as the regional strategy for water resources development which is described below. The second part included the diagnoses, objectives, goals, policies and programs for water resources development, for each of the different activities which use water.

The third part is the integration of the program and policies; an analysis is made of its financial, technical and human resources feasibility, and the actions necessary to implement the Plan are suggested.

Regarding irrigation and drainage, construction and improvement of the hydro-agricultural infrastructure will contribute to the solution of some of the problems faced by the farming and livestock sector, since this permits an increase in the productivity of land, generation of employment, and an increase in the aggregate farming and livestock value.

The internal demand for farming and livestock products has registered an accelerated increase due to the increase in population, *per capita* income and inputs for industry. Until recently, it was possible, on the average, to satisfy basic needs and to export articles which permitted financing for the development of the nation's industry. However, there are still serious nutritional problems due to the low income level of a large part of the population and the lack of knowledge regarding proper diet.

At present there is an area of almost 5 million ha with hydro-agricultural infrastructure; these hectares are distributed in irrigation and drainage districts, irrigation units for rural

Fig. 2. National Water Plan's zones, regions and subregions.

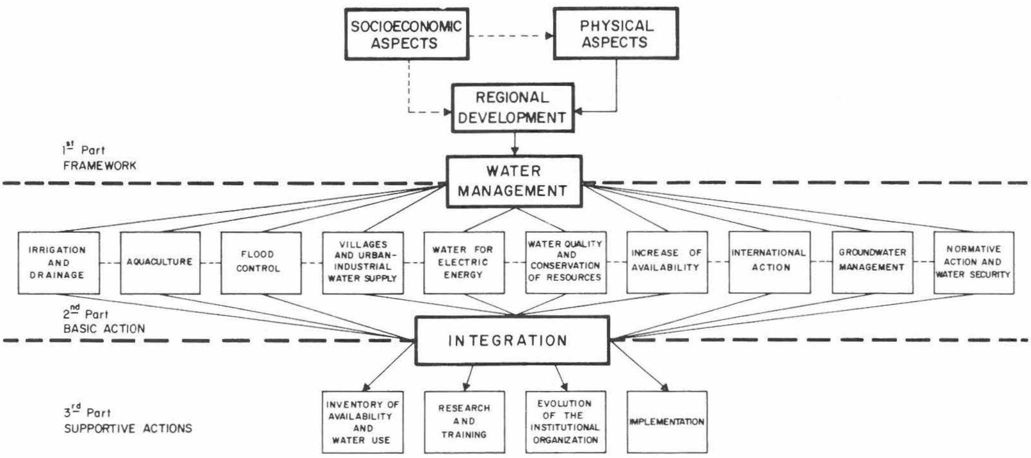

Fig. 3. National Water Plan, 1975.

development, and in private property, which represent 30% of the national harvested area, contribute 50% of the value of the total agricultural production, and contribute a large variety of basic products.

The goals proposed for the year 2000 involve the duplication, in 25 years, of the area with hydro-agricultural infrastructure put in operation during the last 50 years, reaching 10 million ha by the end of the century. The following paragraphs describe the suggested strategy for the regional water resources development of Mexico. In order to meet our agricultural production demands, large-scale water transfers are needed in the Northern and Central Pacific Zone (NCPZ). Mexico City, in the Central Zone (CZ), will increase the use of water from surrounding watersheds.

Regional strategy for water resources development

The soil and water inventory, the computation of water demands and potential pollution in different uses and for different alternative scenarios, and identified projects, allowed the accomplishment of integrated water and soil balances. This study required the use of detailed models of hydrologic simulation at watershed level, and estimates concerning the possible effects of pollution.

The results of these balances, expressed as water and soil potential, are shown in Fig. 4.

In the *Northern and Central Pacific Zone*, water resources and soil with high agricultural potential, part of which is still uncultivated, do not coincide spatially. There are 1.5 million ha unexploited, the majority of which are located in the central and northern part of the coastline of the Northwestern region, while abundant water is found mainly in the Pacific Central region.

Irrigation infrastructure has played an important role in economic development. Those areas under irrigation can still grow considerably larger with new hydraulic development; this can be accomplished through transfer between watersheds and local water resources developments, and in a very important way, through an increase in efficiency, taking advantage of the aptitude of the production apparatus of the area to increase its production and respond to the incentives without much inertia.

Under these conditions, the increase in harvested area could be significant. In spite of this, irrigated agriculture is not considered to be the only activity capable of satisfying the great demand for jobs which the increase in population will provoke; the great need to motivate the industrial, agro-industrial, and service sectors stems from this. For this expansion, it is advisable to reinforce some urban centers and industrial corridors located between the northern border and the country's central economic system.

It will be necessary to provide these centers with an infrastructure of water supply and sewerage, services which will also be required because of the encouragement of tourist activities, mainly in Lower California.

Aquaculture in fresh and brackish water is another activity which has great importance both in food and inputs production for industry as well as in employment generation. This activity has received a great deal of incentive since 1970; there is still a great potential which is extensively and intensively exploitable along the coastline, in present and future reservoirs, and through rural fisheries.

In the *Northern Zone*, geographic conditions dictate an extreme, arid climate in a large part of the region. It has the lowest precipitation in Mexico. The increase in irrigated areas has

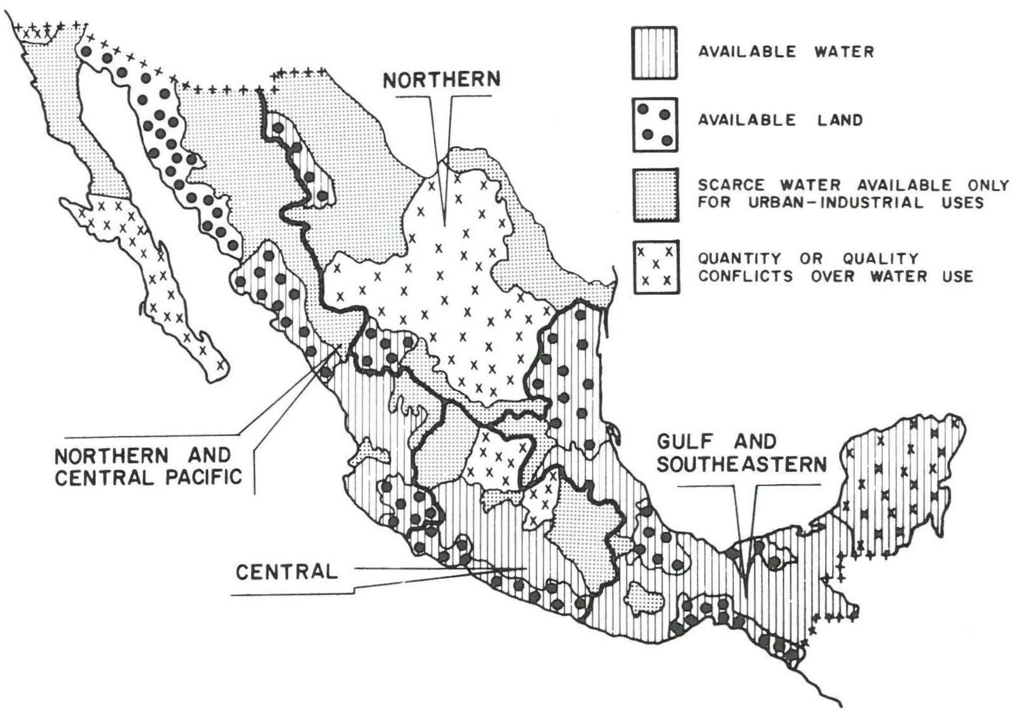

Fig. 4. Water and soil framework for the regional water resources development.

become stagnated due to the scarcity of water shown in Fig. 4. In the present decade, the increase in the work force is absorbed by a dynamic secondary sector; this in turn causes a greater urban concentration. Together with the problem of little availability of water, this resource is managed with low efficiency, especially in agriculture. In general, investments oriented towards efficient water management are highly profitable because of the opportunity cost caused by water's own scarcity. This region does not compete with the other three for government investment grants to open new areas through big hydro-agricultural projects, because of the small reserves of water still available. For this reason, the investments are mainly oriented towards projects tending to increase productivity.

In an increasing measure, the industrial sector is the one which absorbs the increase in the work force. The expansion of this sector is limited by the water scarcity; this, along with characteristics of the regional industrial profile, support the idea of selective growth with increase in productivity and a more efficient use of water which considers the reuse and recirculation of this resource. Water supply for the large urban industrial centers will come to a greater and greater degree from groundwater sources, except in a few cities, supplied from the River Grande, whose future growth will affect the hydro-agricultural areas which at present use water from the same river.

The most outstanding and attractive physical characteristic of the *Central Zone* is its climate; this has, to a degree, originated the immigration to this area, especially to the Lerma and Valley of Mexico regions, and to the high part of the Balsas River watershed.

This region has some very peculiar characteristics such as an agricultural tradition dating from the prehispanic era, disproportional distribution of the population and of economic activity in the metropolitan areas of Mexico City and Guadalajara, a net of cities of secondary importance with more than 50,000 inhabitants, and a serious income inequality between urban and rural areas.

Water resources and the demand centers do not coincide geographically; more than 80% of the run-off is formed in the Balsas region, where, because of its accidented topography, it is difficult to accomplish significant new hydro-agricultural development. On the other hand, the intensive use of water in the Lerma and Valley of Mexico regions causes conflicts due to the fact that the availability of water in these areas is not sufficient; this problem is made worse by the intense and growing pollution of the river courses, and in some cases, by the waste and loss of water in the systems.

Based upon these characteristics, the following global orientations for hydraulic development have been identified: to increase efficiency in the use of water, above all in agriculture, the main consuming activity, and to intensify the schemes for reuse of water in the urban–industrial conglomerates; to open new areas of agricultural production with irrigation, diversifying their crop patterns to participate in improved conditions in the consumer markets in the region; to decentralize industrial activities with basis on a selective location, taking into consideration the withdrawal, the consumption and the quality of the waste effluents, as well as the type of production; and to improve the level of the municipal water supply. Considering the growth and concentration of the population, from the years 1980 on, it will be necessary to make water transfers from nearby watersheds to the Valley of Mexico, maintain an adequate quality of water resources, as well as of aquatic organisms, and to implement a more efficient and coordinated water resources management.

Agricultural activity occupies the major part of the economically active population in the *Gulf and Southeastern Zone*; 96% of production is obtained in rain-fed areas.

The management of the scant hydro-agricultural infrastructure is very inefficient, mainly due to the characteristics of the soil, to the lack of technical assistance, and to the climate. The main checks on development are: from a technical point of view, the lack of experience in intensive agricultural exploitation in tropical areas, and from a social and cultural point of view, the scant knowledge of the motivational factors of the population, as well as the profound modification of the agrarian and social structure caused by the change from an individual farming and livestock production of subsistence level to an intense commercial production on a collective level.

The development of the vast natural resources of this zones, shown in Fig. 4, is a challenge which will have great economic importance for the country. Due to the difficulties mentioned here, the Gulf and Southeastern Zone would seem to be the least attractive, from a purely economical point of view, to channel federal investments for hydro-agricultural development; however, in order for the inhabitants to benefit from the national policy for shared development, and to satisfy future demands for agricultural products, the process of intensive production through adequate policies and incentives must be incorporated to the zone.

Since the agricultural technology and rural administration in the ecological conditions of the tropics are little known (Biswas, 1978), a strategy of development by stages must be implemented for hydro-agricultural projects in which an infrastructure oriented towards drainage, flood control and supplementary irrigation is considered. The first stage of each project is a pilot project whose main objective is to test modern technology and the corresponding administrative system which help the users to acquire the entrepreneur's capacity necessary in the new types of exploitation. Parallel to the building of structures, it is indispensable to develop and adapt technologies which are adequate for the humid Mexican tropics, to carry out specific farming and livestock research, to train technical personnel, and spread the results of the research and experiments to the users. The creation of an Institute of Tropical Development is foreseen, for the purpose of applying these investigations and experiments.

Some conditions which favor an important increase in industrial activity and in the infrastructure of this zone, as well as the opening of new work centers are: a commercial policy to dynamize the exports even more and diversify external markets, the recent trend to decentralize economic activity, the possibilities of farming and livestock development which will propitiate the formation of agro-industries, the enormous hydroelectrical potential and the discovery of new oil fields. In this sense, a dynamic development in industrial centers in the Northern Gulf and Southern Pacific Isthmus regions can be foreseen. Merida is another urban area of importance, though it is not as dynamic as those regions mentioned above; its location on the Yucatan Peninsula and its cultural tradition make Merida a city which should be integrated, along with future developments in the Mexican Caribbean, to an extensive area of touristic interest.

WATER TRANSFERS FOR AGRICULTURAL DEVELOPMENT IN THE PACIFIC REGIONS

A series of rivers crosses the coastal strip of the Mexican Northwestern region from the Santiago River to the Hermosillo coast; these rivers have a mean annual run-off of 26,500 million m^3. As can be seen in Fig. 5, 900,000 ha of this approximately 6 million ha area are now under irrigation utilizing annually 10,700 million m^3 of surface water from these rivers controlled by nine large storage dams and 1530 million m^3 of groundwater.

Along this strip there are still 1.5 million ha of idle lands adequate for irrigation agriculture; 80% of these are located in the northern part, while the rivers which are still uncontrolled are in the south.

The present development of surface water is being carried out through the conduction and distribution for irrigation of areas located near the rivers already controlled. At present, storage dams with a total capacity of 6300 million m^3 are being built; these dams will allow the incorporation of approximately 150,000 ha to irrigation through an interconnected system from the San Lorenzo River to El Fuerte River.

In order to develop 800,000 ha more, systems which would satisfy the demands of areas near each river and would allow exportation of excess volumes of water to the Northern region are necessary. Studies on water transfer for this region were begun 10 years ago. In the feasibility analysis, deterministic models of digital simulation have been used; these models reproduce the monthly behavior of water supply and demand centers, taking into account historical run-offs in the rivers during a 20-year period.

In the short range, the opening of some 50,000 ha has been proposed; this would be carried out by rational and temporary groundwater mining in the aquifers located between the Piaxtla and Yaqui Rivers for about 10 years. At the end of this period the groundwater will be substituted by surface water, and the surface being irrigated will be increased by 180,000 ha since the works for enlargement of the interconnected system between the Piaxtla and the Yaqui mentioned before will have been completed, as shown in Fig. 6. These structures include five storage dams with a total capacity of 6000 million m^3, a 240 km conduit and a distribution and drainage infrastructure for 230,000 ha.

The economic evaluations which have been carried out are favorable for the entire program over both short and medium ranges; that is, for the actions considering the rational mining of aquifers as a first stage followed by the enlargement of the transfer system from the Piaxtla River to the Yaqui.

A model of linear programming which works coupled with the hydrological simulation model has been used to define the scheduling of medium range works and the allocation of water in the Piaxtla–Yaqui system. The objective function considers net regional benefits and the linear model has as restrictions the available land and water in each center of demand and supply, respectively, as well as the production volume per crop which has been imposed at the regional level based upon the demand projections at the national level, and the participation which the northwestern region is estimated to have in the satisfaction of these demands. The results of the linear model are tested in the hydrological simulation model until a convergence between the results of both models is reached. The scheduling of the works is determined by ranking the values of the objective function obtained when different alternative components of the system are included.

This water allocation mechanism not only allows finding the best water distribution, but also makes it possible to find out the cost to the country of both alternative policies of water distribution as well as directed policies to stimulate the production of a certain crop in any of the production areas. This cost is estimated by calculating, for different alternative policies the decrease in the value of the objective function and the production volume which is no longer produced.

Over the long range, the integration of the great northwestern system from the Santiago River to the Hermosillo coast (shown in Fig. 6) is being considered; this implies another six dams, 1500 km of conduits which includes 12 km of tunnels and pumps and requires around 600 GWh/yr to raise the water 500 m. This system permits the opening of another 450,000 ha through the water exportation and of 130,000 ha in the vicinity of the controlled rivers, for which another 7500 million m^3 will be utilized annually. This volume of water will also make it possible to suspend the mining of the aquifers in Southern Sonora.

The long range program, which is planned to be completed in the year 2000, offers the opportunity to attain an important increase in the national grain supply, in such a way that our country be self-sufficient in those products. For this reason, traditional evaluation indicators are not given too much weight, and less so, considering the changing nature of the price system.

Since the water resources systems have multiple uses, the short, medium and long range construction programs lead to the opening of a total of a million new hectares to irrigation, to the generation of 3650 GWh/yr, to the provision of flood control in the coastal flatlands and to the regulation of the fresh water flow to coastal lagoons to propitiate aquaculture activities.

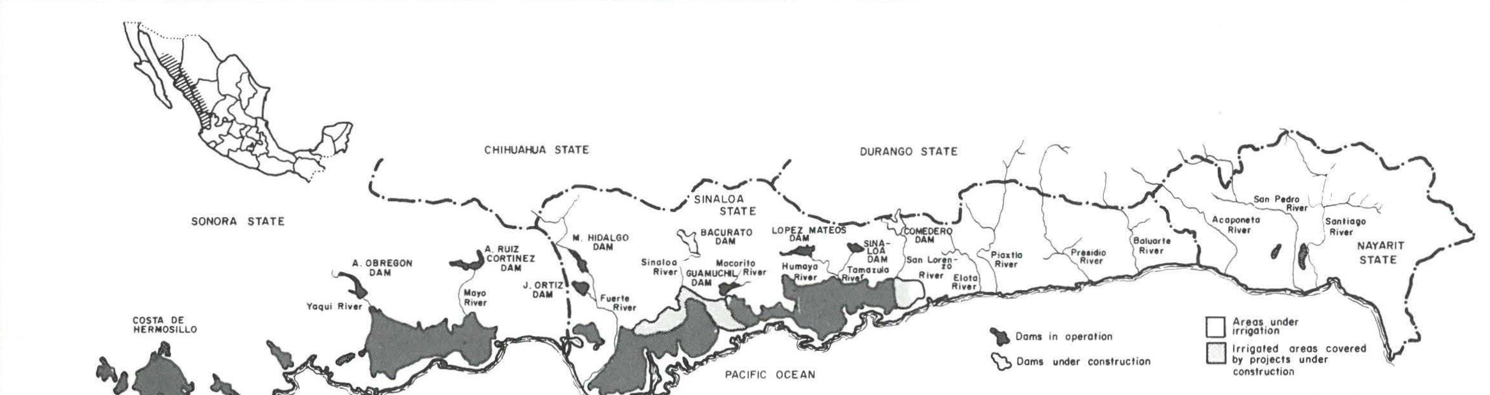

FIGURE 5 PACIFIC REGIONS. AREAS IN OPERATION AND UNDER CONSTRUCTION

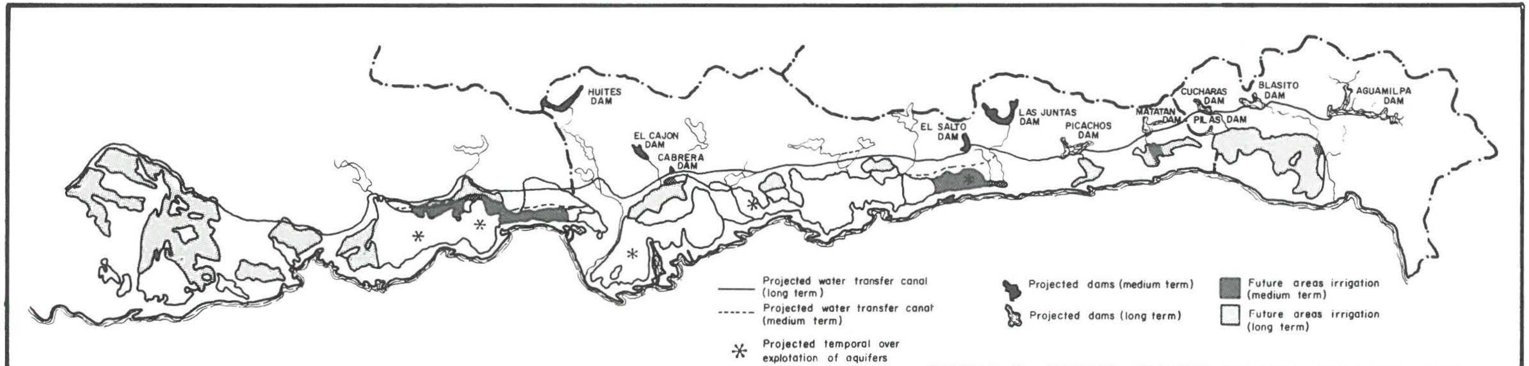

FIGURE 6 PACIFIC REGIONS. FUTURE PROJECTS FOR MEDIUM AND LONG TERMS

TRANSFERS FOR THE WATER SUPPLY OF MEXICO CITY

The metropolitan area of Mexico City, located in the Valley of Mexico in the central plateau of the Mexican Republic, 2240 m above sea level, and with a population of more than 10 million, now faces one of the most serious problems in the world regarding water supply.

The water supply problem has worsened due to the explosive way in which the population has increased (6% annual rate). At the middle of this century mining of aquifers underlying Mexico City was begun. This caused a notable increase in land subsidence and considerable damages, especially in the sewerage nets. From 1957 on, the importing of 13 m^3/sec

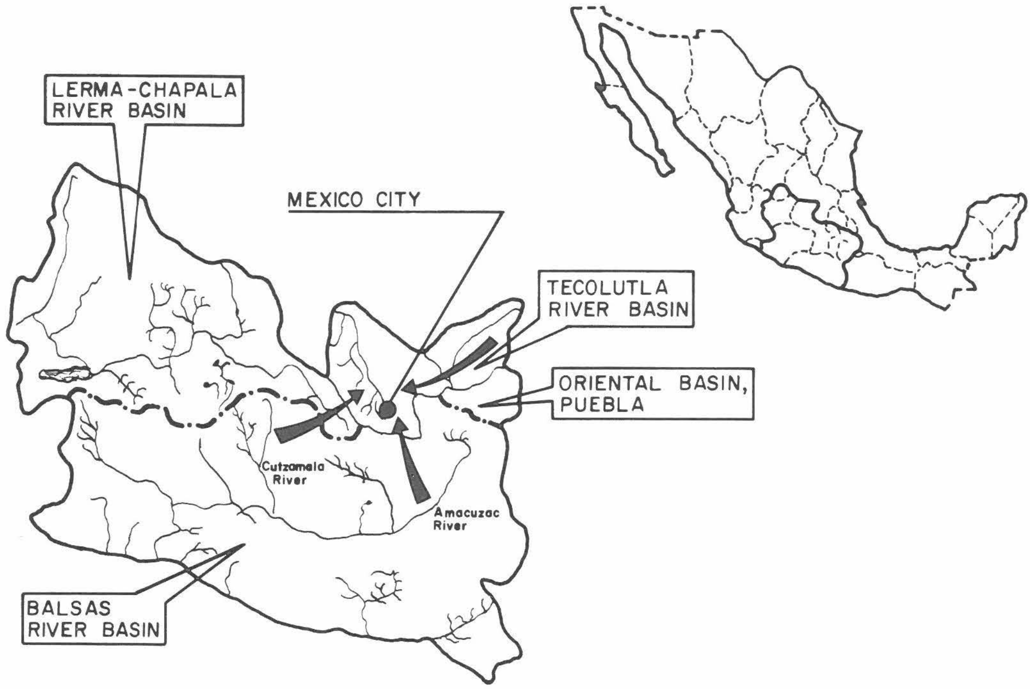

Fig. 7. Water transfer projects to the Valley of Mexico.

from the Lerma watershed, shown in Fig. 7, was begun. These aquifers are located about 70 km from the capital, and it was thought that this was the long range solution. However, now there are mining problems.

The water supply to Mexico City increased from 0.8 to 42 m^3/sec between 1900 and 1977. It is estimated that by 1980 the hydrological potential of the Mexico Valley watershed will have been used to its maximum.

The federal government is treating the problem of water supply to the Mexico City Metropolitan area through the Water Commission of the Valley of Mexico (WCVM), an agency created fundamentally with the idea of delivering the necessary volumes of water which are distributed in the corresponding networks by the municipal authorities. The programs of the WCVM will solve this problem up until 1979 by using the resources of the Mexico Valley watershed. It is estimated that by the year 2000 the water supply system will provide 109 m^3/sec – including the reuse of 5 m^3/sec – to about 30 million people in Mexico City. Until now, four alternatives have been identified: the Cutzamala River, the Tecolutla River, the Amacuzac River, and the closed watershed of Oriental, as can be seen in Fig. 7.

The WCVM has carried out technical–economic studies in order to analyze and evaluate the different alternatives. Until now, it has been demonstrated that the Cutzamala River is the alternative with minimum cost, even taking into consideration the consequences these transfers have in the agricultural and hydropower uses downstream from the places from which the water is physically to be transferred.

During the year 1976 the National Water Plan Commission carried out the Mexico State Water Plan project; a large part of the Cutzamala River watershed is located in this state. In this plan a study was made of the hydraulic feasibility of carrying out the water transfers of the Cutzamala River watershed, using a digital simulation model, which reproduces the behavior of the considered storages and considers different operational policies of these storages. The result of the analysis shows that it is feasible to transfer 19 m^3/sec in the first stage of this watershed with the existing hydraulic infrastructure, giving first priority to water supply for Mexico City. This implies a 46% reduction in the new agricultural project areas and a very important decrease in the hydropower potential in the plants which use the water to be transferred. It is estimated that, if carried out the transfer of 19 m^3/sec, the mean annual generation of all the affected plants would be reduced by 25%, which corresponds to 1500 GWh/yr.

Given the high opportunity cost of each m^3 of water for the metropolitan area of Mexico City, it is considered that the water allocation policy of this watershed should be for this purpose by means of water transfers and not for agricultural ends, since there are other possibilities for developing agriculture in the region, such as the technication of the rain-fed areas and irrigation with groundwater.

At present, the Water Commission of the Valley of Mexico is studying the evaluations which correspond to the second stage of the Cutzamala River watershed and to the Tecolutla, Amacuzac and Oriental alternatives in hopes of programming over a longer period the best solution to the problem of municipal water supply to the metropolitan area of Mexico City. Schemes for the future consider a strong component of water reuse and the improvement of efficiency in its use. However, all of the alternatives solutions require large investments and enormous quantities of energy for operation.

CONCLUSIONS

Large interregional water transfers must be tied to master water planning and to national global planning in a country. The main reasons to arrive to this kind of solution is the uneven and non-coincident distribution of water resources, soil, population and regional development.

In Mexico, the first national priority of food self-sufficiency will probably call for large water transfers in the northwest to take advantage of potentially productive arid land. The application of classical project evaluation criteria pose the problem of using unstable prices for agricultural products. Also, interregional water transfers imply the use of significant amounts of energy and, given the rising cost of this input, it will be harder to justify economically those projects in the future. A fresh look at existing methodologies and possibly formulation of new ones, is necessary so that projects that help to achieve national goals can be rationally scheduled.

On the other hand, the accelerated population growth and migration will make it necessary to devote large investments for the water supply of Mexico City. Greater efficiency in the use of present supply is urgent, as well as measures to reach a decentralized and better balanced regional development.

Since interregional water transfers usually involve several political entities within a country, watershed organizations are needed to achieve an effective water management that take into account political conflicts among the states covered by the hydrological regions. Also a central planning and management body is necessary to make sure that water development in fact helps to achieve national objectives and balanced regional development.

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Interregional Water Transfers: Case Study on India

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India is the seventh largest country in the world. Its territory extends over an area of 3,327,520 km^2 and the population is 618 million. Agriculture is the predominant occupation of the people and more than 70% of the people are engaged in agriculture. Agriculture contributes more than 50% to the gross national product. Successful agriculture in most parts of the country is not possible without irrigation or the artificial application of water to land. This is because of the peculiar climate that India and most parts of South Asia experience. The bulk of the rainfall precipitates in the monsoon months from June to September. Even during these months the rainfall in some places is more than is required by the crops but in other places is deficient even for the cultivation of ordinary dry crops. Also during the 'monsoon' months, sometimes the gap between two precipitations is so large that it affects the plant growth. Pressure on land is quite high and therefore, there is greater need for irrigation. Provision of irrigation affects the environment and life in a big way. To appreciate the problem of India, it may be helpful to recollect in brief, the geography and climate of the Asian continent.

Asia covers about one-third of the earth's surface but has nearly two-thirds of its population. The continent incorporates many different kinds of topography. The central areas are made up of plateaus and high mountain ranges. Great deserts extend in a wide strip from the ever-warm deserts of the Arabian peninsula northeastwards to the Gobi in Mongolia, where the winters are very cold. These desert areas are mostly inhabited by nomads who, like their counterparts in Africa, wander in search of water and pasture for their livestock. Northern Asia has extensive areas of tundra and coniferous forests. Further south, there is a steppe zone of grasslands and in the very south lies the hot and rainy equatorial zone with its steaming jungles. This part of Asia figures largely among the water-deficit areas of the world. Thus, rainfall is not sufficient for the type of vegetation which temperature conditions permit. This applies to the entire western part of southern Asia. India and Indonesia are the only places with a water surplus.

Apart from its mountainous areas, southern Asia has a hot climate all the year round. The year is divided into a rainy season and a dry season. The rains last from June till October, with daily cloudbursts in some places. Cherrapunji, in the north of India, receives more than 10,000 mm (10 m) of rain every year. The regular alternation of rainy and dry periods is connected with the monsoon winds, which are the main factor governing the climate of Asia. During winter, a dry, cold wind blows from Central Asia towards the southern and eastern parts of the continent whereas in summer, the wind blows in the opposite direction, carrying moist, rain-laden air over the land areas. The reverse applies in southwest Asia where the summers are long and hot and the winters mild. In some areas winter is the rainy part of the year, during which crops can be cultivated without irrigation.

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Most of the rivers of Asia rise in the mountain areas of Central Asia, whence they radiate – the Ob, Yenisey and Lena northwards to the Arctic Ocean; the Indus, Ganges, Brahmaputra and Mekong sourthwards; the Yangtse-Kiang and Yellow River eastwards. Millions and millions of people inhabit the warm, fertile valleys of these rivers. Needless to say, climate has a crucial effect on people's living conditions.

India is a continent in its own right, larger than western Europe. The country is a union of 22 federated States and nine centrally governed territories. It has the same disparity of languages, ethnic groups, religions and geographical subdivisions as Europe. The population of India is growing by about 14 million every year. Fifty five per cent of the total area of the country is cultivable, and agriculture accounts for half the national income. Climate, geology, topography, soil conditions and vegetation all vary a great deal; India has lofty mountain ranges, undulating hills, high plateaus, and rolling plains. Savannah and steppe are the natural vegetation of large areas of the peninsula.

South Asia derives the greater part of its precipitation from the southwest monsoon, which blows from the Indian Ocean. This monsoon is made up of two moisture currents. One, coming from the Arabian Sea, strikes the mountain ridge of the Western Ghats along the west coast of India, discharging large amounts of rain in the process. The other comes in over the Bay of Bengal, where it veers northwest and becomes a southeast air current sweeping over the lowlands of northern India. Both these air currents carry large quantities of moisture but they discharge only 20% of their moisture content on India. Spread out over the entire area of the country, this is equivalent to an average annual precipitation of 1100 mm, making 3700 km^3 in all. About a third of this precipitation evaporates and about 1700 km^3 returns to the sea through the rivers. It is estimated that the remaining 20%, or 790 km^3, seep into the ground and recharge deep-seated groundwater reservoirs. Of this amount, 270 km^3 are thought to be available. The densely populated valleys of the Ganges and Brahmaputra are particularly well endowed with groundwater. Central India is a primary plateau of rocks similar to those underlying large areas of Sweden and Finland. This rock is usually well-fissured, especially in the uppermost 30 m.

India's precipitation is unevenly distributed. In the eastern parts of the Himalayas and along the mountain range of the west coast it amounts to 4000 mm/yr. In the east of the country, local precipitation can be as much as 10 m/yr in parts of Assam. Central and southern India, on the other hand, lie in the rain shadow of the Ghats and receive less than 600 mm/yr, which is roughly the same precipitation rate as southeast Sweden. The driest areas are the northwestern States of Rajasthan, with its Thar desert, and Gujarat, north of Bombay, where precipitation is less than 100 mm/yr. Ninety per cent of India's rainfall falls during the short rainy season between June and September.

The rivers drain the entire area of the country, except for the desert area of Rajasthan, and for the most part run east and west. The following is a summary of India's annual resources of river water:

	km^3
Ganges–Brahmaputra	876
Indus (eastern tributaries)	40
Eastward flowing rivers in the Indian subcontinent (Mahanadi, Godavari, Krishna, Cauvery etc.)	414
Westward flowing rivers in the Indian subcontinent (Tapi, Narmada etc.)	308
Total	1638

It is stressed that these figures are not reliable because it is only recently that gauging has been undertaken on any considerable scale. There are two kinds of river: snow-fed, giving rise to perennial floods in the north and northwest, and monsoon-fed, associated with intermittent floods in central and southern India, where rivers regularly dry up during the dry season.

On account of its tropical climate, the irregularity of the monsoons and their limitation to a few months of the year, India is greatly dependent on irrigation for stable and successful agriculture. Without irrigation, farming in India would be a gamble with the forces of nature. The great plains of the Indus, Ganges and Brahmaputra have been farmed for at least 6000 years. Irrigation is also a very ancient science and there are many remains of prehistoric constructions. Some installations from historic but remote times are still in use today. Irrigation received a stimulus in the mid-19th century, but the partition of the subcontinent in 1947 gave most of the irrigated areas to West Pakistan. India acquired land areas where rainfall was highly capricious. The total irrigated acreage at that time amounted to some 20 million ha equalling about 20% of the cultivable area. A massive development programme was launched which gave top priority to the development of water resources. The irrigation acreage in 1947 has now been at least doubled. Altogether, 22 million ha are now provided with large or medium size irrigation works and an equally large area provided with small-scale works.

DEVELOPMENT TO DATE

As already mentioned, at the time of Independence in 1947, India had an irrigation facility of 20 million ha. Since then during the last 30 years more than 500 major and medium irrigation projects have been taken up and nearly three-fifths of them have been completed so far. Quite a few are in the process of completion and have already started giving benefits. Even so, the development of irrigation to date is roughly of the order of half the total irrigation potential estimated for the country.

Even the very process of estimating total irrigation potential of the country is still in a very preliminary stage. Most of the work is based on paper studies and assessments. Detailed investigations and preparation of basin plans are yet to be undertaken. However, one thing is clear from the studies carried out so far, that the water resources of India are distributed geographically in a very uneven way. There is plenty of water in the northeastern parts of India and the Gangetic plains during the monsoon months and the southwest coast. In contrast to this, the northwest part of India is practically dry – in fact it is a desert (Rajasthan Desert). A good part of Central India and the Deccan Plateau also suffer from serious shortages of water every year. One very rough estimate suggests that one-third of India has more water than it needs and one-third suffers from serious shortage. In the final one-third, the water is more or less sufficient, but even here in many years, because of the uneven distribution of rainfall, there is crop failure and consequent sufferings.

The best and the surest way of harnessing the water resources of India is, therefore, to store the monsoon flows in reservoirs and utilize them for stabilizing the *kharif* irrigation, and to extend irrigation in the *rabi* season to the extent that the flow and the storages permit.

In spite of the massive efforts undertaken so far, the total quantum of storage built in India till 1976 can be placed at 160 million acre-ft. The table below indicates some of the principal storages – existing and under construction – in India.

This, as compared to the average annual flow of 1500 million acre-ft is hardly adequate to have effective control and optimum utilization. One basic difficulty in this regard is the

River system/storage site	Live storage	
	million m^3	million acre-ft
Storages of more than 2500 million m^3		
1. Bhakra	7450	6.04
2. Pong	6970	5.65
3. Rihand	8980	7.28
4. Gandhisagar	6900	5.60
5. Hirakud	5830	4.73
6. Nagarjunasagar	7730	6.27
7. Pochampad	3170	2.57
8. Ukai	7100	5.76
9. Srisailam	5090	4.13
10. Sharavathi	6540	5.30
11. Koyna	2690	2.18
12. Tungabhadra	3710	3.01
13. Mettur	2660	2.16
14. Balimela	2840	2.30
Storages between 1250 m^3 and 2500 million m^3		
1. Bhadra	1790	1.45
2. Kadana	1220	0.99
3. Rana Pratapsagar	1590	1.29
4. Mahi Bajajsagar	2010	1.63
5. Hidkal (Ghataprabha)	1420	1.15
6. Krishnarajasagar	1250	1.01
7. Jayakwadi	2070	1.68
8. Bhima	1700	1.38
9. Tawa	2100	1.70
10. Iddiki	1470	1.19
11. Maithon	1360	1.10
12. Panchet	1330	1.08
13. Ram Ganga	2210	1.79

lack of suitable storage sites on the Ganges and the Brahmaputra. Also the southwestern coast has very limited storage potential. It is in this context that the need for long distance water transfer, including storage at other sites, becomes relevant and important to India's future proposals for water resources development.

Long distance mass transfer of water has been practiced in India for over 5 centuries. The Western Jamuna Canal and the Agra Canal, built in Mughal times, are examples where water was carried from the Himalayas to the distant parts of Punjab, Uttar Pradesh and Rajasthan. In the last century, the waters of west-flowing rivers in Kerala in the southwestern part of our country were diverted to the eastern dry plateau. In the middle of the 19th century, large-scale canal construction was undertaken from the Ganges, the Godavari and the Krishna to transport water across numerous streams and valleys for extending irrigation benefits.

Compared to the present activity of mass transfer of water, these attempts of the previous century pale into insignificance. To quote a few examples – the Rajasthan Canal Project, which is now under construction in northeast India, will provide irrigation for more than 3 million acres. The water is transported all the way from the Himalayas to the deserts of Rajasthan through a series of storages, diversion barrages and canal systems. Lands which were once barren, infertile and sand-dunes are now humming with activity, with green pastures, verdent forests and teeming populations. One has only to visit some of the villages and towns on the banks of these canals to witness the transformation that has taken place in this part of the world with the mass transfer of water from the Himalayas. One of the earliest projects was the Ganga Canal in the Bikaner district of Rajasthan built in 1927. It irrigates over 600,000 acres and has transformed what was once a desert into a prosperous district.

The Rajasthan Canal Project, estimated to cost over 5000 million rupees, comprises the construction of a huge multipurpose project across the Beas River at Pong, a barrage at Harike and a grand canal system. The feeder canal from the barrage up to Rajasthan border runs for 178 km and carries a discharge of 18,500 cusecs. The Rajasthan Canal is 469 km long with numerous branches and distributaries.

The Pong Dam is now complete and more than 4 million acre-ft of water is stored behind it. The Rajasthan Canal System is also more than half complete, with work going on at full speed on the rest of the system. Today the investment on this project is of the order of 300 million rupees and each year an area of 200,000 ha is being added to the irrigation potential.

Another notable achievement of the present times is the Sarda Sahayak Project in Uttar Pradesh in north India. This project envisages transport of water from the Ghagra River to the plains of the Ganges over an area of 6 million ha. The project comprises construction of two barrages, a link channel to transport 17,000 cusecs and a feeder canal 260 km long to deliver supplies to various existing channels. It also envisages remodelling and improvement of the existing canal system to provide adequate and efficient water conveyance. The cost of the project is estimated at over 2000 million rupees and on completion will provide irrigation to 4 million acres. To date, 80% of the work is complete and already more than a million acres are receiving irrigation benefits.

Another equally important major project is the Ram Ganga in Uttar Pradesh. Here again, the waters of the Ram Ganga, a tributary of the Ganges, are being stored in the Ram Ganga Dam and transported south to various districts for assured irrigation to over 1.5 million acres. This project is almost complete.

Many other big projects completed in recent years also envisage large-scale mass transfer of water. The Bhakra–Nangal, the Nagarjunasagar and the Tungabhadra are giant schemes, irrigating 4 million, 2 million and 1 million acres, respectively. Volumes can be written about these projects and their effect on the environment and people in the area benefitted by these projects.

The long distance mass transfer of water definitely has an influence on the environment of a place. Mention in this connection may be made of the improvement in salinity in the Godavari and Krishna Deltas as a result of the introduction of irrigation through large canals flowing over long distances. But for the introduction of irrigation, a good part of these deltas would still be affected by high salinity and a high incidence of malaria and other pestilence.

LONG DISTANCE TRANSFER – THE FUTURE PERSPECTIVE

Notwithstanding the massive development of irrigation that has taken place during the last 30 years since independence, the Government of India and the State Governments are now engaged in planning and investigating a large number of schemes for mass transfer of water. For, it is obvious that unless such mass transfer is carried out, there is little opportunity of providing even the basic facilities of a single crop and drinking water in most parts of the country. It is a common feature every year to hear stories of large-scale water shortages even for drinking and the subsequent mass movement of population and cattle. The planning for irrigation development has, perforce, to take into account this essential feature of the Indian topography and climate and so the schemes now under contemplation visualize large-scale mass transfer of water from one part of the country to another. Some important schemes are briefly described below.

Godavari–Krishna–Pennar link

The Godavari River, the largest river in the Indian peninsula, according to preliminary studies, has a surplus of water, whereas the Krishna and the Pennar Basins as compared to the Godavari, have more land potential than water. The Pennar, in particular, has a serious shortage of water in its basin. Schemes for transporting water from the Godavari to the Krishna and the Pennar have, therefore, been under investigation for more than 70 years now and various alternatives have been contemplated at different times. Just at about the time of Independence, a gigantic scheme was proposed by the then Madras Presidency for transporting water from the Godavari to the Krishna and from the Krishna to the Pennar up to the outskirts of Madras city. For various reasons this project did not see the light of the day at that time. Recently, however, in the sixties, an alternative of transporting nearly 10 million acre-ft of water was conceived. Some detailed investigative work has been done in this connection, but because of certain inter-state aspects involved in such a transfer of water, there has been some delay in its implementation. At present, a more limited scheme to benefit the areas within a State from the mass transfer of water are now being formulated. Transfer of water within the State from the surplus areas to the deficit areas is envisaged. The Godavari waters are for irrigation and to meet drinking and industrial needs of the steel complex at Visakhapatnam. Parts of the water will also be transported southwards to augment the flows in the Krishna and from the Krishna to the Pennar basin.

Almost the entire Pennar basin in Andhra Pradesh is drought-prone. The irrigation and drinking water requirements of this area can be met – topography permits it – by the diversion of the Godavari and Krishna waters to this area. The proposals now under consideration envisage such a diversion, but the finalization of the scheme will depend on the final award of the Godavari Tribunal which has yet to pronounce its judgement. In the case of the Krishna, the Krishna Tribunal has already given its verdict and therefore there should be no difficulty in taking some of the surplus flows in the Krishna to the deficit areas in the Pennar basin by cutting across the ridge and by extending canals. Detailed investigations are now in progress for this scheme.

The Narmada High Level Canal

Another major proposal for mass transfer of water is the Narmada High Level Canal Scheme of Gujarat State. In this scheme, the construction of a high dam at Navagaun in Gujarat is proposed. Leading from this dam a high level canal will be built crossing numerous rivers and streams and extending into North Gujarat and the desert areas of Kutch. Parts of Rajasthan can also be benefitted by this canal. The scheme, as formulated by the Gujarat Government, envisages a canal of 15,000 cusecs capacity, 600 miles long and benefitting 5.7 million acres. In this case also there is an inter-state dispute between the Gujarat State and the other basin States of Madhya Pradesh and Maharashtra. A Tribunal has been in session examining this matter and a decision is expected soon. The implementation of the scheme has, therefore, to await the verdict of this Tribunal.

The Scheme formulated by the Gujarat Government will completely change the face of the scarcity areas of North Gujarat and the saline areas of the Rann of Kutch. This is an instance where the environment will be completely transformed with the introduction of water by mass transfer from the Narmada river over a long distance.

Preliminary estimates have placed the cost of the scheme at over 6000 million rupees. The correct figure can be worked out only at the time of implementing the scheme, as the cost of materials and labour have been fluctuating from time to time.

West-flowing rivers

Another major possibility that exists in India for large-scale mass transfer of water from one area to another, is the diversion of the west-flowing rivers to the east to provide irrigation facilities in the drought-prone areas of Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu.

As indicated earlier, the west coast has a surfeit of rainfall and river flow. The land area that can be benefitted from this river flow is limited and even assuming that the entire land in this stretch will be provided with high intensity of irrigation, there is, according to indications, surplus water available. What is required is a careful assessment, field investigations and finalization of schemes for the conservation and transfer of the surplus waters to the eastern side of the Western Ghats to meet the irrigation and drinking water requirements there. It is in this connection that studies are in progress at various levels. According to some rough indications, more than 200 million acre-ft of water are now going waste into the Arabian Sea and even if a small part of it is harnessed this way, it will provide tremendous relief to the drought areas in Tamil Nadu and other States.

The Ganges lift schemes

While the plains north of the Ganges are blessed with numerous tributaries and good groundwater aquifers, the southern portion of the Ganges basin, south of the Ganges, consists mostly of broken land mass, criss-crossed by numerous streams which are not often perennial. There is great scarcity and shortage of water and parts of this area are often prone to drought. A number of dams, mostly medium and small, have been built, but the total effect of all these on the people and the land has not been appreciable. Schemes are, therefore, being formulated to provide irrigation facilities in the southern half of the Ganges basin in a big way, by lifting water from the Ganges and the Yamuna and providing direct irrigation in as large a part of the area as possible. It is also proposed to store a part of the lifted waters where feasible and then extend irrigation. This appears to be the only way of solving the problem of this drought-prone area. While most of the earlier schemes were confined either to small storages or to low lifts, the present thinking is on high head, large-scale lifting of water and storage. It also envisages interlinking of numerous tributaries of the Ganges through canal systems. Preliminary studies have indicated that there are very good possibilities for such lift schemes and detailed investigations are being organized for this purpose.

Brahmaputra–Ganges Link

The Brahmaputra carries very large flows not only during the monsoon season but also in fair weather. Recurring floods of this river cause great loss of life and property both in India and in Bangladesh. Therefore, the possibilities of control and development of the Brahmaputra are currently under consideration. The Brahmaputra rises two months ahead of the Ganges and a Brahmaputra–Ganges Link, supplemented by storages, could enable integrated development, and would enable flood control, power generation and optimum utilization of the water resources of the lower Ganges–Brahmaputra region for the benefit of the two countries. It is hoped that studies on these possibilities may start in the near future in co-operation with Bangladesh.

The Rajasthan Desert

As already mentioned, part of the Rajasthan Desert is deriving a great benefit by the mass transfer of water through the Rajasthan Canal, the Gang Canal and other irrigation projects which are already complete or nearing completion. However, schemes are still under formulation in respect of quite a few other major projects. Mention may be made in this connection, of the storage scheme on the Yamuna whereby the flood waters of the Yamuna are stored at a place near Kishau and the water transported to the deserts of Haryana and Rajasthan. Proposals are also under consideration for building storages on the tributaries. A preliminary paper scheme has also been formulated for transporting some water from the Chambal River to the northwest parts of Rajasthan through both lift and long distance carrier system. These and many other proposals are still being investigated.

In this connection, mention may be made that the Central Government, realizing the importance of mass transfer of water for development and a better environment, have recently constituted a new Investigation Unit in the Central Water Commission. A full-time Chief Engineer has been appointed with necessary field staff and technical supporting staff at headquarters to prepare a number of feasibility studies for long distance mass transfer of water. In fact, India can take a justifiable pride in having made an earnest effort in national water planning and in the coming decade or two it is hoped that a number of these mass transfer schemes will fructify and change the human environment in many parts of the country.

CONCLUSION

With the advance in science and technology the world over and the refinement in the techniques of high head pumping and tunnelling, the dream of taking water over long distance for the benefit of man no longer remains a vision. Large-scale mass transfer of water has become a reality. Keeping in view that nearly one-third of the country is drought-prone, such transfer of water will definitely usher in a new era of better environment for the people in these drought-prone areas and also lead to a change in the ecology of these places. It is a fact that with the introduction of irrigation, the vegetation, the fauna and the flora change, thereby altering the ecology of the place. Such improvements have added advantages of a chain reaction in many spheres which lead to a more prosperous life for the people of the area. The economics of long distance transfer of water has to be viewed in this context and also the appreciable savings in millions of rupees that are spent at present on relief in drought affected areas.

The mass transfer of water is one major answer to the two faces of water – floods and droughts – in India and in the rest of the world. An earnest endeavour in understanding the implications and improvements in the technology of such transfer would be of great benefit to the people of India and to mankind as a whole.