PART II: Problems of Interregional Water Transfers

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Economic Issues Related to Large-scale Water Transfers in the USA

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I. EXISTING AND PROPOSED TRANSFERS

The distribution of precipitation in the United States is quite uneven. In very crude terms, the eastern half of the country (east of 100° west latitude) is well watered while the western half is dry. It is not surprising then, that water quality problems predominate in the East while water quantity problems predominate in the West. The greatest interest in interregional transfers has therefore been in the West. However, large metropolitan concentrations of population often demand more water than can be found in their immediate drainage basins, so transfers have been undertaken to large cities even in the East.

New York City developed one of the earliest systems, starting with staged development of the Croton River, a distance averaging 250 km, over the period 1842–1904. The Catskill system, averaging 400 km in distance, was built over the period 1915–1924. Together, these two systems provide about 1.21×10^9 m^3/yr. In 1936, development of the Delaware River, which is shared with the States of Delaware and Pennsylvania, was begun, culminating in a system of large reservoirs and aqueducts with a safe yield of 1.3×10^9 m^3/yr.

Conflicts of interest accompanied the Delaware development. The State of Delaware tried to prevent New York City from transferring water, even though the Delaware River rises in New York State, then flowing into the State of Delaware. A decree of the Supreme Court permitting the city to divert water while requiring the city to meet minimum releases from its reservoir system was required to settle the argument.

The prolonged drought of 1961–1966 caused the estimated "safe yield" of the entire New York system to be reduced from 2.46×10^9 m^3/yr to 2.0×10^9 m^3/yr. An interesting feature of the New York City system is that the Hudson River which flows through the City has not been used for water supply, even though the Croton and Catskill units are in the upper Hudson River drainage. Economists have argued that water from the Hudson could have been developed at a fraction of the cost of the Delaware system. The City's Department of Water Supply has counter-argued that pure sources of supply justified the additional cost.

In the West, the State of California exhibited the earliest large interregional transfer and has recently completed the largest one. The City of Los Angeles built the Los Angeles Aqueduct in 1913 to bring water from Owens Valley on the eastern side of the Sierra Nevada Mountains, a distance of 300 km. This aqueduct was extended on to Mono Lake, a distance of 500 km for a total yield of 580×10^6 m^3/yr. Severe controversy surrounded the Owens Valley development, for the valley residents didn't want to give up the agriculture based on the water. The City finally bought the lands of the valley, but some parties continued to resist the building of the aqueduct.

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Continued growth of the Los Angeles area led in 1928 to the construction of the 400 km Colorado River aqueduct to tap California's share of that river. This aqueduct currently delivers 1.5 × 10^9 m^3/yr to the south coastal area. Some of this water is used to recharge coastal aquifers from which much pumping takes place.

The US Bureau of Reclamation in 1935 started the Central Valley Project (California) to capture and transfer mountain waters from Northern California to points along the San Joaquin Valley with distances up to 600 km, delivering 3.4 × 10^9 m^3/yr. This system has been supplemented by the State Water Project along similar lines, capturing Feather River water in the north and transporting, in total, 5.2 × 10^9 m^3/yr to the San Joaquin Valley and the Los Angeles area. The 2.5 × 10^9 m^3/yr going to Los Angeles travels as much as 800 km and must be lifted 610 m over a range of mountains.

The severe drought affecting Northern California in 1975–1977 has affected the yield of this system severely, and Los Angeles received no water from the State Water Project during part of the summer of 1977. The State Water Project has been severely criticized by environmental interests for damming the scenic Feather River and by others for the high cost of the project.

Smaller transfers are found in other parts of the West, but among the larger and more important is the Colorado–Big Thompson project which transfers water about 80 km across the Rocky Mountains to eastern Colorado for irrigation and municipal use. While this system transfers only 370 × 10^6 m^3/yr, it has provided a vital supply for a rapidly growing region of Colorado. The institutional arrangements for distributing the water and for allowing transferability of the water among uses, are nearly unique in the US and will be described in Section II.

Discussions of new large-scale transfers for the western United States reached a peak in 1967 or 1968. After that time, interest waned quickly, first because of the strong objections of the potential exporting basins, and later because of rapidly rising costs. Since the oil embargo of 1973 and the severe drought of 1976, interest has been somewhat revived. Some particular regional problems have also led to renewed interest.

The most actively debated interregional transfers during the mid–1960s were several plans for Columbia River Basin transfers. These transfers were designed to carry from 3 × 10^9 m^3/yr to 18 × 10^9 m^3/yr. Several of the plans called for taking water from the Lower Columbia River which had the effect of substituting higher pumping costs for greater instream opportunity costs of the water. Other plans called for taking the water from the tributary Snake River at higher elevations, saving on pumping costs but incurring greater foregone uses downstream; primarily foregone hydroelectric power. During the past two summers, it would have proven impossible to export water from the Snake River because of extreme drought in the Northwest (see Fig. 1).

The only active proposal involves the possibility of importing water into the high plains region of western Texas and eastern New Mexico, a region where a highly productive irrigated agriculture has been developed from the use of groundwater. The entire regional economy is dependent on the current high yields of agricultural commodities, but the groundwater is being exhausted. Only in recent years has there been any effective attempt to control the use of these non-renewable groundwaters – much too late in terms of an optimum strategy from a national point of view. This kind of water import situation has been referred to as a "rescue operation" because the region itself cannot afford the large water transfers necessary to maintain its economic base.

A potential source for the 6 × 10^9 m^3/yr which would replace current consumptive uses of groundwater, is the lower Mississippi River, probably by pumping the water up the Red

River Valley, involving a distance of some 1300 km and an attitude difference of 1200 m. Since no power recovery is possible, this route currently has prohibitive energy costs associated with it. A second route currently being discussed involves taking water from the State of Arkansas and transporting it through a system which the intervening state of Oklahoma would like to develop for similar purposes. The incremental distance in the length of the canal system could be as little as 500 km and the altitudes difference would be much less than the other route.

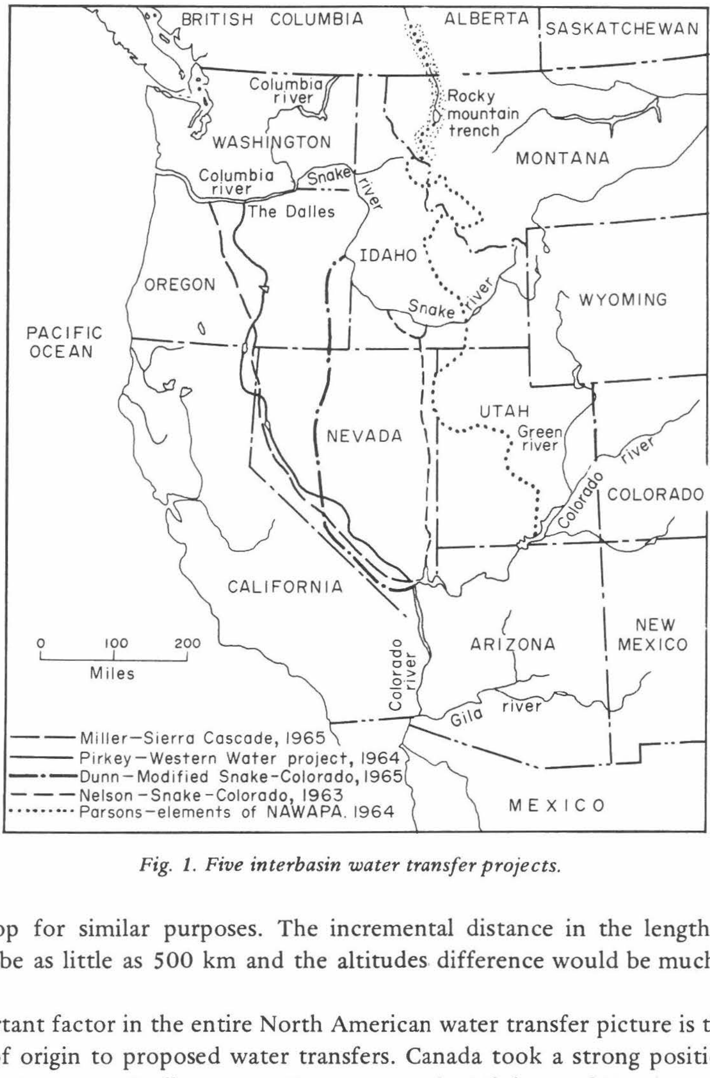

Fig. 1. Five interbasin water transfer projects.

An important factor in the entire North American water transfer picture is the opposition of the areas of origin to proposed water transfers. Canada took a strong position (e.g. statement of John H. Turner, Parliamentary Secretary to the Ministry of Northern Affairs in the mid–1960s) that Canadian water was for Canadian development, and only after the most careful studies of potential Canadian uses would Canada consider exporting water to the US. The states of the Northwest have solidly opposed exports from the Columbia River Basin, and their united political power was sufficient to prevent the various river basin commissions and even the National Water Commission (formed to study US water policy and problems) from considering or studying interregional transfers. Senator Jackson of Washington has stated:

> The people of the Northwest deeply believe that before any other region asks for a study of the diversion of the Columbia River, such region must first establish that it actually needs additional

> water ... What for? ... Can sufficient water be secured through conservation and reuse? ... How will the economy of the Northwest be affected if large quantities of water are taken away?

This opposition emphasizes not only the need for the studies called for by Senator Jackson, but the need to consider new institutional arrangements within the United States for managing these large transfers if they occur and for providing compensation to the areas of origin. Primary jurisdiction over water is held by the States. Distribution of the waters of interstate rivers has been decided by interstate compact (treaty) in the arid regions and generally remains undecided in the water plentiful regions. The River Basin Commissions which exist to coordinate planning *within* a major basin are expressly forbidden to consider transfers from outside their drainage areas. Only the Federal Bureau of Reclamation is in a position to consider transfers and to put together compensating programs for the areas of origin. However, compensation is limited to the construction of more water projects. This has proved to be a costly, inefficient way to provide regional compensation.

II. ECONOMIC BENEFIT ISSUES RELATED TO TRANSFERS

A. *Low benefits in agriculture*

The regions of the US where calls for imports of water are most frequently heard are characterized by arid climates and irrigated agriculture as the largest consumptive use. Examples would be the Lower Colorado River (especially Arizona and California) and the High Plains of western Texas and eastern New Mexico. While these areas are highly productive in physical terms and are partly devoted to speciality crops of high value, they also contain vast areas of low value crops, especially forage crops and low value feed grains. Net income per hectare often does not exceed \$100 per yr, i.e. as little as \$0.008 per m^3 of water applied. While multiplier effects might raise this value to \$0.016 per m^3 from the region's point of view, it is not sufficient to justify transfer costs of at least twice that amount.

The relevant comparison for evaluating transfers is between the lowest values in agriculture and the unit transfer costs, since water can almost always be transferred from the lower valued uses to speciality crops or even to industries and city use if those demands grow. An excellent reference, describing the economic structure of the arid Southwest and the value of water to agriculture there, is Kelso *et al.* (1973) who studied the effects of the falling groundwater table on the economy of the State of Arizona. They projected, using linear programming models, the likely reductions in cropped acres, consumptive water use, gross value of farm output and net farm income caused by increased pumping costs. Their findings nicely illustrate the low marginal value of water in agriculture in terms of regional income. Some relevant data are given in Table 1 below.

B. *Agricultural displacement effects*

During the period from 1950 to 1965 or somewhat later, US agriculture was faced with a continuing problem of surplus production. World markets were poorly organized, foreign aid for food purchase was not well established until later in that period, and domestic US demand was income and price inelastic. During this period, agricultural technology was rapidly advancing, raising productivity and lowering costs. As a result, farm prices were kept low and large surpluses accumulated in government hands. Under such conditions, in a market

Table 1. Projected declines in Arizona agriculture due to rising groundwater costs: 1966–2015

Cropped area (1000 ha)	119	28%
Water use (10^6 m^3)	1684	29%
Gross value farm output (millions of dollars)	37	13%
Net farm income (millions of dollars)	17	15%
Direct income loss per m^3 (dollars per m^3)	0.006	
Direct plus indirect income loss	0.007	

economy, the opening of new acreage either depresses prices further, driving existing farms out of business or causes government surpluses to increase or both.

The relationship of these observations to many proposed interbasin transfers is that many transfers are designed to provide irrigation water. If the newly irrigated lands are to be profitable to the farmers when crops nationally are already in surplus, it may be necessary (as it was in the US) to charge much less for imported water than its true cost, for when the new lands come into production, they will lower prices. This can have the effect of driving equivalent acreage out of production elsewhere. These effects for the US during 1944–1964 are documented in Howe and Easter (1971). Planners must be aware of the possibility of these problems in the future, even though world market conditions have changed.

C. *Efficiency of use of transferred waters*

Transfers are usually planned into growing regions whose economies are changing rapidly. In market economies, it may be difficult to predict the future structure of the region's economy, e.g. which industries will be there, what the urban population will be, etc. It is therefore important that the institutional arrangements made for the allocation of the imported water allow for changing priorities and water demand patterns over time.

The arrangements developed by a large water administration district in Colorado have been particularly innovative and efficient in this respect. The Northern Colorado Water Conservancy District was established to develop and distribute water in a 2300 square mile area of northeastern Colorado. While some local river flows were available for distribution, most of the water was to be provided by a new federal storage and diversion project, named the Colorado–Big Thompson project, which diverted water from the western slopes of the Rocky Mountains to the eastern slopes and plains. The amount of water handled annually is about 380×10^6 m^3.

Water allocations were originally made to landowners, municipalities, and industries in the District, irrigation being by far the largest user. The "shares" so distributed are freely saleable among parties located within the District, so permanent sales of water from less productive to more productive uses can take place.

Seasonal water "rentals" also take place. If a farmer finds that his allotment for the year is more than his planned crops or livestock will require or if high prices offered for the seasonable transfer of water make it attractive to reduce his applications, he can advertise through the District office that some of his water is available for sale for this year at whatever price he cares to ask. Farmers seeking additional water can then bargain with sellers of water, and a very smooth market process has developed. Seasonal rental prices of water sometimes reach \$25 per 10^3 m^3.

As a result of this ready market for water, water use is carefully planned by the farmers. Since there is no danger of losing one's permanent water rights by a sale of part of one's annual allotment, farmers prefer to sell the water if its value rises above the return they can obtain on their own farm. Economic efficiency of water use is very high.

D. *Benefits along the transfer route*

While most transfers are initially thought of in terms of an area of origin and a distant area of destination, it may turn out that investigations will uncover potentially beneficial uses along the transfer route which can be served at low marginal cost. It may also be politically necessary or advantageous to include some developments en route to secure the backing of the regions through which the transfer will pass.

In the US, some of the Columbia River—Colorado River transfers would have passed through semi-arid farmland where supplemental irrigation would have increased productivity. Whether benefits would have offset incremental system capital and operating costs was not investigated. Industrial projects may beneficially be expanded into multiple purpose projects, as with the Shashe Project in Botswana, which captures and transfers water about 80 km to a copper—nickel smelter complex, passing through arid areas in which severe village water supply problems exist. These problems might have been dealt with at low marginal cost by designing several small pipelines off the main trunk line.

E. *Secondary benefits*

In predicting the impacts which large projects will have on regional and national economies, the question of "secondary benefits" always arises. The most usual definition of secondary benefits is "benefits legitimately countable from a national viewpoint accruing to parties other than direct project beneficiaries". Two features of this definition should be emphasized for purposes of correct economic analysis: (1) that the benefits should be net additions from a national viewpoint and not simply a transfer from one region to another; (2) that they accrue initially to parties other than direct project beneficiaries. The first feature tells us, for example, that if a processing industry shifts to a riverside location because the river has become navigable, only the cost-savings it experiences can be counted as economic benefits, not the net value of its total output. The second feature reminds us that we must not double-count benefits which initially accrue to direct beneficiaries and are later passed on to others through the market or because of central direction to do so. Thus, if the cost of supplying water to Industry A is reduced by a transfer and if, as a result of this cost reduction, the unit price of the industry's output is reduced, one must not count *both* the initial cost reduction and the lowered price to Industry A's customers as benefits.*

The reason for raising this issue in our present discussions of interregional transfers is that the secondary benefit concept has been greatly abused by the water resource agencies in the United States as a way of overstating water project benefits. Practices have included

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* The details of the final incidence of the benefits are difficult to determine. Of course, allowance must be made for possible changes in Industry A's output rate made profitable by the cost change.

counting the gross output (sales) of project related enterprises (such as farm suppliers) and counting the outputs of existing industries which simply shift location because of minor cost advantages associated with being close to the water project.

However, interregional transfers are likely to be large projects relative to the size of the regional economy, so secondary benefits and costs must be analyzed, preferably from both national and regional points of view.

III. ECONOMIC COST ISSUES RELATED TO TRANSFERS

A. *Energy intensity and energy recovery*

Preliminary design studies of several Columbia River—Colorado River transfer systems and several routes for the transfers to West Texas have shown clearly that the amount of pumping which must be done and the amount of energy recovery which is possible are crucially important. From the Lower Columbia Basin, a lift of at least 1800 m would be necessary, but the water would be delivered to the Colorado River at an altitude of about 600 m so that a substantial amount of energy recovery through electric generation would be possible. Transfers from the Snake River would originate at a higher altitude reducing pumping requirements but increasing the opportunity cost of the water and reducing the reliability of the supply. Transfers from the Mississippi to West Texas involve the large attitude differences noted earlier with no possibility of power recovery. With energy costs at current levels, the latter transfer is grossly infeasible from economic and financial viewpoints.

B. *Water opportunity costs and other externalities*

These costs are frequently ignored in US water planning, largely because States' legal claims to water or the allocations under interstate compacts (treaties) are at variance with the criterion of economic efficiency. The major forms of opportunity cost are foregone irrigation uses, foregone power generation and deterioration of water quality because of reduced dilution. Reduced esthetic values and reduced sport fishing have occurred as a result of transmountain transfers to the Denver metropolitan area.

Increases in salinity concentrations reduce agricultural yields, impose additional costs on municipal and industrial systems, and at times severely impact coastal zone fisheries. The Gulf (of Mexico) Coast of the US has suffered reductions in important shrimp and oyster catches, and the west coast of Mexico has suffered major reductions in its shrimp fishery, both because of reduced fresh water flow.

IV. THE TIMING OF LARGE INTERREGIONAL TRANSFERS

Scale economies in all water transfer technologies and the low unit value of water imply that interregional transfers must be large to be economically feasible. Large increments to regional water supplies by definition imply that timing of the project is very important. Even with water demands in the receiving region growing, premature construction will mean unused capacity for long periods of time, while deferring construction to allow demand to grow closer to the transfer's designed capacity implies either the interim use of costly short term supplies or a delay in regional growth.

Three large transfers in North America, the Plan Hidraulico de Noroeste for the Costa de Hermosillo in northwest Mexico, the Mississippi–West Texas transfer and the Central Arizona Project in the US were intended as "rescue operations" – the provision of water to replace exhausted groundwater. In such a case, timing is crucial from the economic and possibly from a physical viewpoint.

In the Costa de Hermosillo, highly productive commercial agriculture had been established on water pumped from a large coastal aquifer. Pumping exceeds recharge by a wide margin and salt water intrusion from the Pacific Ocean is proceeding at a rate of over 1 km/yr. Several questions were raised:

(1) From a purely economic viewpoint, when (if at all) should an alternative supply be developed?

(2) Can the salt water intrusion be reversed in the future through artificial recharge and/or reduced pumping?

(3) What economic cost is worth incurring to avoid the possibility of irreversible loss of large parts of the aquifer?

Regarding the first, Ronald G. Cummings (1974) analyzed the economics of a large transfer of water up the West Coast to the Costa de Hermosillo. Through a large programming model linked to a digital model of the aquifer, he was able to show that very large quantities of water could still be economically mined from the aquifer, with the optimal rate of pumping gradually approaching the recharge rate over a 36-year period. The shadow price of water in the aquifer, giving its real scarcity value, was shown to equal the estimated unit cost of imported water only 29 years from now. Thus, from a purely economic point of view, construction should be delayed *many* years, saving many millions of dollars in terms of the present value of project costs. The results of one model run are given in Table 2 below.

Somewhat similar conditions are faced in the central part of Arizona, a rapidly growing region between the cities of Phoenix and Tucson. In this area irrigated agriculture has been quite important historically, but the growth is in light industry, commerce and services for the retirement communities. Groundwater is the main water source and, largely because of agricultural uses, the water table is falling from 3 to 6 ft/yr. In some places, pumping depths are over 600 ft (183 m). The aquifers are very deep and vast quantities of water remain available, but costs are increasing and surface subsidence has become a problem.

The Central Arizona Project, while not "interregional" is a major pumping project to lift 1.5×10^9 m^3/yr of water from the Colorado River to replace part of the groundwater being used by agriculture and municipalities. Given the continued availability of groundwater and a rather smooth market process of transferring groundwater stocks from agriculture to municipalities as the urban areas grow, the question of the optimum time of construction arises. Farmers seem unwilling to pay more than about \$0.008 per m^3 since they can pump water at that cost, and cities are reluctant to pay the price of \$0.04 per m^3 which has been proposed since they, too, can pump water from the lands into which they are expanding. Nonetheless, there is a long-term problem, the solution to which *should* have involved estimating optimum timing of the transfer.

V. FINANCING INTERREGIONAL TRANSFERS

The main point to be made here is that inefficient large-scale water projects are much less likely to be undertaken if public financial policy calls for the direct and secondary beneficiaries to pay a major portion of the construction, operating and maintenance costs. With the

Table 2. Optimum use of groundwater: Costa de Hermosillo

Year	Annual rate of pumping (million m^3)	Groundwater storage at the beginning of of year (million m^3)	Increase in storage attributable to pump relocation (million m^3)	Shadow value of water not discounted) (dollars/m^3)	Increase in saltwater intrusion (km)
1	1,219.1	22,253.0	1,989.6	0.0008	0.96
2	1,219.1	23,023.6	795.3	0.0035	0.96
3	1,219.1	22,234.0	828.1	0.0038	0.96
4	1,219.1	21,412.0	829.4	0.0042	0.96
5	1,219.1	20,588.7	829.5	0.0046	0.96
6	1,219.1	19,765.3	829.5	0.0051	0.96
7	1,219.1	18,941.9	829.5	0.0054	0.96
8	1,219.1	18,118.5	829.5	0.0060	0.96
9	1,206.3	17,295.1	143.3	0.0067	0.95
10	1,206.3	17,834.8		0.0074	0.95
11	1,206.3	16,941.7		0.0080	0.95
12	1,206.3	16,048.6		0.0089	1.7
13	1,206.3	15,091.2		0.0096	1.7
14	1,218.6	13,976.3		0.0109	1.7
15	1,202.2	12,806.5		0.0118	1.7
16	1,126.5	11,638.3		0.0122	1.4
17	1,048.7	10,546.3		0.0124	1.4
18	978.5	9,552.7		0.0134	1.3
19	915.3	8,656.0		0.0138	1.3
20	865.1	7,848.5		0.0141	1.0
21	796.5	7,115.5		0.0156	0.9
22	756.7	6,471.1		0.0173	0.9
23	603.5	5,890.4		0.0175	0.5
24	555.3	5,480.2		0.0178	0.4
25	552.5	5,164.1		0.0184	0.4
26	527.0	4,876.2		0.0188	0.4
27	524.6	4,621.5		0.0192	0.4
28	512.5	4,378.2		0.0203	0.3
29	510.3	4,150.0		0.0224	0.3
30	508.1	3,928.0		0.0246	0.3
31	506.0	3,709.9		0.0272	0.3
32	503.9	3,495.1		0.0296	0.3
33	501.8	3,283.1		0.0320	0.3
34	500.0	3,074.1		0.0360	0.3
35	497.7	2,868.0		0.0360	0.3
36	350.0	2,644.5		0.0400	0.3

Source: Cummings, 1974, p. 98.

early US transfers like the New York City system, financing was completely done by the water utility itself through bonds which were paid off through volume charges to water users. As the federal government has come to dominate the planning and funding of large water projects, the degree of subsidy has grown greatly. This has served to make inefficient projects look desirable to local interest groups who then attempt to rally political support for their favorite projects. A solid policy of full cost recovery on transfer projects will be of great assistance in guarding against inefficient projects.

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Some Theoretical and Measurement Issues in Economic Assessment of Interbasin Water Transfers

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1. INTRODUCTION

With the tremendous increases – of an order of magnitude or more – in size and cost of recently proposed interbasin water transfers (IWT's) over those of existing projects, careful consideration of their economics takes on new importance. In this paper I offer some critical remarks about concepts and measurement techniques in assessing the costs and benefits of IWT's. I say critical, because I think that is what is needed, but I hope to provide some constructive suggestions as well. Also, I want to acknowledge, right at the outset, that I speak as a relative outsider, one not familiar with much of the work in the field. This has obvious drawbacks, but perhaps, in view of the ample expertise represented at this Conference, it may be useful to hear a fresh voice.

The remarks will fall into three categories: methods of measuring conventional economic costs and benefits, introduction of environmental effects, and special problems posed by the very long-lasting and uncertain consequences – including those to the environment – of IWT projects. Not coincidentally, these categories are listed, and will be treated in the sections to follow, in order of decreasing specificity. That is, I hope to be specific and constructive about methods of measuring conventional benefits and costs. About the environment, I can be specific with respect to the problems but not very helpful with respect to solutions (though I do have one or two ideas), and about long-run uncertainty I fear I can indicate only in a rather vague way the nature of the problems this poses for economic assessment, and suggest some qualitative policy implications.

The current "best practice technology" for assessing the impact of an IWT on a region's economy (presumably positive for a region gaining water or transmitting it, negative for one losing, or competitive with the gaining region) is input–output (I–O) analysis. The critical part of my remarks in the next section will be to the effect that I–O, especially of the required regional variety, is not entirely adequate to address the concerns of decision makers about project impacts. It does represent an advance over a number of alternative, simpler methods of regional impact analysis, as I shall indicate. But, more constructively, I shall propose the use of an econometric modeling technique that can take account – as I–O does not – of both changes in the structure of the impacted region's economy, and the time periods required for these changes to work themselves out.

The environmental problem is simply that an IWT is virtually certain to have an impact – quite possibly adverse – on the environment that is not reflected even in the most sophisticated econometric analysis. In Section 3 below, I say a bit more about the nature of the impact and indicate how it can, in principle, be incorporated into the benefit–cost analysis. Prospects for achieving a common metric – say money units – are not especially

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encouraging. But the notion of *dominance*, described in Section 3, may offer a way, even without this, to comprehensively evaluate an IWT in comparison to some alternative for providing water.

The third set of problems, involving the very long time spans over which the effects of an IWT may be felt, and uncertainty about the nature of these effects, is still less tractable to conventional benefit–cost analysis. Long time spans raise questions about rates of discount, and transfers of resource endowments between generations. And there is no one accepted method for handling uncertainty, even in the short run. What I shall indicate, though, in Section 4, is that the interaction between uncertainty and irreversibility (of a project's effects) does have some rather sharp *qualitative* implications for policy. If it is known that the environmental effects of a project are irreversible, i.e. cannot be undone, except perhaps at prohibitive cost, and if it is possible over time to acquire information about the costs and benefits of the project, and its (reversible) alternatives, then there is some presumption in favor of deferring the project. This proposition is demonstrated with the aid of an example in Section 4. Unfortunately it is difficult, in the present state of our knowledge, to make any *quantitative* assessment of the "option value" of deferring.

2. MEASUREMENT OF REGIONAL ECONOMIC IMPACTS

Let us begin the discussion of measurement techniques by restating the basic benefit–cost relationships for an IWT, as presented in the important work of Howe and Easter.[1]

$$(\mathrm{DB}_M + \mathrm{SB}_M) + (\mathrm{DB}_T + \mathrm{SB}_T) > (\mathrm{DC}_X + \mathrm{SC}_X) + \mathrm{SC}_C + \mathrm{TC} \tag{1}$$

and

$$\mathrm{TC} + [(\mathrm{DC}_X + \mathrm{SC}_X) - (\mathrm{DB}_T + \mathrm{SB}_T)] < \mathrm{TC}_A, \tag{2}$$

where DB is the direct benefit from the water, DC the direct cost (of foregone water), SB and SC are secondary benefits and costs (to be described below), and TC is the cost of the physical transfer system. The subscripts are M = region importing water, X = region exporting, T = region through which water is transferred, and C = region whose output is competitive with M.

Inequality (1) then states that the direct and secondary benefits, to importing and transfer regions, must be greater than the direct and secondary costs, to exporting and competitive regions, plus the cost of the transfer facilities. Inequality (2) states that the cost of the transfer must be less than the cost of the best alternative, TC_A, for providing the water. All costs and benefits can be considered in present value terms (i.e. each cost or benefit term represents, where appropriate, a discounted sum). If an IWT meets both conditions (1) and (2), it is said to be economically *efficient*.

I propose to use these relationships as a framework for discussion of some specific measurement issues. In the remainder of this section I consider the measurement of the conventional economic direct and secondary benefits and costs. As noted in the introduction, the most advanced method, used in a number of studies described by Howe and Easter and also in their own work, is regional input–output (I–O) analysis. Below I briefly survey a range of alternative methods, and indicate the advantages and disadvantages of regional I–O.* Then I

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* For a much more complete review of methods of regional impact analysis, see Isard.[4]

propose still another alternative, a form of regional econometric analysis, that I feel holds the promise of avoiding the difficulties associated with the earlier methods.

Regional I–O and other methods of impact analysis

Typically, analyses of the economic impact on a region of some proposed policy or resource development project employ some variant of one of the following methods: projection of past trends, economic base multiplier analysis, or regional I–O.

Simple projection, or extrapolation of past trends of such economic variables as output and employment by sector, or of demographic variables such as the school-age population, clearly are not adequate to measure the impact of a major new development on the region experiencing it. This is particularly true if, as in the case of the newly proposed IWT's, the development is quite large relative to the current economic base. In this case we can be fairly certain that past trends will in fact be modified in some way.

Economic base multiplier methods offer some improvement over simple extrapolation. The multiplier methods divide economic activity in a region into two types: basic and non-basic. Basic activity produces output for export, and non-basic other goods and services. Account is taken of the proposed development by specifying, exogenously, a new level of basic employment. This might mean, for example, employment in agriculture in an area irrigated by water from an IWT. Total employment (basic plus non-basic) and population are then forecast on the basis of multipliers, the ratio of total to basic employment, for employment, and the ratio of population to basic employment for population. The problem, however, is that the multipliers are derived from the current level and composition of employment in the region. For the forecasts to be accurate, the multipliers must remain constant, and there is no reason to expect them to do this in the face of dynamic change in the region's economy.

Another problem with this approach is that it is much too aggregative. The basic–non-basic split, rather arbitrary to begin with, does not capture interrelationships between sectors, or changes in them over time.

This is no problem for the regional I–O models, which are explicitly concerned with the disaggregated structure of production: how much of each of a variety of separate inputs are required for an increment to some regional output? Given a knowledge of these technical production relations, it is possible to determine output in each sector consistent with a new bill of final demands and supply of the region's "primary input", labor. There are, however, a number of problems with the regional I–O approach. To begin with, final demand, though disaggregated, is determined exogenously. Clearly, we would prefer that demands for goods and services in the region be determined endogenously, in response to the proposed new development and the changes in the economy it triggers.

Another drawback of these models is that the I–O coefficients, reflecting the amounts that industries in the region buy from other industries in the region, are fixed. National interindustry models have been criticized for this reason, but the problem is even more serious on a regional level, since movement of firms and industries into or out of the region will almost certainly affect the (assumed fixed) coefficients.* This is noted also by Howe and Easter (p. 58). And the search by firms and owners of resource inputs (including labor) for higher returns in turn ensures that this movement will be a pervasive feature of the region's

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* Both problems – exogenous demand and fixed coefficients – also beset interregional input–output models. In addition, interregional models are hampered by a lack of interregional trade data.

economic landscape. Ideally, this sort of maximizing behavior ought to be explicitly modeled.

A final – and perhaps most serious – disadvantage of the I–O method is that it sheds no light on the dynamic adjustment of the economy to the new equilibrium level and composition of output. But this process of adjustment may itself be crucial in studying the effects of a major construction project like an IWT. Perhaps the heaviest impact, for example, on a region's economy and public finances (taxes and expenditures) will come with the early construction phases, and not with the later operation of the project.

These observations have been implicitly directed to the impact on the region benefiting from the water transfer. They obviously apply as well to the other relevant regions, those losing water, those through which water is transported, and those competitive with the region gaining water. But the econometric model I am going to propose as an improvement over the foregoing methods, including regional I–O, is an improvement in fact in part because it can do a better job of assessing the impacts on these other regions. As Howe and Easter put it, "the use of state input–output models precludes any industry-by-industry analysis of impacts outside the states directly affected by the transfer project, so impacts external to the region must be analyzed in *ad hoc* ways" (p. 58). What is wanted, then, is a method for assessing simultaneously, and with equal rigor, the changes in all affected regions. And as noted earlier, it ought to be able to both trace the dynamics of these changes, and relate them to maximizing behavior by private economic agents (or a planner).

A regional econometric model

The essential features of a method, or model, that holds the promise of satisfying these conditions, can be set out briefly as follows. First, it should be *recursive*. That is, forecasts for period t should be made on the basis of data for the previous period, $t - 1$. Then the t forecasts become the input for forecasts for $t + 1$, and so on. This allows us to trace the time paths of the economic activities in a region, including their adjustments to developments like the construction and operation of an IWT.

Second, the model ought to be disaggregated by (economic) sector and region. That is, we are interested, as in I–O, in the behavior of each of a number of key sectors in a region's economy: energy production, other manufacturing, transportation, agriculture, and so on. But – and this is important – we are interested in the behavior of each of these sectors, and the employment in them, in *all* affected regions, not just the one gaining the water.

Third, and perhaps most important, the model ought to be driven by some sort of maximizing behavior, whether we ascribe it to private economic agents or a social planner. That is, the changes in output and employment by sector and region from period to period ought to reflect some attempt to maximize returns.

Putting it all together, we can write a set of forecasting equations like

$$\Delta Q^t_{ij} = f_i(\mathrm{TC}^{t-1}_{Xij}, \mathrm{TC}^{t-1}_{Mkj}, W^{t-1}_{ij}, R^{t-1}_j, K^{t-1}_{ij}) \tag{3}$$

$$i = 1, \ldots, n$$
$$j = 1, \ldots, m$$
$$k = 1, \ldots, l$$

where ΔQ^t_{ij} represents the change in output, in *value* terms, from period $t - 1$ to period t in sector i in region j; TC^{t-1}_{Xij} the transport cost (in $t - 1$) of shipping a unit of output i from region j; TC^{t-1}_{Mkj} the cost of obtaining (in region j) a unit of input from sector k; W^{t-1}_{ij} the wage rate in sector i in region j; R_j^{t-1} the rental price of land in region j; and K_{ij}^{t-1} the existing undepreciated capital stock in sector i in region j. Equations (3) obviously represent a highly simplified version of a multi-region multi-sector forecasting model. There might, for example, be more input prices specified – for different types of labor, for capital if interest rates exhibited any regional variation, and so on. Also, agglomeration variables, such as outputs of major buying and supplying sectors in region j, or measures of congestion, could be significant. But equations (3) do, in my judgment, capture the essential features of regional economic activity and the changes in it. To get a measure of the change in *aggregate* economic activity within a region, we simply take the sum $\sum_i \Delta Q_{ij}^t$, i.e. the sum of the changes over all sectors i.

This change in aggregate activity, or regional product, reflects *all* of the direct and secondary benefits and costs, as defined in equations (1) and (2), to each affected region. And note that regions losing water or competitive with the region gaining are treated on the same basis as the region gaining.

Let us now look more closely at equations (3) and describe the expected relationships between the variables. It is clear, first of all, that output changes ought to be negatively related to all of the input prices, including transport costs. A decrease in any one of these prices, all others held constant, ought to lead to an increase in the change in output. The other (non-price) independent variable in the model, the existing capital stock, is included to reflect the importance of depreciation of existing plant and equipment to a decision on location of production. It ought to be *positively* related to the change in output; given input prices, the larger the fixed investment, the larger the expected increase in output at a particular location. Conversely, the smaller the fixed investment, the more "footloose", or responsive to changes in regional input prices, a firm or industry can be.

Just as the set of equations in (3) represents the changes in output by sector and region, changes in employment (and therefore population) in a region, also presumably of interest to planners and policy-makers, can be represented by a set of equations like

$$\Delta L_j^t = f_j(W_j^{t-1}/W^{t-1}), \; j = 1, \ldots, m \tag{4}$$

where ΔL_j^{t-1} is the net migration of labor into region j from period $t-1$ to period t, W_j^{t-1} is the average wage in region j, and W^{t-1} is the average wage in the (national) economy. We would expect the relationship between the wage ratio and net migration to be positive, to reflect the search by individuals for better earnings opportunities. This is the basic relationship that has been used to explain such familiar patterns of migration as those from Europe to the US in the 19th century, from the south to the north and west in the US for most of the past century, from southern Europe to northern Europe over the past couple of decades, and so on.

Again, an equation like one of those in the set (4) is probably too simple for actual estimation. Moreover, I have said nothing about the form of the functions f_i and f_j, about how regions and sectors ought to be disaggregated, or – most important – how the required data are to be obtained. But at least the elements have been set out of a model which (a) disaggregates by sector and region, (b) gives equal attention to all affected regions, (c) allows for changes in the structure of each region's economy, (d) relates the changes to economizing behavior, and (e) traces the path of the changes over time.

Further elaboration of such a model, and the prospects for implementing it in a study of the economic impact of an actual IWT are beyond the scope of this paper. But those interested in the subject of regional econometric forecasting can consult the work of Harris,[3] in particular. He has in fact developed a model for the US – and more recently for Canada – along the lines just hinted at in equations (3) and (4), but in much richer detail. The Harris model has not been used to assess the impact of an IWT, but clearly it, or something similar, could be, along the lines of the applications to a variety of other resource development projects (see Krutilla and Fisher[4]).

Before proceeding to consider some aspects of the thus far neglected environmental costs of an IWT, let me very briefly indicate how a regional econometric forecasting model like that suggested in equations (3) and (4), or developed by Harris, might be used to measure the conventional economic costs and benefits. The idea is to specify, exogenously, the "primary" activities, such as the construction and operation of a water transfer facility. These activities are then fed into the model, resulting in changes in regional input prices, which in turn trigger output shifts. For example, a lower price of water will lead to an expansion of water-intensive activities within a region. And the expansion of these activities can enlarge the market for still other activities – recall the suggested agglomeration variables like output of major buyers in a region – triggering still further output shifts. Of course, not all changes occur overnight. There is a construction schedule for the project, and the outlays on it, and only some fraction of an industry will move into or out of a region in any one period in response to these outlays and their effects – recall the influence of fixed investment. But presumably the search for higher returns motivates some movement – some change in output – in each period. Once again, the process is much more complicated than I have been able to indicate in these brief remarks, and the interested reader is urged to consult the seminal work of Harris, or some of the applications.

3. ENVIRONMENTAL COSTS OF INTERBASIN WATER TRANSFERS

The basic Howe–Easter benefit–cost relationships, inequalities (1) and (2), provide a framework for consideration of environmental effects of IWT's. There is nothing in these expressions about environmental effects, and indeed, nothing in the ensuing calculations of the direct and secondary benefits and costs of some specific transfers – though the possibility of such effects is noted (pp.106–107). And environmental effects are not treated in the two other excellent comprehensive studies of the economics of IWT's of which I am aware, those by Hartman and Seastone[5] and Cummings.[6] Yet there is no reason why these effects, increasingly recognized as potentially serious, cannot be included in one or another of the cost terms.

One obvious possibility would be "secondary costs", which Howe and Easter indicate arise "through the existence of failures of the market mechanism" (p. 27). Since environmental side effects of various resource development projects are among the outstanding examples of market failure in recent years, the associated costs could be considered a component of secondary costs. But Howe and Easter also define secondary costs in terms of foregone (money) "incomes of factors of production" (p. 26). For example, if the resources employed in an activity displaced by the IWT are not mobile, i.e. cannot move quickly to an alternative, their loss in income is a secondary cost. This definition then looks only at conventional economic costs – even though they are attributed to market failures.

It might be desirable, then, to break out environmental costs separately. This we can easily do by adding a term, "EC", for external, environmental costs, to the right hand side of inequality (1). It would also be added to the left hand side of inequality (2), as an "EC_A", for environmental costs of the alternative (to the water transfer), would be added to the right hand side. If one were interested in the distribution of these costs among the affected regions, they could be entered separately, as EC_X, EC_M, and so on as appropriate.

In principle, then, there is no problem in accounting for the environmental effects of an IWT in the economic calculus. But in practice there is of course a problem; or rather two problems. First, the physical effects must be determined. Second, perhaps more difficult, an economic valuation must be put on them (if, that is, we wish to account for all of the project's effects in a common metric).

About the physical effects I don't claim to know very much. Other participants in this conference, expert in these matters, will be addressing them. But I gather that they can be both substantial and difficult to determine and evaluate. Apparently, changing the water regime of a region can have an effect on its climate, due to greater or lesser evaporation, formation of cloud cover, and so on. And in addition to these micro-climatic effects, certain diversions of water, in particular the very large diversions from Arctic regions to the south now being contemplated in both North America and the USSR, can have an effect on global climate and environment. In one plausible scenario, a reduction of fresh water flow into the Arctic Ocean could lead to a melting of the Polar ice cap, with profound consequences for low-lying coastal areas around the world (Inadvertent Climate Modification: Report of the Study of Man's Impact on Climate, pp. 159–162).[7]

Needless to say, economic evaluation of such effects would not be easy. In some cases, where there are determinate effects on particular economic activities, such as agriculture, evaluation would be feasible. But where it is not, a useful strategy for assessing an IWT might rely on the notion of *dominance* (Fisher and Peterson[8]). This has been helpful in assessing at least one other development project with important, but hard to monetize, effects on the environment: the Trans-Alaska Pipeline (Cicchetti[9]).

Briefly, the notion of dominance is as follows. Suppose two projects, an IWT and one other, say pumping of a groundwater reservoir, can yield the same water output. Suppose further that the costs of each can be broken into two parts: conventional economic costs, measured in money outlays on the required inputs, and environmental effects, measured in various physical units. Let C_m^I and C_e^I represent the conventional and environmental costs of the IWT, and C_m^G and C_e^G the conventional and environmental costs of the groundwater alternative (C_e^I and C_e^G can of course be vectors containing several elements). Then if $C_m^G < C_m^I$ and $C_e^G < C_e^I$, we say that the groundwater alternative dominates the IWT. To compare them it may not be necessary to aggregate conventional and environmental costs in the same metric.

3. UNCERTAINTY AND IRREVERSIBILITY

One final set of issues I wish to address here has to do with the problems and implications for benefit–cost analysis of (environmental) effects of IWT's that are sufficiently long-lived as to be considered irreversible, yet (as with all such effects) not perfectly predictable. What I shall show is that the presence of such effects leads to some presumption in favor of refraining from the activity that gives rise to them. Recall that the basic economic efficiency criterion for an IWT, as given in expression (1) of Section 2, is that the benefits exceed the costs (all properly discounted), or that the *net* benefits be positive. Below I derive a more "conservative" efficiency condition, namely that the net benefits must exceed some positive number.

Since this is a fairly strong result, we ought to be clear about the assumptions which underlie it. First, it is assumed that the environmental effects are uncertain. This seems a very weak assumption; indeed, the converse would be hard to motivate. Second, it will be assumed that the passage of time reduces the uncertainty, in a sense to be defined precisely below. This seems plausible enough, though perhaps not in the rather strong form in which it will be made. Third, perhaps most important, and at the same time most questionable, is the assumption that the effects are irreversible. This may be plausible for certain types of water transfers. One that comes to mind, already mentioned in the preceding section, is the substantial diversion of fresh water flow into the Arctic Ocean, resulting in a reduction in the Polar ice cap, resulting in turn in inundation of low-lying coastal areas, including many of the world's cities. I don't know how likely this is, or whether there are other, more localized effects of IWT's that can be considered irreversible. Other participants in this conference will be addressing these questions. But let me proceed, on the assumption that such effects *are* possible, or even likely, to trace out some implications for policy.

*A sequential model of irreversible investment in an uncertain environment**

Let W_1 be the fraction of a large IWT developed in the first period and W_2 be the fraction developed in the second (and last). Let b_1 be the benefit, *net* of environmental costs, from developing the entire project in the first period and b_2 be the benefit from developing in the second. Assume b_1 is known at the start of the first period and b_2 is a random variable with known distribution $b_2 = \alpha < 0$ with probability p, $b_2 = \beta > 0$ with probability $q = (1 - p)$, and expected value $E(b_2) > 0$. The decision problem is how to choose W_1 to maximize the expected value of the project if it is known that the development is irreversible.**

Assume, first, that no further information about b_2 will become available before the start of the second period, when W_2 must be chosen. Since $E(b_2) > 0$, $W_2 = (1 - W_1)$ in any case. The decision rule for W_1 is: $W_1 = 0$ if $b_1 < 0$, $W_1 = 1$ if $b_1 > 0$. This is of course perfectly consistent with inequality (1).

Now assume that b_2 will be known at the start of the second period. If $b_2 = \alpha$, $W_2 = 0$, and net benefit in the second period is αW_1. If $b_2 = \beta$, $W_2 = 1 - W_1$ and the benefit is β. The expected value, at the start of the first period, of benefits over both periods, is then $b_1 W_1 + p\alpha W_1 + q\beta = W_1(b_1 + p\alpha) + q\beta$. This expression is to be maximized by an appropriate choice of W_1. Since the expected value criterion is linear in W_1, the decision rule is again of the "bang-bang" type: $W_1 = 0$ if $(b_1 + p\alpha) < 0$, $W_1 = 1$ if $(b_1 + p\alpha) > 0$. But note that, since $p\alpha < 0$, this rule is clearly more conservative than the previous one. Now b_1 is required to exceed some positive number, $p\alpha$, whereas previously it was required only to exceed zero.

The point of this exercise has been to show that the accumulation of new information (reduction in uncertainty) about a project that will have an irreversible impact on the environment implies that the project's expected value will be maximized by a relatively conservative decision rule, one that puts a greater "burden of proof" on the project. Or in other words, there is some presumption in favor of refraining from it. Note, however, that just because something is irreversible it should not, on that account, not be undertaken. The rule just derived is more flexible. It says that the combination of irreversibility and (reduction in)

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* A more general statement of the model can be found in Arrow and Fisher[10].

** Maximization of expected value is perhaps the simplest decision criterion. Others, more complicated, involving one or another variant of risk aversion, would not change the results obtained below. On the contrary, the results would be obtained more easily.

uncertainty in effect gives rise to an additional, but finite, cost of a project. The economic efficiency condition is a modified form of inequality (1). The project's net benefits, i.e. the left hand side of (1) *minus* the right hand side, must exceed this new, positive, "cost" term, rather than zero.

5. SUMMARY AND CONCLUSIONS

With recent increases in the size of proposed IWT's, careful consideration of their economics becomes particularly important. In this paper I have put forward a number of proposals and propositions concerning the theory and measurement of the costs and benefits of an IWT. They can be restated briefly as follows.

(a) 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. In Section 2 I propose an econometric modeling approach that might accomplish these objectives.

(b) Calculations of the benefits and costs of an IWT ordinarily ignore its effects on the environment, yet these are likely to be substantial. In Section 3 I indicate how the standard decision criterion should be modified to include the costs of environmental effects. Where the costs cannot be estimated, I suggest a technique for comparing an IWT to an alternative means of producing water, that still accounts for both conventional economic and environmental effects of each.

(c) 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, I show that 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.

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The Water Grid Concept

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ABSTRACT

Phases in the history of the development and use of water resources are reviewed. A possible ultimate pattern of such development for a nation or a large international region is discussed. It is 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 are described. The most significant characteristics are large interbasin and interregional aqueducts and a central coordination and management.

I. INTRODUCTION

The foundation of our civilization is the human development of two primary natural resources: land and water. Our early views of man are of him emerging from the shadows of the Stone Age as a cultivator of soil and an applier of water. The story of the development of that water from the earliest times to the present has many chapters.

Phases in the history of water development

In the early phases of development of regions, the demands on the water resources generally, were negligible compared with the quantities available. As regions became settled and permanent communities were established, the region's water resources were put to use to meet human and livestock needs, to meet the needs of communities and settlements and, in the arid regions of the world, to irrigate agricultural lands. The first irrigation developments were shallow wells and diversions from flowing streams for immediately adjacent uses. This was the first pattern of water development; and in many parts of the world, it is still the only pattern of water development.

Development of surface-water supplies — As diversion of water from a stream increased, a point was reached when the natural flow of the stream was at times insufficient to meet the needs. Reservoirs were then constructed. The first such reservoirs were generally single purpose, supplying water to a farming area or to a community. With further increases in demands on the water supply, larger reservoirs were needed to increase the quantity of water that could be made available by providing cyclic storage where run-off was carried over from wet portions of the year into the dry portions, from wet years to dry years, and from wet cycles to dry cycles. The larger reservoirs also served multiple purposes. They provided storage space which could be held empty in reserve to impound flood flows and they could be operated to serve other purposes such as to produce hydroelectric power and to maintain more uniform

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flows in downstream reaches for navigation, fish preservation and enhancement, and to provide water quality control. Not only were water supplies put to greater use, but the economic and financial bases of projects were broadened by providing for such multiple uses.

Development of groundwater supplies – As the settlement of regions using groundwater proceeded and the water needs increased, the number of wells was increased as well as their depth. Drilling of deeper wells was made possible by greater technical knowledge and by improved drilling equipment. Significant advances also have been made in well construction.

An appropriate number of deeper and improved wells combined with management of pumping and recharge made possible a greater utilization of the groundwater reservoir. In theory, a groundwater reservoir can be operated in much the same manner as a surface reservoir with both annual and long-period cycles of filling and drawdown.

Coordination of use of surface- and groundwater supplies – In most of the irrigated areas of the world, the development and use of both surface-water and groundwater recources is the rule rather than the exception. The development and use of each is, however, generally independent. But a next and logical step is their coordination, and in some groundwater basins this is being done. Full coordination of the operation of surface- and groundwater supplies requires special management and legal arrangements. The objective of such an operation is to make the most economic use of a basin's surface- and groundwater reservoir volumes to regulate the total basin water supply for all uses.

Water conveyance facilities – In addition to surface- and groundwater storage reservoirs to conserve and regulate the water supplies, it is necessary to construct canals and aqueducts to convey the regulated water to the area or place of use. In the first stage of development, a canal was constructed to bring water from a stream to a farm, then from a river or reservoir to a larger area of use, and finally long aqueducts were constructed to carry water from a remote source of supply. The large aqueducts are often interbasin and a few are interregion. They transfer water from areas with excess water supplies to those deficient in water supplies.

Management of the use of water – Man has learned to regulate natural water supplies as they occur with respect to time, in order to have them available at the time they are needed for human use. He can build conveyance systems to move the regulated water supplies to the places of use. More recently he has learned how to manage the removal of the accumulating saline drainage waters which brought ruin to early irrigation projects and which are still a problem to all. He is also learning about water quality control. No water is good for every use, but every water is good for some use and the quality of the water should fit its use. As it is an objective to have the most economic balance between use of surface- and groundwater reservoirs, so it should be an objective to make the most economic use of water supplies from a water quality standpoint. Higher quality should be used where it is required and lower quality water used where it can be tolerated. Improvement of water quality by treatment should also be considered.

II. WHAT IS THE ULTIMATE PHASE OF WATER DEVELOPMENT?

Section I discussed phases in the history of the development and use of water resources. All of those phases exist today in the world. In fact, in most nations water development is in its early phases. In only a few areas is there beginning to be a coordination of the operation of surface- and groundwater reservoirs. Water quality control is beginning to be considered, but only where pollution makes it absolutely necessary. There are very few interbasin or interregion aqueducts to balance water supplies between areas of surplus and areas of deficiency on a large scale.

There is much remaining to be done to develop the world's water resources for all uses. It is suggested that it would be worthwhile to consider the possible phases that might exist in the future or to consider what might be an ultimate phase of water development. A general description of such an ultimate phase would be a useful guide to water resources planners and managers. Its primary value would be as a guide so that interim steps taken today would fit into the next phase and into the ultimate phase.

Objectives of the ultimate phase of water development – As a first step in attempting to describe such an ultimate phase of water development, the objectives should be set forth.

What should be the objectives of the ultimate phase of development of the water resources of a nation or a large international region?*

Such an ultimate development should:

(1) meet all human needs including those of nomadic people and their livestock;

(2) meet water needs for all purposes:
  (a) villages and communities,
  (b) agriculture and livestock,
  (c) city and municipal,
  (d) industrial,
  (e) power plant cooling,
  (f) hydroelectric power,
  (g) navigation,
  (h) fish and wildlife,
  (i) recreation,
  (j) environment,
  (k) esthetics.

(3) The foregoing needs should be met as they occur and particularly in dry portions of the year, in dry years, and in dry periods of climatological cycles.

(4) The foregoing needs should be met by water of adequate quality, both mineral and biological.

(5) Human developments and natural resources should be protected against damage by floods.

(6) To meet the foregoing needs, water supplies available in all phases of the hydrologic cycle should be considered.

(7) Adequate drainage should be provided.

(8) Constructed facilities and their operation and management should be such that all of the foregoing needs and requirements are met in the most economic manner.

Development of other natural resources

The world has many other resources, in addition to water, which man has developed. For example, the human, animal, mineral, vegetative, power and ocean resources all have been put

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* In the discussion in this paper the term "region" is often used. It is assumed to be a large area that might transcend national boundaries.

to use by man to meet his needs. In looking for guides to future phases of water development, the patterns of development of these other resources should be considered. One of these, power, has some attributes similar to water. It is made available at specific points, it requires distribution, needs should be met on demand, and for efficiency and economy its facilities require coordination. It is these similarities that suggest a concept of water development similar to a power grid system where the power needs of a region are met on demand by integration and coordination of resources and facilities and where large-capacity power transmission links are the backbone features of the physical facilities.

III. CHARACTERISTICS OF A POWER GRID

The term "Power Grid" is a familiar one. Power grids, often international, exist today in the developed nations and are an objective of the underdeveloped nations. Today the emphasis in electric power systems is on coordination between systems. This trend began in the late 1920s when strong interties began to be built to provide economy and improved reliability of service. With the interties, separate electric systems could join into increasingly larger power pools.

Many benefits resulted, including larger generating units, savings in providing reserve capacity, exchanges to take advantage of diversity between systems, and the ability to select the most favorable generating sites.

The development of electric power interties has resulted in the construction of lines to transmit large blocks of power in the extra high voltage range. A 345 kV line was constructed in the United States in the early 1950s. In Sweden a 400 kV line was placed in operation in 1952, and in the USSR in 1954. The voltage on the Soviet lines was increased to 500 kV and then to 750 kV. Such interties are the backbone of the world's power grid systems. They are super highways of low cost power.

A power grid is an interconnected power system which serves, on demand, the needs for electric power including, for example, domestic, municipal, industrial, transportation, manufacturing and agricultural needs. In a power grid, electric power from various sources can flow on alternative routes to the many points of use either under a planned operation or in unforeseen circumstances of outages of production facilities, of transmission systems and of demand loads, and there usually is an excess capacity to meet unexpected needs.

IV. CHARACTERISTICS OF A WATER GRID

If a power grid is used as an analogy to define a water grid, a water grid could have the following characteristics:

(1) It could be a conveyance system that conveys water from water sources to places of water use.

(2) It could have alternative sources and alternative routes in the event of the primary sources or routes being out of operation.

(3) It could have interconnecting links, so that diversity in the availability of water among different water sources and in demand for water among different service areas could be taken advantage of to make maximum use of the available water resources and to obtain the most economic use of facilities.

(4) It could have sufficient conveyance capacity to meet peak demands as they occur

with some excess capacity.

(5) It could be connected to, and convey water from all sources including those sources under the various phases of the hydrologic cycle and those sources where water is made available by technological processes such as desalination.

(6) The operation of the facilities of the grid system could be coordinated and there could be an integrated management.

In summary, the water grid could link the water sources to the areas of water demand. It could provide a physical system to convey water to meet needs under the various conditions of demand and of availability. It would transmit various quantities and qualities of water from available natural sources in the hydrologic cycle together with supplies from technological developments such as desalination, waste water reclamation and weather modification. Finally, it could be a complex and frequently large scale interbasin or interregion water transfer system transcending physical boundaries with an integrated operation of facilities and a centralized management. It is these two characteristics, large water transfer facilities and an integrated operation of facilities and centralized management, that would be the primary characteristics of a water grid.

Specific objectives that a water grid would need to meet

There are specific objectives and operational requirements that a water grid would need to meet. A number of these are set forth in the following sections. They have been developed using the power grid as an analogy by which to visualize a water grid and in addition by introducing some concepts of a power grid into our water management thinking and by introducing some recent and new concepts of water management.

Variations in water demand – Depending upon a number of factors, including the weather, type of use, rate of development, etc., demands for water vary during the day, during the week, by months, and from year to year. A water grid system operating in conjunction with water conservation facilities should have adequate capacity and sufficient operational flexibility to meet water needs under such variations. The daily and weekly variations are usually met by adjusting releases from reservoirs and by withdrawing water from or adding water to the aqueduct facilities. On the other hand, longer term variations in demand occur during a year. For example, agricultural demands are high during the growing season and low during the nongrowing season while municipal and industrial demands are more constant through the year. These variations are met by adjusting releases from storage reservoirs.

In sizing of facilities to meet such variations in demand, it is important to consider the peak demands that will occur under conditions of full development. As can be seen, two factors are important. The conservation and transportation facilities must have adequate capacity and there must be operation flexibility.

Water quality management – In the same way that adequate quantities of water must be made available, water of adequate quality, both mineral and biological, must be made available. In a water grid system water quality monitoring and management would need to be carried out so that water of various qualities would be utilized appropriately throughout the system depending upon the types of need and the physical characteristics of the service areas.

Alternative routes – At the present time there are very few examples of alternative routes in major water conveyance systems. This is probably because canals and aqueducts operate reliably and because of the large cost involved. When an aqueduct is constructed linking a water source with an area of demand, it is difficult to justify construction at the same time, of a second aqueduct along an alternative route. As water demands increase, however, and it becomes necessary to construct a second aqueduct either to the original service area or to a new service area, and an aqueduct extending in a general direction parallel to the first is envisioned, it would be important to consider the advantages that might result if the second aqueduct were built on another alignment and if some additional capacity were constructed in the second aqueduct so that one could be out-of-service either from emergencies or as a planned operation, for example, to relieve peaking needs. An interconnection or interconnections between the two would also be needed.

Interconnections – As just mentioned, to get maximum use from generally parallel aqueducts along alternative routes, it would be necessary to have interconnections. Interconnections also would increase the operational flexibility of existing systems, and such systems should be reviewed looking for opportunities to make interconnections.

Consideration of reversible flow – An important characteristic of a power grid is that power can flow in either direction. Such a concept is not so applicable to water conveyance systems but the possibility that it might prove useful should not be overlooked.

There are a number of possible situations where an aqueduct with this capability would be useful. Such a situation would exist when weather conditions resulted in there being excess water supplies at some point or points along an aqueduct and there was a need for water at upstream locations. An aqueduct that could carry water in either direction would also be useful as a connection between two or among several adjacent basins in order to move water that was excess to needs in one basin, to basins where water supplies were deficient.

It would be possible to design, construct and operate an aqueduct to provide for reversible flow. Large aqueducts are constructed with very small slopes. For example, a concrete lined aqueduct with a capacity of about 300 m^3/sec (about 11,000 ft^3/sec) has a slope of about 1 in 25,000. Such an aqueduct can convey large quantities of water with only a small loss of head. This gives rise to several possibilities if reversible flows are desired. Aqueducts of this size could be constructed at no grade, i.e. level, and the hydraulic head could be created by pumping stations at both ends of such an aqueduct. Intermediate pumping lifts with reversible pumps also could be utilized.

To provide reversed flows in existing aqueducts, either temporary or permanent pumping facilities could be constructed. For each of these possibilities in a large aqueduct of the size stated, a pumping lift arrangement providing a lift of 1 m (3.3 ft) for every 25 km (15 miles) would be necessary.

The same possibilities exist with smaller aqueducts but the distance between pumping stations would be less or higher lifts would need to be provided.

Groundwater basins as parts of the water grid

The most important function of a groundwater basin is to store water. It has the advantages of not requiring any land area and it has no evaporation. In addition, a groundwater basin has several physical characteristics which are analogous to characteristics of a power grid. It is important to recognize these in considering the functioning of groundwater basins as parts of a water grid system. A groundwater basin provides alternative routes from areas of supply to points of use, it provides interconnections and it will allow reversible flow. These characteristics can be used in the management of both water quantity and water quality.

Possible arrangements to give operational flexibility

So far the discussion has generally related to physical facilities. An important concept of the water grid is the coordinated management of the physical facilities. The objective of such coordination would be to give complete flexibility of operation so that the greatest overall economic benefit for the least economic cost would result.

To attain the most economic operation, water needs would be met by releasing appropriate amounts of water from the most appropriate reservoirs. Determination of the amount to be released from each reservoir should not be based upon ownership or rights to the water but should consider the needs to be met, the capabilities of the facilities, the amounts of water available and the costs and values involved. In a water grid system with integrated management, all water in the system and all facilities of the system would be used to the maximum and in the most economic manner. Reservoir spills should be avoided and all possible discharges should be through power plants. Releases for managed river flows should be from those reservoirs where abundant water supplies are occurring. Diversions to aqueducts also should be from streams and reservoirs where there are abundant water supplies. Conveyance of water to places of use or to terminal reservoirs for later use should be by the most economic route. All conveyance facilities should be used during wet periods to avoid loss of water.

Following are some suggestions for possible exchanges and possible operation and management plans to make maximum use of water supplies and to get maximum operational flexibility and performance from the total physical system. When exchanges and banking of water and power and exchanges of rights to the use of physical facilities are discussed, it is pointed out or is to be understood that it is necessary to keep accounts of such exchanges and banking and often of the values being exchanged or banked. This is necessary when the grid system consists of a number of smaller systems being coordinated as a single larger system so that the rights and values of these smaller systems are preserved. It also is necessary for a single large system in order to attain the most economic operation.

Exchange of water in reservoirs – Contractual or management arrangements should be worked out so that exchanges of water, in an ownership sense, between and among reservoirs are possible. This will require a system for accounting for the amounts of water exchanged and of the value of the water on some common base for the grid system.

Exchange of capacity in reservoirs – Rights to the use of the capacity in the grid system reservoirs should also be able to be exchanged. This will also require an accounting of the capacity so exchanged and its value.

Exchange of water in aqueducts – Exchange of water flowing or stored in an aqueduct should be provided for. This will require an accounting of the water and its value.

Exchange of capacity in aqueducts – Exchange of rights to use the physical capacity of aqueducts should be provided. This will require an accounting of the capacity so exchanged and its value.

Power exchange – In addition to the reservoirs and water conveyance aqueducts, the facilities of the water grid system will usually include hydroelectric power plants and pumping plants. The electric capacity and the electric energy production capability of the power plants are important system resources. The pumping capacities of the pumping plants are also important system resources and the energy required for pumping plant operation is a significant system requirement. Exchanges in the use of power plant and pumping plant capacities should be provided for. Exchanges of the energy produced by the power plants should be provided so that the power needed for system pumping or to meet other system obligations is furnished from the plant of the system that is the most economic for the particular situation.

Power and water banking – In the coordination and integration of power and water systems, the terms "exchange" and "banking" have special meanings. The use of these terms is not always consistent among systems. For the purpose of this discussion, the term "exchange" when used in the accounting for water, covers not only operational exchanges that might be made on an hour-by-hour or day-by-day basis, but also exchanges over a long time period, possibly as long as a year. When electric power is exchanged on an hour-by-hour or day-by-day basis, the term "exchange" is used. When, however, the exchange of electric power is for a period longer than one day, the term "banking" is used. In operation of the water grid system exchanges of water and power should be accounted for and banking accounts should be provided for accounting of long-term exchange of electric power among facilities or among segments of the system.

Exchange of use of facilities – In the operation and management of a water grid system, the concept of the exchange of use of facilities is an important concept. In previous sections of this paper, the need has been discussed to provide for the exchange of the use of capacity in reservoirs, for exchange of the use of capacity in aqueducts, and for the exchange of the use of capacity of power production plants and pumping plants. Arrangements should be made so that such exchanges can be made in as complete and as flexible a manner as possible. Exchanges in the use of the production capacity of power plants will allow project pumping needs and other obligations of either the entire system, or portions of the system, to be met by the power plant or where the most abundant water supplies are available or by the most economic plant, considering not only the plant characteristics but the distance of transmission. Exchange of the use of capacity in aqueducts and of the capacity of the related pumping plants should be provided for so that water can be conveyed by any of the alternative routes available, depending upon circumstances of operational needs, emergency situations or economic considerations.

On-peak and off-peak operation of generation and pumping facilities – The general character of the daily, weekly and yearly demand for electric power throughout most of the world is generally similar. Daily demands are high during the daylight hours and lower during the night. Demands are highest during the weekdays and lower on weekends. The demands throughout the year do not fall into such consistent categories because there are generally differences in demands because of the uses that are met and because of the different characteristics of summer and winter needs. But the general consequence of these variations in demands and their interrelations is that there is a predictable minimum base load demand that must be met continuously throughout the year and from year-to-year. Demands above this base load are the peaking demands and the power production facilities, which do not operate continuously, meet such demands. Although the power production facilities which meet the peak loads do not operate continuously they must be dependably available. The facilities which meet peak loads are often called on-peak facilities and the period of their operation is called the on-peak period. Since they must be available but do not operate continuously, their costs are higher for each unit of production. Therefore, the value of the power produced during these periods or the cost of power needed during such periods is higher.

These considerations must be kept in mind for the most economic operation of a water grid system. To take advantage of these circumstances, hydroelectric power production facilities should be operated as much as possible during the peaking periods and pumping plant facilities should be operated as much as possible during the off-peak periods.

Operation to maximize power production and operation to maximize water yield – A given reservoir with its related power production facilities can be operated under an infinite number of operation plans. These plans fall, however, into two general categories – an operation which will maximize power production, or an operation which will maximize water yield. Although multi-purpose reservoirs are operated to meet many other demands, such as those to provide flood control and to provide minimum flows in the downstream channel, such demands can usually be readily met whether the reservoir is being operated to produce a maximum amount of power or a maximum water yield. Planning of the operation of the grid system reservoirs should be such that each reservoir produces an appropriate dependable power capacity, energy production and water yield so that in the aggregate, all system needs and commitments are met.

Controlled volume concept of aqueduct-operation – Much of the activity and many of the problems in the operation of aqueducts and aqueduct systems relates to adjustments required when changes in flow are made. That activity and those problems are at a minimum when the aqueduct is conveying a constant unchanging quantity of water. When that flow is changed, adjustments of all control facilities are required. The more frequently such changes are made, the more frequently adjustments are required with consequent higher costs. In addition, for aqueducts of considerable length, the time between when the flow change is made at the head of the aqueduct and when it is felt at the lower end is considerable – that time being only somewhat less than the time it takes a particle of water to flow the length of the aqueduct. In other words, the time required to respond to a change in demand in a service area at the end of the aqueduct is long. When agricultural demands are being met, this problem generally is not significant but when municipal and industrial demands are being met, or when emergencies occur, problems can arise.

Modern control system techniques, including the use of computers, have improved this situation substantially. If by the use of such equipment, all facilities along an aqueduct, which generally include pumping plants, check gates, and major delivery turnouts can be operated so that their operation is simultaneous, a much higher degree of control of the operation of the aqueduct can be obtained. For example, an aqueduct with such a remote control system can be brought from a condition of no flow to a condition of full flow in a short period by simultaneously starting all pumping plants and simultaneously opening all check gates. In the same manner, the flow can be brought to a halt by simultaneously turning off all pumping units and closing all check gates. Such a method of operation should be considered for appropriate aqueducts and interconnection links of a grid system to improve service to the users and to allow faster response to emergency conditions.

Long-range forecasts – Long-range forecasts of the operation of grid system facilities should be made for two primary purposes. First, to assure that system facilities are in as good a position as possible to meet demands as they occur under the many possible conditions of demand and water availability that may arise, and second, to assure that additions to and physical changes in the system facilities are made on a timely basis, considering the long lead time for design and construction. Detailed operation studies made on a monthly basis and projections of water needs and operation requirements at least 20 years into the future, should be updated annually. The 20-year or longer projection, and possibly an intermediate projection, should be studied in relation to a long-term water supply period which includes not only critical water supply periods but also is representative of the long-term water supply.

Projections for about the next 5 years, and particularly next year's operations, should be made in great detail, considering at least three possible conditions of water supply – the normal water supply and two extremes, for example, a upper and a lower quartile water supply. If a critical water supply year is actually being experienced, an operation under the possibility that the next year also will be another critical year should be considered.

Need to make computer studies – Studies and implementation of the foregoing concepts of exchanges, banking, alternatives of operation, and operation management require not only a large number of computations but computations in considerable volume. In fact, operation studies of the coordinated operation of the reservoir and aqueduct facilities of a large regional area would be virtually impossible without electronic computers.

System operation models are in existence which allow the study of the coordinated operation of a large number of reservoirs and related aqueducts. For example, the United States Bureau of Reclamation and the California Department of Water Resources have jointly developed a computer model for the entire Central Valley of California. In this model the Central Valley is divided into 40 hydrographic areas, including both the mountain watersheds and the valley service areas. With this model the individual and coordinated operation of the Central Valley's 56 major reservoirs can be studied. Routines for operation of the major power plants also are included.

Projections of future demand for 1980, 1990 and 2020 have been made and each of these future demand projection periods can be studied over a 33-year water supply period, and this is being extended to 51 years.

A separate but related model has also been developed by the California Department of Water Resources not only to study but also to manage the operation of the California Aqueduct which extends nearly 450 miles from the Delta of the Sacramento and San Joaquin Rivers to terminal reservoirs in Southern California. In this study, the aqueduct is divided into 72 separate reaches with the six enroute and terminal reservoirs each being handled separately.

In addition, both analog and digital computer models have been developed to study the flow patterns in some 1100 miles of channels of the Sacramento–San Joaquin Delta with its 50 islands.

All of the foregoing models consider only quantities of water either stored in reservoirs, flowing in the rivers and channels of the Central Valley, or in the aqueducts of the Federal and State projects. A model to study the mineral water quality of the Delta channels and the San Francisco Bay system also has been developed since the lower estuaries and the Bay involve a transition from fresh to ocean water with the problem of saline intrusion modified by tidal flows. One final model, although not yet operational, is being developed to study the biological quality in the Delta and estuary channels. Such models are examples of those that would be needed for a water grid system, depending, of course, on the particular physical situation and the system facilities.

Centralized operation control – In order to optimize the operation of all system facilities and to provide the essential central management, it would be necessary to have a centralized control of the management of the grid system, including its facilities and operation management. Such a central management, however, must be responsive to the total needs and economy of the area being served.

In developing and carrying out the plan of operation, all water demands must be considered, as must be the need to produce hydroelectric power, to provide navigation, to provide water quality management, to protect and enhance the fish and wildlife resources, to provide flood protection for human developments and for natural resources, to provide recreation, to protect and enhance the environment, and to enhance the quality of human life. Input from all of these interests must be provided and must be considered. These interests must be involved in the decision making process.

Water use management

In all the foregoing, the discussion has related to providing for and managing the water supplies to meet water needs. However, the situation should also be studied where water supplies do not meet water needs. In this situation two alternative courses are possible; either additional water can be supplied or demands can be reduced. The objective should be a compromise program which considers both concepts and results in the most economic program.

Water utilization can be improved in a number of ways and this reduces demands with the result that available water supplies can be extended to meet additional uses. Operational losses can be reduced by lining of aqueducts and canals. Irrigation efficiencies can be increased by improved irrigation methods which involve application of smaller amounts of water such as by drip irrigation. Reuse of water is possible either by subsequent use or by reclamation and reuse. Other management methods also are available. For example, the amount of use of water is closely related to its cost. Therefore, revised or new pricing systems could be effectively used to influence the demand for water.

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Environmental Assessments in Water Resources Planning

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INTRODUCTION

Since 1970, environmental assessments have been required for water resources planning studies carried out by the federal agencies responsible for water resources development in the United States. The principal reason for this is the National Environmental Policy Act of 1969 (NEPA), a law that requires all federal agencies to describe the environmental impacts of actions they propose to take. As a consequence of NEPA, federal water resources development agencies like the US Army Corps of Engineers and the Soil Conservation Service prepare "environmental impact statements" for proposed water projects, and these statements are reviewed by other agencies, various interest groups and individual citizens.

A more recent requirement for environmental assessments is contained in a set of planning regulations issued by the US Water Resources Council.[1] These regulations, known formally as the "Principles and Standards for Planning Water and Related Land Resources" (referred to herein as the "Principles and Standards"), require an assessment of the environmental effects of alternative actions considered by an agency. The regulations elevate "environmental quality" to the status of a formal planning objective along with the traditional objective of "economic efficiency". In addition, the Principles and Standards require that an alternative action known as the "Environmental Quality Plan" be formulated to demonstrate how water resources planning goals can be met while preserving and enhancing environmental values. Taken together, NEPA and the Principles and Standards have caused the federal water resources agencies to devote a good deal of attention to the ways in which environmental assessments should be carried out.

This paper examines several aspects of the process of conducting environmental assessments. It begins with an overview of the types of environmental impacts associated with water projects. This is followed by a discussion of the collection of procedures that have been brought together under the label of "environmental assessment methods". The portions of the paper that come after the discussion of methods are based on the premise that the principal issues involved in the environmental assessment of water projects do not concern methods *per se*; rather, they concern the ways in which the information generated by the use of these methods is integrated into other activities that are part of the water resources planning process (e.g. the formulation of alternatives). Questions relating to the influence of information resulting from environmental assessments are pursued in two parts. One of these parts concerns research which indicates that the environmental assessments carried out in response to NEPA have not had a great influence on federal water resources decision making. The second

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of these parts, which is also the last major section of the paper, outlines a planning process which fosters the use of information from environmental assessments in various aspects of water resources planning and decision making.

ENVIRONMENTAL IMPACTS OF WATER PROJECTS

Because the term "environmental impact" has acquired several different meanings it is necessary to clarify its usage herein. In so doing, a position similar to the one taken by the US Army Corps of Engineers is adopted. Under the River and Harbor and Flood Control Act of 1970 (Public Law 91–611), the Corps is required to assess the economic, social and environmental effects of any projects it proposes to carry out. As regards economic effects, the Corps has been making such assessments since the late 1930s; these have taken the form of benefit–cost analyses and have been conducted by organizational units typically known as "economics sections" in the various District Offices of the Corps. The environmental and social effects have come to include all impacts that are not considered in a traditional benefit–cost analysis, e.g. air quality degradation and noise pollution. These effects are generally assessed by Corps staff members located in an "environmental section" (or branch). It is this collection of effects (i.e. all impacts except those assessed in a benefit–cost analysis) that receive prominent treatment in Corps' environmental impact statements and that are referred to herein as "environmental impacts".

Examples of environmental impacts: the California State Water Project

To further illustrate the types of effects included under the above definition of "environmental impact", we briefly note aspects of the California State Water Project, a major undertaking involving the interbasin transfer of water. As shown in Fig. 1, the Project carries water from northern California rivers (e.g. the Feather River, the Sacramento River) across the Sacramento–San Joaquin Delta and south via the California Aqueduct to serve the bulk of its users in Southern California.[2] The project is designed to deliver of the order of 4.23 million acre-ft/yr (5.21×10^9 m^3/yr).

The State Water Project has been severely criticized because of the adverse environmental effects it may cause. Gill, Gray, and Seckler have identified three principal lines of criticism in terms of environmental effects.[3] First, it has been argued that the Los Angeles area has "already grown beyond supportable dimensions" and that further growth should not be encouraged by Project water; the premise here is that by providing municipal water supply, an important mechanism for controlling urban population growth is lost. Second, the overall effect of the Project on the Delta and on San Francisco Bay is not known, but it is likely to be significant and adverse. For example, the Project could lead to losses of fishery resources and wildlife habitats and to significant adverse effects on water quality, e.g. excessive growths of undesirable aquatic plants. (A summary of possible effects on the Bay–Delta system is given by Goldman.[4]) The third and final criticism concerns the necessity to supplement the freshwater flows to the Delta as water withdrawals increase there and in the Sacramento Valley; this would likely require impoundment projects on the rivers of the State's north coastal area, namely the Eel, the Klamath and the Trinity. According to Gill, Gray and Seckler, Project critics cite the effects in the north coastal area as including: destruction of "one of the last refuges of nature in California"; destruction of the area's valuable fishery resources; and the accumulation of silt in upstream areas with its attendant effect, the

SOURCE: Adapted from California Department of Water Resources (1966)

Fig. 1. The California State Water Project.

degradation of downstream beaches that depend on the rivers' silts to replenish natural beach erosion.

Impacts associated with typical projects

The California State Water Project illustrates some of the effects that are included under the heading of "environmental impacts". A more general overview of the impacts commonly

*Table 1. Types of environmental impacts commonly associated with Interbasin Water Transfers**

Area of impoundment	Along conveyance route
Submerges land area Modifies aquatic ecosystem (e.g. fisheries, insect populations) Modifies terrestrial ecosystem (e.g. wildlife habitat) Changes water quality and temperature Increases evaporation and affects microclimate Affects erosion and sedimentation Alters groundwater and geologic features Influences land use (e.g. recreation facilities near impoundment)	Using river channels Increases flows and changes groundwater recharge Changes water quality and temperature Alters fish production Changes riparian vegetation Modifies erosion and sedimentation Using canals Interferes with land access Destroys fish at intakes Decreases wildlife habitat Creates safety hazards for children Provides opportunities for recreation
Downstream from impoundment	Area of water use
Modifies hydrographs Affects groundwater recharge Changes aquatic and terrestrial ecosystems Alters water quality and temperature Modifies sediment transport Influences land use (e.g. residential development in flood plain)	Allows population to grow Accommodates expansion of urban centers with associated effects Supports expansion of irrigated agriculture with associated effects

* Adapted from Hagan and Roberts[5] and Ortolano[6].

associated with major water projects like interbasin water transfers is given by Hagan and Roberts.[5] They organize their discussion of impacts in terms of geographic location: (1) area of impoundment; (2) area downstream from impoundment or project diversion, or both; (3) area along conveyance route; and (4) area of water use. Table 1 elaborates on this four-part classification by indicating the broad categories of impacts associated with each of the areas.

In addition to the work by Hagan and Roberts, there have been several other general reviews of the environmental impacts commonly associated with water projects. Three such reviews, each focusing exclusively on a particular type of structure or activity, are contained in a report by the Stanford Workshop on the Environmental Impacts of Water Projects[6]: one concerns impoundments, the second concerns channel modifications, and the third concerns dredging and spoil disposal. Reviews of this type can provide a path into the widely scattered literature on environmental impacts; they can also provide the engineers and economists who have been traditionally involved with water resources planning with insights into the broad range of impacts that need to be considered in the course of an environmental assessment.

ENVIRONMENTAL ASSESSMENT METHODS

Having provided a definition for the term "environmental impact" and an indication of the environmental impacts commonly associated with water resources projects, we now consider the methods used in carrying out such assessments. These methods have been the principal subject of several recent textbooks and at least six survey articles or reports.[7]

Following Dickert,[8] we discuss environmental assessment methods in three parts corresponding to impact identification, prediction and evaluation (see Table 2). Methods for identification consist of materials that provide those conducting environmental assessments with general guidance on the types of impacts that *may* be associated with a particular type of project or activity. Methods for prediction include the kinds of standard procedures and mathematical models used by natural and social scientists and others to forecast the changes likely to occur as a result of a given project or activity. In contrast, methods for evaluation are techniques used in the process of putting a relative value on different impacts and establishing a preference ordering among alternatives. This differentiation between identification, prediction and evaluation makes it possible to distinguish between professional judgments on the nature of expected impacts (identification and prediction) and the kinds of value judgments that are associated with making trade-offs and ranking alternative actions (evaluation).

The first column in Table 2 divides impact identification procedures into four categories. First are checklists, i.e. lists of environmental factors to be considered (or questions to be answered) in analyzing the impacts of a given type of project component. For example, if the project includes an impoundment, the relevant checklist might call for an estimate of the extent of expected change in dissolved oxygen in the reach of stream below the proposed dam. The guidance issued by agencies often includes checklists to assist their field level planners in carrying out environmental assessments. A second category of materials consists of matrices (or tables) that array the components of a given type of project (e.g. dredging, spoil disposal) against the characteristics of the environment that may be affected by these components (e.g. dissolved oxygen, benthic organisms). A dot is indicated in cells of the matrix for which there is a postulated relationship between a project component and an environmental

*Table 2. Environmental assessment methods**

Impact identification	Impact prediction	Impact evaluation
Checklists	Single discipline procedures	Environmental evaluation procedures
Factors to consider	Air, water quality models	Judgments by panels or interdisciplinary teams
Questions to answer	Techniques for visual impact analysis	Weighted average of factors
Matrices	Noise forecasting techniques	
Network diagrams	Social science forecasting methods	Multi-objective evaluation procedures[c]
State-of-the-art reviews[a]	Biological science forecasting methods	Mathematical programming
		Statistical decision analysis
	Cross impact procedures[b]	
	KSIM	
	Systems dynamics models	
	DELPHI panels	

* Except where otherwise indicated, a discussion of the entries listed in the body of the table is given by Canter.[7]

[a] See, for example, the article by Hagan and Roberts.[5]

[b] A general discussion of these procedures is given by Sage,[9] and a discussion of application of these procedures in water resources planning is given by Mitchell *et al.*[10]

[c] An overview of these approaches is provided in Cochrane and Zeleny,[11] and applications in water resources are reviewed by Cohen and Marks.[12]

characteristic; sometimes numerical values are used to indicate the "strength" of this relationship. The third category of impact identification materials consists of network diagrams. These are ordered collections of boxes and arrows that are used to indicate the types of cause–effect relations that may be set in motion if a particular type of project is implemented; e.g. an impoundment may lead to thermal stratification which in turn causes a shift in dissolved oxygen concentration, etc. The fourth category of materials consists of reviews of the literature on impacts associated with a given type of project; the several reviews mentioned in the previous section (e.g. Hagan and Roberts[5]) illustrate this category of materials.

The second column in Table 2 concerns procedures for environmental impact prediction. These can be divided into two broad categories: single discipline procedures and cross impact methods. The former typically provide in-depth treatment of a small group of related factors and constitute the well established products of traditional research. This single discipline category can be described by examples: techniques used by sanitary engineers to predict water quality changes caused by the impoundment of free flowing streams; approaches developed by landscape architects to describe the visual impacts of water resources projects, and procedures used by biologists to estimate the effects of channel modification on fishery resources.

The cross impact methods represent attempts to account for the complete range of factors relevant to a particular forecasting problem when the underlying interrelationships are either too diverse or too poorly understood to be treated by single discipline procedures. An illustration of a situation that could require a cross impact method is the problem of forecasting changes in land use induced by a project providing flood control and recreation facilities. The variables affecting land use are wide ranging and the relationships between water project outputs and land use are not well understood. Table 2 lists three examples of cross impact methods that have been used recently in the context of water planning. Two of these (KSIM and systems dynamics models) involve the use of mathematical simulation modeling, and the third (DELPHI panels) is a procedure for utilizing the opinions of experts in making forecasts. Details of these applications and a discussion of other techniques in this cross impact category are given by Sage[9] and Mitchel *et al.*[10]

The third column in Table 2 includes two categories of procedures for impact evaluation. The first category consists of methods that have been devised by those concerned primarily with environmental assessments (as opposed to economic assessments); these methods indicate how the results from environmental impact analyses can be used to assist decision makers in ranking alternative projects. These methods typically rely heavily on the judgments of those carrying out the planning. One often noted approach, the "Leopold matrix", involves a matrix of the type described above in connection with impact identification procedures. In this case, however, the matrix is used in the context of a specific project, and the cells of the matrix contain two numerical ratings indicating the magnitude and significance of the interaction between the project component and the environmental condition associated with the cell. Other approaches in this category rely on the development of a single overall measure of a project's worth, as follows: First, all of the important factors (or indicators) that may be affected by the alternative projects are set out; this includes economic and engineering factors as well as environmental factors. For any one alternative, each of these factors is given a numerical score which in some sense reflects the extent of the project's impact in terms of the factor. Weights (i.e. measures of the relative value or significance of the different factors) are then ascribed to each factor and a weighted average of factors is computed; it serves as an index of the overall value of the alternative. Weighted averages are computed for each alternative and used to aid in the selection of a proposed action. A discussion and critique of typical applications of this approach to incorporating environmental assessments in water resources planning is given by Ortolano.[13]

The second category in the third column includes methods that have been devised by those concerned with the evaluation of alternatives in the face of multiple objectives. Although environmental quality may be included as one of the objectives, those devising such methods typically have a much more general orientation and are not preoccupied with environmental assessment *per se*. The general literature on this subject includes such topics as mathematical programming and statistical decision analysis and is reviewed in the works edited by Cochrane and Zeleny[11] and Zeleny.[14] The subset of the literature that concerns water resources planning has been reviewed by Cohen and Marks;[12] additional relevant materials are contained in Haimes *et al.*[15]

One of the issues that preoccupied many researchers in the early 1970s was whether or not a single, general-purpose environmental assessment method could be developed to meet the requirements for environmental assessments imposed by the National Environmental Policy act of 1969. In considering this question, the Stanford Workshop on the Environmental Impacts of Water Projects concluded that a single, general-purpose environmental assessment method was an impractical goal and not one that they would choose to pursue.[6] They preferred to leave aspects of methodology development to the numerous researchers in a variety of well established disciplines who had, for generations, been pursuing questions relating to forecasting the effects of water projects and evaluating alternative water resources proposals.

For the members of the Stanford Workshop, the key issues in ensuring that environmental factors received adequate consideration in water resources planning did not relate to environmental assessment methods *per se*; rather, the key issues concerned the ways in which the results from these environmental assessments were being (and could be) utilized in water resources planning and decision making. These issues are pursued in the remainder of this paper. The next section concerns results from studies documenting the extent to which the environmental assessments carried out in response to NEPA have influenced federal water resources planning and decision making. The section following it concerns ways in which the information generated as a consequence of environmental assessments can be integrated more effectively into processes for water resources planning and decision making.

INFLUENCE OF ENVIRONMENTAL ASSESSMENTS ON PLANNING OUTCOMES

In 1973 a series of research studies was initiated at Stanford University to determine the extent to which various federal water resources agencies were integrating environmental considerations into their planning and decision making in response to NEPA. Of particular concern was the field level implementation of the "environmental assessment process" set up by Section 102(2)(C) of NEPA and by the associated guidance issued by the President's Council on Environmental Quality.[16] This process requires a federal agency proposing an action that may have a significant impact on the environment to prepare a draft environmental impact statement (EIS). The draft EIS is to contain an environmental assessment of the proposed action and alternatives to it, and this draft is to be circulated for review and comment by other agencies and various segments of the public (e.g. citizens' groups). After the draft EIS has been circulated, the agency proposing the action must respond to any comments it receives by, at the very least, modifying the EIS. Other, more substantive responses to these comments include: the addition of so-called "mitigation features" (i.e. project components designed to offset adverse effects); the shift to a different action; or the decision not to proceed with any action. After modifying the draft EIS, a final EIS must be circulated before the agency can implement the recommended action.

Detailed case studies

Carmel River case study – As part of the above-noted research effort, Randolph and Ortolano carried out two detailed case studies of Corps of Engineers planning in Northern California. One of the case studies involved "pre-authorization planning" on the Carmel River in California.[17] Pre-authorization planning is preliminary in nature and generally leads to a recommendation for a specific action by the Corps of Engineers to Congress. The Carmel River investigation was initiated by the San Francisco District after the passage of NEPA, and thus it provided an opportunity to gauge the influence of NEPA on early planning decisions, especially decisions relating to the initial formulation and ranking of alternatives.

The Carmel River case study demonstrated that the attitudes of persons responsible for managing a planning study can play a key role in determining the extent to which environmental factors are considered (cf. White[18]). During the early stages of planning, the process of conceiving and formulating alternatives was dominated and controlled by the "study manager", a member of the San Francisco District's Planning Branch; the study manager focused on several alternative multi-purpose reservoir projects for dealing with flooding and water supply problems. The "environmental coordinator", the member of the District's Environmental Branch responsible for directing the environmental assessments, was unable to use environmental factors to broaden the range of alternatives. The one place where environmental assessments had a significant influence on decision making was in connection with the action that emerged as the one to be recommended. In this case, the detailed assessments conducted in preparing the draft EIS led to the introduction of various mitigation features in the project design (e.g. inclusion of provisions for a fish hatchery). It is noteworthy that the portion of the Principles and Standards calling for a plan emphasizing an environmental quality objective played a much more significant role than NEPA requirements in broadening the range of alternatives and in fostering substantive coordination between the environmental specialists and the study manager.

New Melones case study – A second case study concerned "post-authorization" planning, i.e. the detailed engineering and design studies carried out after Congressional authorization of a project. The particular study examined was the Sacramento District's planning for the New Melones project on the Stanislaus River in California.[19] Much of the planning had taken place prior to NEPA's passage, and the case study was designed to examine NEPA's influence on planning and decision making under these circumstances.

The influence of NEPA was, for the most part, restricted to effects on coordination and on the mitigation of adverse effects. With regard to coordination, the case study demonstrated that the process of review and comment on various NEPA related documents (e.g. the draft EIS) can be an effective means of generating useful information from other agencies and citizen's groups. In part because of limited distribution, this review and comment process was ineffective in soliciting information from citizens who were not affiliated with groups (cf. Hill and Ortolano[20]). With regard to mitigation, the information generated for preparation of various environmental assessment documents contributed to the introduction of the following project features to offset adverse environmental impacts: (1) a plan to preserve fish and riparian wildlife habitat areas to offset the areas of such habitat that were to be inundated; (2) the preservation of a 4 mile reach of stream suitable for recreational kayaking to partially offset the loss of a popular "white water" recreation area upstream of the New Melones dam; and (3) the purchase of land containing cave resources that would offset the inundation of what the National Speleological Society considered to be valuable cave resources.

The New Melones case study demonstrates the great difficulties involved in attempting to force an agency to modify its position in response to environmental concerns, when these concerns are made known very late in the planning process. The late stage opposition to the New Melones project was substantial: a law suit was filed, court injunctions were used to halt construction, supplemental environmental studies were ordered by the courts, and the citizens of California actually voted on a project related issue that was included as a proposition in a statewide election. Despite all this, there were no major changes in the project as it was conceived before the opposition began. As elaborated by Randolph and Ortolano,[19] there were significant institutional factors (e.g. agreements made with the US Bureau of Reclamation, financial commitments made to the project as designed) that constrained the Corps' ability to initiate a major re-analysis and a reiteration of their planning process.

Mail questionnaire surveys

Another aspect of the research on how NEPA has influenced federal water resources planning involved the use of mailed questionnaries administered to field level water resources planners in the Corps of Engineers and the Soil Conservation Service (SCS). Three different questionnaires were used, one for each of three different types of field level planning personnel in the District Offices of the Corps and the State Offices of SCS (i.e. planning supervisors, study managers and environmental specialists). Questionnaires were mailed out to each Corps' District Office and each SCS state office early in 1974. SCS returned a total of 139 completed questionnaires (99% response rate), while 103 were returned from the Corps (93% response rate). Complete details regarding the methodological aspects of the survey are given by Hill and Ortolano,[21] and a discussion of all aspects of the survey results is given by Hill.[22] Although the surveys yielded information on a wide range of topics, only a few of those topics will be noted herein.

Formulation of alternatives — One issue explored with the mail survey concerned the influence of environmental assessments on the formulation of alternatives. This was examined by asking respondents to answer several "project specific questions", i.e. questions that referred to a planning study that each respondent had been involved with recently. (These were "pre-authorization planning" studies for Corps respondents and the equivalent for SCS respondents.) One such question asked if any alternative actions or project modifications had been suggested as a result of environmental assessments done for the particular planning study that they were using to answer the project specific questions. Approximately half of the respondents indicated that environmental assessments had served this function. A second part of the question asked respondents who had responded in the affirmative, to indicate the nature of these alternatives or modifications. Most of the responses here could be categorized as either design modification (e.g. eliminating some channel modifications, reducing the level of flood protection) or fish and wildlife mitigation features (e.g. maintaining a minimum flow below a dam to protect fishery resources). Only three respondents in each agency indicted that a non-structural measure (e.g. flood plain zoning) was suggested, and virtually none of the respondents mentioned the so-called "no-project alternative" as a suggestion. Thus, while there were suggestions for new alternatives in roughly half the cases, most of the suggestions involved the types of features traditionally considered in project planning; non-structural approaches to dealing with water problems were rarely mentioned. It is significant that roughly half of the assessments did not lead to any suggestions regarding new alternatives. Taken together, these results suggest that environmental assessments were not being used to broaden the range of alternatives considered in planning by the agencies.

Evaluation of alternatives – Another issue explored with the mail survey concerned the influence of environmental assessments on the evaluation or ranking of alternative projects. This was examined by asking respondents whether any alternatives had been eliminated from further consideration on the basis of environmental assessments. In this case, only one quarter of the respondents answered in the affirmative. Those responding positively were asked to indicate the nature of the alternative eliminated. In nearly all such cases, the alternatives that were eliminated involved channel modification works. This may well reflect the high level of controversy surrounding channel modifications in the early 1970s. (See, e.g. the US House of Representatives hearings on this subject[23].) In any event, the results to this question do not suggest that environmental assessments played a significant role in eliminating alternatives. It could be, of course, that there were very few alternatives that should have been eliminated because of adverse environmental effects. The mail survey data cannot be used to clarify this point.

As Hill and Ortolano[24] point out, the overall conclusions to be drawn from such data depends very much on one's expectation regarding what NEPA was to accomplish. Based on their expectation that NEPA was to force federal agencies to consider environmental factors equally with engineering and economic factors in planning and decision making, Hill and Ortolano interpret the data as indicating that NEPA had not been very effective. Their more complete set of data indicate that, in the Corps and SCS planning studies underway in early 1974, NEPA had not greatly affected either the types of alternatives being considered or who and what influenced the formulation and evaluation of these alternatives.[24]

Organization design studies

One of the findings to emerge from the studies conducted by Hill, Randolph and Ortolano was that organization design seemed to play a significant role in determining the extent to which environmental factors are integrated into agency planning and decision making. Jenkins[25] pursued this subject by analyzing the designs of two water resources planning offices: the San Francisco District of the Corps of Engineers and the Santa Clara Valley Water District. The discussion below is restricted to the Corps District Office since it is of more general interest. Although much of what Jenkins did (e.g. testing hypotheses of the contingency theory perspective of organizations) is not germane to this paper, there is one aspect of his study that is especially relevant. It concerns questions relating to the extent to which different individuals and groups in a flood control planning study influence the study outcomes.

Jenkins carried out much of his data gathering by interviewing the planners and environmental specialists in the offices included in his investigation. In the case of the San Francisco District Office of the Corps, this involved interviews with the ten individuals in the District who were involved significantly in flood control planning at the time of his interviews (1975).

To examine who influenced the outcome of flood control planning studies, Jenkins divided the tasks in water planning into four categories: problem definition, alternative

Table 3. Amounts of influence of key participants in planning decisions: San Francisco District Office – Corps of Engineers, 1975

Decision making task	Amount of influence	
Problem definition	Local interests	4.1
	Superiors	3.7
	Planners	3.7
	Outside agencies	3.6
	Environmental groups	3.1
	Environmental specialists	3.1
	General public	2.5
Alternative formulation	Planners	3.9
	Local interests	3.7
	Superiors	3.5
	Environmental groups	3.3
	Environmental specialists	3.1
	Outside agencies	2.8
	General public	2.6
Impact assessment	Environmental specialists	4.5
	Outside agencies	3.5
	Environmental groups	3.5
	Planners	3.1
	Superiors	2.8
	Local interests	2.8
	General public	2.7
Plan selection	Superiors	4.0
	Local interests	3.9
	Planners	3.6
	Environmental groups	3.2
	Environmental specialists	3.0
	General public	3.0
	Outside agencies	2.8

Source: Adapted from Jenkins,[25] p. 277.

formulation, impact assessment and plan selection. Those interviewed were asked to consider the influence of the following groups: engineering planners, environmental specialists, supervisors and other superiors, the general public, environmental groups, and local interests. Each interviewee was asked to indicate the amount of influence of the aforementioned groups on a scale from 1 (little or none) to 5 (a very great deal). The results, shown in Table 3, indicate that the predominant influence of environmental specialists and groups is in the task of impact assessment. This reflects one of the major preoccupations of such specialists, namely, the preparation of environmental impact statements. Moreover, many of these specialists were under pressure to prepare EIS's for projects that were either under construction or part of operation and maintenance programs. Jenkins observed:

> Several respondents referred to the environmental unit as an 'EIS factory'. The pressure to prepare impact statements to meet legal requirements has kept environmental specialists from becoming very involved as members of project teams for planning studies.

Taken together, the results from all of the research studies referred to in this section indicate that the influence of environmental assessments on the outcome of water resources planning studies has not been great, and that there is a notable lack of integration of the results of assessments into other aspects of the planning process. (These observations are consistent with those made by White[18,26] in the context of large-scale water resources developments in Africa.) This lack of integration has been recognized by agencies like the Corps of Engineers, and efforts have been made to modify the ways in which water resources planning studies are carried out. The discussion below makes note of some of the research that has been used to guide changes in the Corps' planning process that are now being implemented.

INTEGRATING ENVIRONMENTAL ASSESSMENTS INTO WATER PLANNING

As indicated above, environmental assessments are very often divorced from other planning activities; they have often been conducted to meet procedural reporting requirements without being viewed as an integral part of planning. In 1972, a group of researchers in the Civil Engineering Department at Stanford, working in collaboration with the US Army Engineers Institute for Water Resources, began to think of ways to effectively link environmental assessment activities with more traditional planning activities. The result was a planning process, soonafter labeled the "iterative, open planning process" (IOPP), that was proposed for use in the District Offices of the Corps of Engineers.

Iterative, open planning process

The IOPP, which has been described elsewhere by Ortolano,[27] is based on a few simple concepts that have far reaching implications for the way in which water resources planning is carried out. The IOPP is "open" in the sense that it relies on continual two-way communication between agency planners and a wide range of interested citizens and government agencies beginning at the earliest stages of a planning study. The IOPP is iterative in that it calls for the concurrent (as opposed to sequential) performance of the four traditional planning activities: problem definition, formulation of alternatives, impact assessment and plan ranking. (For a description of water resources planning that relies on the sequential performance of these tasks, see Mussivand.[28]) At any point in the process, information from each of the four planning activities influences each of the other activities. For example, the assessment of impacts may reveal new concerns of affected citizens. Thus, the information from the impact assessment activity "feeds back" to the problem definition activity, which in turn, may be expected to influence the alternatives that are considered.

The need for an open process is based on the premise that the "public interest", which is mandated as the basis for decision making by federal water agencies like the Corps of Engineers, cannot be determined through objective analysis performed by technical specialists.[29]

Rather, the concept of the public interest is more appropriately conceived of in terms of a process whose direction and outcome can be influenced by the various agencies, citizens' groups, and individuals that may be affected. Other arguments commonly made by advocates of an open planning process are: other agencies and various elements of the public have relevant expertise and information to contribute to water agency planners; public participation is an important part of the process of placing relative values on environmental effects (planners cannot do this alone because no objective techniques exist for doing so); late stage opposition to proposals can be minimized by involving potential opponents in planning from the outset; and a host of recent laws and regulations require significant levels of public participation in water resources planning. (For other and often opposite perspectives on the appropriateness of public involvement activities, see Pierce and Doerksen.[30])

An iterative process is required if continual public involvement is to be encouraged and accommodated. As planning proceeds and information is provided to other agencies and various segments of the public, new concerns and problems may become evident. These newly delineated concerns and problems may call for the abandonment of previously favored alternatives, the formulation of new alternatives, the assessment of impacts that had not been previously considered, etc. With a rigid, sequential process, these types of activities are often viewed as setbacks and not as important opportunities to be responsive to the needs of the various affected interests.

There are several ways in which the IOPP serves to integrate environmental assessments into planning. For one thing, it makes no distinction between environmental impacts and economic impacts; all impacts that are relevant to decision making need to be analyzed and evaluated, regardless of their placement in one taxonomic category or another. Also, because of its deliberately iterative nature, the IOPP requires that information regarding the impacts of alternative actions be considered from the earliest stages of planning. In addition, the information from continual public involvement and inter-agency coordination can help those engaged in impact assessment to decide on which impacts to analyze in detail.

Another way in which the IOPP facilitates the integration of environmental assessments into all other planning activities is provided by the notion of "evaluative factors", i.e. "the goals, concerns, constraints, etc. that various decision makers and effected publics consider important in ranking alternative actions".[27] These evaluative factors are established on the basis of: the judgments of planners and technical specialists within the water agency, the requirements imposed by relevant laws and regulations, and the concerns of interested citizens and administrative agencies other than the water agency. Evaluative factors provide the basis for determining the impacts that need to be assessed in detail, and they play a central role in problem definition, the formulation of alternatives and plan ranking. As such, they serve to drive the entire planning process and link all four planning activities together.

The IOPP has gone beyond the stage of being an exercise in the articulation of concepts. It has, in many respects, been adopted by the Corps of Engineers in their regulations for implementing the Water Resources Councils' mandate for multi-objective planning.[31] In addition, as part of the overall effort to implement these regulations, the IOPP was subjected to a formal testing and evaluation process in a real-world planning context. Some of the results from this field test indicate potential problems in implementation, and these are noted below.

Potential problems in implementing the IOPP

The IOPP was field tested in the context of a study of flooding on San Pedro Creek in

Pacifica, California; the study, carried out between 1973 and 1975, was largely conducted by the San Francisco District Office of the Corps of Engineers. An account of the field test of the IOPP has been given by Wagner and Ortolano.[32]

The three results from the field test that are especially relevant to issues involving the integration of environmental assessments into other activities carried out as part of a planning study concern: (1) the study manager's lack of authority to control the timing of study activities; (2) difficulties involved in effecting early, substantive coordination with other agencies; and (3) problems associated with the use of interdisciplinary planning teams to coordinate the activities of technical specialists.

The first of these results concerns the ways in which various study activities are linked over time. The IOPP requires that information from environmental assessments be made available to decision makers before tentative conclusions are reached regarding which alternative to recommend. This information was not made available in a timely fashion in the field test, and the reasons can be traced to the limited authority of the study manager to control the timetable of the study. Although a Corps of Engineers study manager typically has great influence over the direction of a study (e.g. which alternatives are examined), he must go through formal channels in order to have study-related work performed by technical specialists in other organizational units. For example, before members of the Environmental Branch in the San Francisco District Office can conduct an environmental assessment for a study manager, a formal written request for the assessment must travel through channels to the Chief of the Environmental Branch. Upon receiving the request, the Environmental Branch Chief assigns the work to one or more of his staff members and indicates the time at which the work is to be completed. The study manager can exert informal pressure to have the work completed to meet his own scheduling requirements, but he has no authority to force his own scheduling priorities on the Environmental Branch Chief. The study manager's limited ability to control the timing of studies carried out by specialists can make it difficult to meet the coordination requirements associated with the IOPP.

The second of the field test results concerns coordination between Corps planners and staff members in other agencies. In commenting on the field test, Wagner and Ortolano[32] noted the advantages of doing more early, informal coordination than was actually accomplished. Personnel in other agencies indicated that they would have welcomed early involvement in planning and that this early involvement would have been useful. There is evidence to suggest that Corps planners frequently do not effect substantive inter-agency coordination early in their planning studies.[33] To the extent that such coordination is not carried out, the IOPP will be less than fully effective.

The third result concerns the use of interdisciplinary teams to coordinate the efforts of the various technical specialists involved in a study. Such teams are called for by the Corps of Engineers regulations implementing the Principles and Standards, and they could be useful in the context of the IOPP; for these reasons an interdisciplinary planning team was used in the field test. In evaluating the field test some of the District personnel indicated dissatisfaction with the effectiveness of the team leadership and complained that their time was not used efficiently during team meetings. These problems point to the need for extensive training of team members, especially team leaders, in various aspects of group decision processes.[9] The field test also indicated that the interdisciplinary planning team concept requires that members possess an identification with and a commitment to the team. These cannot develop unless the team concept is supported by the relevant branch and section chiefs within a District's hierarchy and unless staff members within these branches and sections are given adequate time to work within the context of the planning team. Both the general literature on the use of interdisciplinary groups (e.g. Galbraith[34]) and the more specialized literature on the use of such groups in water resources planning (e.g. Flack[35]) indicate that there are a host of factors like the ones noted above that have to be dealt with if planning teams are to be an effective organizational arrangement for implementing the IOPP.

Because of its similarity to the IOPP, the planning process recently adopted by the Corps of Engineers will likely lead to similar problems. Despite these problems, the Corps' new planning process should encourage an increase in the consideration given to environmental factors in *all* planning activities: problem definition, formulation of alternatives, impact assessment and plan ranking. This will be in contrast to the early 1970s during which time environmental factors were considered in the context of impact assessment, but seemed to play a much less significant role in the other planning activities.

CONCLUDING REMARKS

This paper has argued that the principal issues involved in the environmental assessment of water projects do not concern assessment methods *per se*, but the way in which the information developed from the application of various methods is utilized in planning and decision making. The various studies by Hill, Jenkins, Randolph and Ortolano demonstrate that much of the effort in conducting environmental assessments for federal water projects in the early 1970s was not being carefully linked with planning activities relating to the formulation and ranking of alternative actions. Rather, much of the effort was directed at producing environmental impact statements that often seemed to have little influence on the decisions reached in planning studies.

For those who feel that the results of environmental assessments are intended to influence all aspects of planning, including the activities carried out in the early stages of planning (e.g. the initial formulation of alternatives), there are grounds for optimism. A number of federal water agencies have made revisions in their planning procedures that encourage the consideration of environmental factors in all aspects of planning; the Corps of Engineers adoption of a process that is similar to the IOPP provides and example of this. Moreover, the portion of the Principles and Standards that requires the delineation of a plan emphasizing an environmental quality objective should significantly increase the extent to which environmental factors influence initial efforts to formulate alternative actions.

The 1970s represent a period of transition with regard to the way environmental factors are considered in water planning. As a result of NEPA and the Principles and Standards, and the increased levels of public participation in planning, field level water resources planners have been forced to give much more consideration to environmental factors then they have in the past. In some instances, this consideration has been superficial and responsive only to legal requirements to provide an environmental impact statement. In other situations, thorough consideration has been given to environmental factors in all planning activities. At this point, it is impossible to say whether this type of thorough consideration of environmental factors will become a characteristic of water resources planning in the United States.

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