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PLANNING THE DEVELOPMENT OF WATER RESOURCES

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ABSTRACT

The three major components of planning the development and allocation of water resources are: engineering investigations, economic evaluations, and environmental impact studies. A few recent developments in these components are described.

Computer simulation modelling has aided the engineering analysis of water resources in whole river basins as well as single dams. Economic evaluations are extending from comparisons of direct project benefits and costs to regional analysis, e.g. using input–output transaction matrices. Environmental evaluation techniques are illustrated by the Leopold matrix and the Battelle system.

Development planning techniques are themselves developing in response to demand for more detailed and diverse assessments.

INTRODUCTION

Until 1950, the dominant concern in planning the development of water resources in Australia was engineering feasibility. Australia is naturally deficient in water sources over most of the continent and, even in well-watered areas, the wide fluctuations between floods and droughts produce problems of reliability of supply.

In the period of post-war reconstruction in the late 1940s, the popular bandwagon was development of latent resources, and the popular game was to devise new and usually incredible proposals for overcoming the shortage of water resources. A variety of suggestions were put forward, including towing icebergs from the Antarctic and creating an inland sea in the Lake Eyre basin by constructing a channel 300 km to the sea. The common element of these proposals was that grandiose engineering works were the answers to problems. Engineering feasibility was the dominant thought in laymen's minds in those days.

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About 1950, interest in the economic analysis of water resources development increased substantially. Interest arose in many quarters in the benefits and costs associated with water resources development works, and in techniques for evaluating and comparing the benefits and costs. These techniques developed substantially in following years, and by the 1960s economic evaluation was the dominant popular concern in water resources.

Economic evaluation techniques were strongly influenced by the report of a sub-committee to the U.S. Federal Inter-Agency River Basin Committee. This document, known generally as the "Green Book" because of the colour of its cover, endeavoured to standardize procedures for evaluating those benefits and costs which could be readily expressed in money terms. Intangible benefits and costs such as recreational use of water resources, or the inundation of scenic areas, were mentioned but in general were not taken into account in the benefit–cost evaluation.

However, objectives other than economic efficiency entered into consideration in later methods of evaluation. Reports by a task force of the U.S. Water Resources Council in June 1969 and July 1970 established four major objectives to be considered in planning the use of water and land resources. These were:

(1) to enhance national economic development,
(2) to enhance the quality of the environment,
(3) to enhance social wellbeing,
(4) to enhance regional development.

United States legislation such as the Wild and Scenic Waters Act had already emphasized the importance of environmental aspects in water resources planning, and in 1969 the U.S. Congress passed the National Environmental Policy Act. This required that an environmental impact statement must be prepared before federal funds could be used for a resource development project. California's Environmental Quality Act of 1970 was patterned after the federal Act and requires similar impact statements to be prepared for projects involving state funds. Guidelines have been issued for the preparation and evaluation of environmental statements under this Act.

In Australia, the Federal Treasury put out guidelines in 1966 entitled "Investment Analysis" to be used in preparing economic evaluations. This was prepared on the basis that economic efficiency alone should be used in project evaluation when considering national investment, and that other objectives should be dealt with by political and administrative processes.

However, by the beginning of the current decade, this philosophy was recognized as inadequate. Recently, formal administrative structures for dealing with environmental control have been set up by the federal and all state governments. Both levels of government now require that environmental impact statements be prepared for all major proposed development works.

This brief review has been made to introduce the three major components which are now investigated in planning the development and allocation of water resources: engineering investigations, economic evaluations, and environmental impact studies.

In Australia, each new report which is submitted to the Government setting out a proposal for a major developmental work now includes these three components – a report on the engineering aspects, a benefit–cost evaluation of the economics of the scheme, and an environmental impact report.

Some aspects of recent development in these three components are discussed in the following sections.

ENGINEERING INVESTIGATIONS

Engineering investigations for water resources development include structural analysis of dam stability, prediction of demand for irrigation or hydro-electric power generation, design of pipe or channel reticulation systems, and many other aspects. For the purposes of this paper, only hydrological studies will be discussed.

These engineering investigations are much better developed than the corresponding economic and environmental studies. Techniques of hydrological analysis have developed to a considerable degree in the past two decades, and have now reached a high level of sophistication.

It is difficult to single out a particular technique as an example of developments in the field. If asked to name the one technique that has contributed most in recent years, I would suggest computer simulation modelling. This technique has been the common basis for development in many areas.

The most publicized use of computer simulation models in hydrology has been simulation of catchment water balance as a means of relating runoff to rainfall. The first of these models was the Stanford Watershed Model, but many others have been developed since. Computer simulation models are now available for study of the behaviour of whole regions of groundwater, the movement of pollutants in streams and estuaries, the behaviour of the water-supply reticulation network of whole cities, and so on.

In practice, the most important use of computer simulation is in modelling the storage behaviour of a single dam or a whole series of dams in a river basin. It should be noted that storage behaviours of these systems were simulated by manual calculation long before computers were available. The advent of computers has greatly increased the scope and depth of studies which are made, by increasing the amount of complexity which can be dealt with, and by increasing the number of alternatives which can be studied as a basis for decision making. It is these advantages which have had the most impact in practice, rather than systems-optimizing procedures or complex mathematical approaches.

Another development in planning water resources development is more a matter of philosophy than of technique. The much publicized *Limits to Growth* drew attention in an impressive way to the narrowing gap between increasing demand and finite resources of the world. In the same way that *Silent Spring* focussed concern over persistent pesticides in the environment, so *Limits to Growth* has focussed attention on the limits of available resources – including, of course, water resources.

It is becoming more commonplace to see assessments of water resources on regional and national levels, and to a lesser extent on projections of demand to the level of commitment of all available resources. The first task of the Australian Water Resources Council when it was set up in 1963 was to collate the necessary information and publish the *Review of Australia's Water Resources (Streamflow and Underground Resources) 1963*.

The projections of water-supply demand are proceeding, more appropriately, on a regional basis. Particular areas of concern are the capital cities, and water supplies for mining development in semi-arid areas where water resources are very limited. Some instances of the latter in Queensland have necessitated government participation in building water-supply dams to the ultimate hydrological capacity of the site beyond the immediate demands of a single mining company, in order that use of the only available dam site will not prohibit future developments by other companies.

ECONOMIC EVALUATION

The basic method of evaluating water resource development projects is benefit–cost evaluation, and developments in the use of this method applied to water resources development can be discussed in three phases.

Through the 1950s and early 1960s, there was considerable development in the ways of comparing benefits with costs. The ratio of benefits to cost, and the excess of benefits over costs, are alternatives to the internal rate of return, which is most used in Australia today. During developments in this aspect of the methodology, there was also considerable interest in the problem of defining what could be classed as a benefit, and what benefits could be included in an evaluation.

The basic benefit–cost evaluation procedure gives most emphasis to direct tangible benefits and costs which can be expressed in money terms as market values. Intangible benefits such as the promotion of employment in depressed areas, or costs such as the loss of areas of scenic beauty, could not be directly evaluated and so were omitted from the evaluation. This weakness was well known, and led to a second phase of development in which attention is being given to evaluating these 'extra-market benefits'. This term is used to indicate the essential feature of these benefits or costs – the lack of a market in which buying and selling determines the value.

One area where some success has been achieved is in evaluating the recreational benefits associated with developmental works. This is of particular significance in Australian water resources developments, which frequently have major recreational value.

Recently, the writer made a study of the recreational value of water storages constructed by the Irrigation and Water Supply Commission of Queensland. The commission owns and controls 10 dams and encourages the use of these for recreation by providing picnic facilities, boat launching ramps, toilets and other amenities. Counts of cars visiting six of the dams in the 1972/73 financial year were nearly 140 000 vehicles, as shown in Table 1. The figures indicate that individual visitors to the dams probably exceed 500 000 per annum.

TABLE 1 — Recreational use of water storages.

Storage	*Vehicle count (1972–73)*
Moogerah	19 867
Borumba	7 300
Tinaroo Falls	50 443
Leslie	26 232
Coolmunda	8 980
Wuruma	4 739
Atkinsons	22 324
	139 885

In addition, permits are issued without charge on request for the use of power boats on these storages. In the 1972/73 financial year, 546 new permits were issued for use of power boats on five of the commission storages, indicating the magnitude of demand for water-based recreational facilities. Using these figures, it was estimated that recreational benefits of these storages may have a total value of about A$2.5 million per year.

The third stage of development in economic evaluation which is only just beginning is an attempt to deal with another weakness of the early benefit–cost procedure: the problem of evaluating secondary and indirect benefits and costs.

In the past, all project benefits and costs were derived from within the boundaries of specific project areas. Vague guesses might be made about the possible benefits which flow from a proposed project to surrounding districts, or about additional costs to surrounding districts arising from a project. But project feasibility studies were generally restricted to the project area, looking out to the rest of the world.

The basic need is to assess the economic impact of a project upon all sectors in a region so that the significance of a major development project can be more adequately assessed. Relevant criteria include employment opportunities, capital requirements, export earnings, structural changes in industry and other facets of economic activity.

The basic technique for handling and analysing such information on a regional basis is that of input–output analyses. This is illustrated by the transaction matrix in Table 2, in which rows indicate the output from each sector to every other sector in the regional economy, and columns indicate the input to each sector from every other sector.

In this example, output from agriculture (A$120 million) makes up approximately one-tenth of all production (A$1338 million). A$4 million is paid to government as taxes; A$26 million is exported. Input to the agricultural sector includes A$10 million from manufacturing; A$10 million from transport and services, and so on.

Manipulation of the transaction matrix enables estimation of the direct and indirect effects of changes in one sector on every other sector; for example, an increase in government expenditure through subsidy or investment will directly influence agricultural output but may also require increased inputs from other sectors such as manufacturing and households (employment). The extent

TABLE 2 — Input–output transaction matrix (values in A$ millions).

	Agriculture	*Manufacturing*	*Transport & services*	*Wholesale & retail*	*Government*	*Households*	*Exports*	*TOTAL*
Agriculture:	48	2	2	1	4	37	26	120
Manufacturing:	10	139	2	10	36	108	29	334
Transport & services:	10	19	37	6	15	72	4	163
Wholesale & retail:	.5	22	6	3	11	57	–	104
Government:	5	16	18	6	10	81	–	136
Households:	37	102	87	74	63	21	–	384
Imports:	5	34	11	4	11	32	–	97
TOTAL:	120	334	163	104	150	408	59	1338

of adjustment required in each sector can be predicted using input–output analyses.

Application of simulation procedures enables further manipulation of basic input–output matrices to incorporate changes over time. Thus, by generating future cash flows between sectors and over all sectors, a comprehensive picture of regional development can be determined. Further, once the cash flows over time are estimated with and without the proposed investment project, the normal investment criteria can be applied to assess viability.

ENVIRONMENTAL IMPACT EVALUATION

There is a profusion of actions and effects involved in environmental evaluation of water development works. These effects occur in the storage areas, along the supply channels or pipelines, in areas of water use, and even downstream of these areas when wastes are discharged. The effects cover a considerable scope including the loss of wildlife habitat, submergence of items of archaeological and anthropological value, the loss of natural scenic areas, as well as problems of pollution, and so on.

It would be wrong to imply that the environmental effects are all adverse or harmful. Oscar Wilde described a cynic as "a man who knows the price of everything and the value of nothing". There can be substantial environmental enhancement by water development works in terms of creating wildlife habitat, creating scenic and recreational areas, as well as the major enhancements of the social and economic environment by provision of the water supply.

The need for some formal technique of evaluation is obvious when all these aspects of the environment are considered. Otherwise. there would be little chance of collating individual effects into an overall assessment or comparing one assessment with another.

A number of different techniques have already been proposed: historical cases; principles and theories; projections; inventories, accounts and indices; probabilistic methods; simulation models; laws, customs and institutions. Only a few methods have developed to the stage of practical application. Those methods which have found practical use can be grouped into three broad classes for ease of description.

The first type is the checklist which contains a list of many possible environmental effects. This serves to jog one's memory to look at aspects of a project which might otherwise be forgotten.

The second type goes further and gives comparative importance rating to each of the individual effects so that these may be compared with each other, and the total of one project compared with another project.

In the third type, the physical behaviour of the project is simulated, usually by computer simulation, and the interaction of the project and the environment can be evaluated in absolute terms.

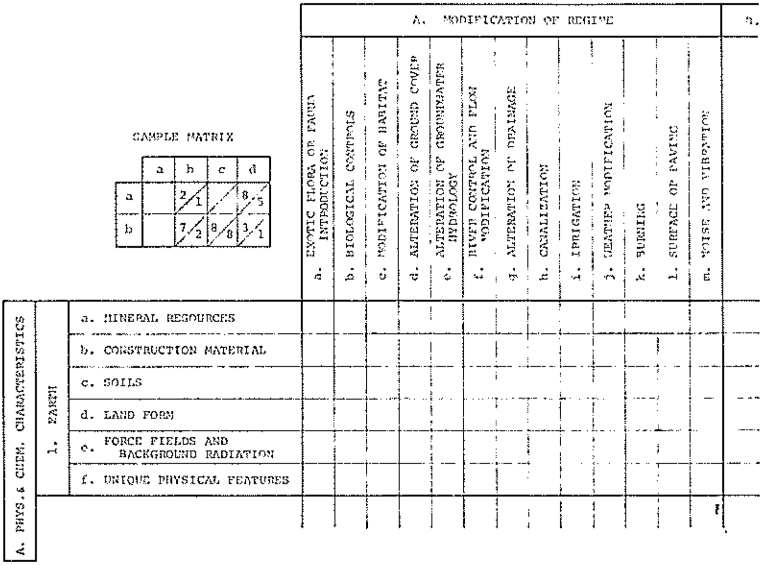

FIG. 1 — Part of the U.S. Geological Survey matrix evaluation system.

	A. MODIFICATION OF REGIME	B. LAND TRANSFORMATION AND CONSTRUCTION	C. RESOURCE EXTRACTION	D. PROCESSING	E. LAND ALTERATION	F. RESOURCE RENEWAL	G. CHANGES IN TRAFFIC	H. WASTE EMPLACEMENT AND TREATMENT	I. CHEMICAL TREATMENT	J. ACCIDENTS	OTHERS
A. PHYSICAL AND CHEMICAL CONDITIONS											
B. BIOLOGICAL CONDITIONS											
C. CULTURAL FACTORS											
D. ECOLOGICAL RELATIONSHIPS											
OTHERS											

FIG. 2 — Main components of the U.S. Geological Survey evaluation system.

Matrix Analysis by U.S. Geological Survey

The first type of technique mentioned above is best illustrated in the procedure for evaluating environmental impact developed by L. B. Leopold of the U.S. Geological Survey. The heart of the system is a matrix in which column headings list activities of man which modify the environment, and the rows list potential effects on diverse aspects of the environment.

The matrix serves as a reference checklist. Each intersection of a row and column indicates a potential interaction which should be considered. There are 100 activities listed in column headings and 88 environmental aspects in the rows, giving a total of 8800 possible interactions. Only a few of these will be relevant to any given project. Part of the matrix is illustrated in Fig. 1. The main divisions of the matrix are shown in Fig. 2.

To use the matrix, each interaction is checked for its relevance to the project under consideration. Where an interaction is likely to be significant, a diagonal slash is drawn across the box as shown in Fig. 1. A number from 1 to 10 is placed in the upper left-hand corner to indicate relative magnitude of the impact. A number from 1 to 10 in the lower right-hand corner is used to indicate relative importance of the impact.

In practice, a written report is prepared which includes discussion of the reasoning behind the numerical assessments given in the matrix. The matrix is intended to serve both as a checklist when preparing the report, and as a summary of the report. This method has achieved the widest publicity and use of all methods to date.

Battelle System for U.S. Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior contracted with Battelle Columbus Laboratories to develop an environmental evaluation system for assessing environmental impacts of the bureau's water resource development projects with respect to ecology, environmental pollution, aesthetics, and human interest. Measures of impacts in each of these categories are expressed in 'environmental impact units' to allow for explicit trade-offs between beneficial and adverse environmental changes. The system has four levels of information, as illustrated in Fig. 3.

The four major categories at the highest level – ecology, environmental pollution, aesthetics, and human interest – are divided into a total of 18 components. These are further divided into a total of 78 parameters. When using the system, each parameter is considered and evaluated as a separate item.

The authors of the Battelle system have incorporated two sets of value judgements, to provide an objective method of evaluation. Each parameter is assigned a relative weight, as shown in Fig. 3, which determines its relative importance. The weights are based on a total of 1000 for the whole system.

The second set of value judgements is given in the procedures for evaluating the environmental impact of each parameter. These

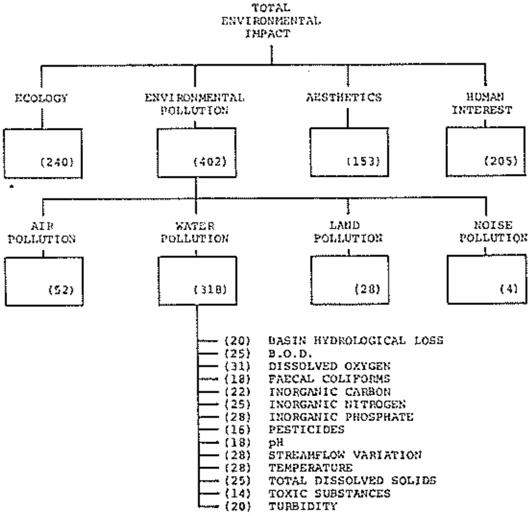

FIG. 3 — Structure of the U.S. Bureau of Reclamation system.

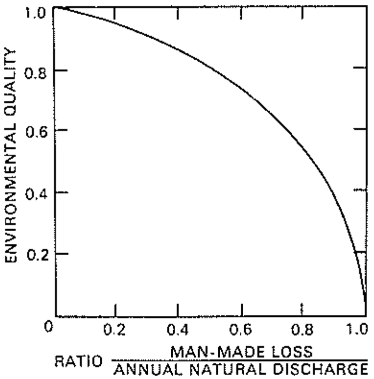

FIG. 4 — Value function for basin hydrological loss.

are best illustrated by an example. Fig. 4 shows the value function given for basin hydrological loss, i.e. the reduction in natural streamflow due to man-made losses. The ratio of losses to natural discharge determines an environmental quality value between 0 and 1.0. This value is multiplied by the 'weight' assigned to basin hydrological loss to give the environmental impact rating for this parameter.

As an example, say that the annual natural discharge of a river basin is at present not reduced by any diversions of water or 'losses'. A project to be evaluated will reduce the uncontrolled discharge by 50 percent, i.e. (Man-Made Losses) ÷ (Annual Natural Discharge) = 0.50. In the value function shown in Fig. 4, this results in a reduction of environmental quality from 1.0 to 0.8, i.e. a reduction of 0.2. In Fig. 3, the total environmental impact units allotted to Basin Hydrological Loss is 20. Hence the reduction in environmental quality, measured in the environmental impact units, is $0.2 \times 20 = 4.0$.

Each of the 78 parameters in the system is evaluated in a similar way, and the total of impact units gives a measure of environmental impact of the project. The system also incorporates the use of 'red flags' which are used to draw attention to items which are of major environmental importance in themselves.

This procedure allows for each of the 78 parameters to be considered on a common basis and allows one project to be compared as a whole with an alternative. The major characteristic of this system is that it provides a formal, straight-forward procedure for making quantitative evaluations, rather than the qualitative procedures described in the previous section.

I do not propose that the value judgements used in the quantitative assessments of the Battelle system be adopted or used in any way. The important point is that this method provides a way in which experience can be reported and communicated. When others prepare similar value judgements in this quantitative way, it allows for experiences to be compared against each other and pooled. This is the advantage over the qualitative matrix procedure.

Simulation Modelling

There have been many applications of computer simulation methods to studies of the natural environment. There are simulation models of whole terrestrial ecosystems such as grasslands, and of aquatic ecosystems in lakes. At the International Symposium on Modelling Techniques in Water Resource Systems, held in Canada on 9–12 May 1972, Holling reviewed the state-of-the-art in ecological modelling and gave reference to information sources in the subject.

Australian use of computer simulation methods applied to environmental studies of water resources has been mainly in the field of water pollution. The biggest application has been in studies of salinity in the Murray River, and models have been prepared by the River Murray Commission, the State Rivers and Water Supply Commission, the Engineering and the Water Supply Department of South Australia, and IBM's System Development Institute.

Computer simulation methods of assessing environmental impact differ from the methods previously described in two ways. First, the evaluation is far more precise and measures in absolute, real terms, rather than in arbitrary units or qualitative terms. Second, the precise detail dealt with makes it impossible to consider the entire range of environmental impact – social, economic, ecological, aesthetic, etc. – in a single model. Therefore, computer simulation modelling is more suited to detailed study of particular aspects, rather than broad-band assessment of the whole environment.

CONCLUSIONS

The problem of assessing the engineering, economic and environmental aspects of any works is never easy because of the very broad scope which is encompassed. The most noteworthy thing is that so much progress has been made in the development of evaluation techniques in the last few years, in response to a very rapid increase in demand for more detailed and more diverse assessments.

There is an apocryphal story of the eastern prince, whose father gave him a gift of 100 wives on his 21st birthday. As the prince is reputed to have said on that occasion – "It's not a question of not knowing what to do. The problem is where to start, and what can be achieved with the limited resources available."

No better words could be found to describe the situation today in evaluating the engineering, economic and environmental aspects of water resources development.