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WATER RESOURCES MANAGEMENT AND THE ENVIRONMENT : SOME CONCEPTUAL AND METHODOLOGICAL ASPECTS

*By Maynard M. HUFSCHMIDT**

1. INTRODUCTION

The years immediately following World War II saw the development and application of methodologies for comprehensive, multiple-purpose water resources planning and development, both in the United States (U. S. President's Water Resources Policy Commission, 1950) and later in a number of other developed and developing countries. Supporting analytical and synthesis methods and tools evolved from microeconomic theory and principles and practices of systems analysis into the methodology for benefit-cost analysis (U. S. Federal Interagency River Basin Committee, 1950 ; Eckstein, 1958 ; Maass et al., 1962 ; U. N. Economic Commission for Asia and the Far East, 1955). However, until the early 1960's water resources activities were directed primarily toward economic development associated with use of water for irrigation, hydroelectric power, navigation, urban and industrial water supply, and control of floods, water pollution control, fisheries, wildlife, and protection for aquatic ecosystems were secondary purposes at best and, especially in developing countries, largely ignored.

Although some advances were made during the 1960 s (Hufschmidt, 1985 a, pp. 318-324), major changes

* Environment and Policy Institute, East-West Center, Honolulu, Hawaii, U. S. A.

Profile

Dr. Maynard M. Hufschmidt, Emeritus Professor of University of North Calorina, is an internationally-known resource economist, professional planner and systems analyst. He is currently Senior Consultant at EAPI (Environment and Policy Institute) of East-West Center, Honolulu, Hawaii. Dr. Hufschmidt is also Coordinator of UNESCO's International Hydrological Programme Project on Alternative Methodologies for Integrated Water Resources Management with Special Reference to Humid Tropical Zones. He received his B. A. in General Engineering from University of Illinois, and both his master's and doctor's degrees in public administration from Harvard University. After his earlier careers as engineer and budget examiner in the U. S. Federal Government, he joined Harvard University Graduate School of Public Administration as research associate and Director of Research, Harvard Water Program, in 1955. Between 1965 and 1971, he was with University of North Carolina, as Professor of Planning and Environmental Sciences and Engineering.

occurred in the early 1970 s with the enactment of the National Environmental Policy Act (NEPA) in January 1970 in the United States (Andrews, 1976) and convening of the U. N. Conference on the Human Environment in Stockholm in the summer of 1972. Attention was focussed in both developed and developing countries on the often deleterious effects of development projects and programs on natural systems and environmental quality[1]. The requirements of the U. S. NEPA for preparation of an "environmental impact statement" for each proposed major development project provided a means of forcing consideration of environmental factors by planners and policymakers, as decisions were made on development projects.

An important consequence in the water resources field of this NEPA requirement was the development and testing during the 1970 s of a number of methodologies of environmental impact assessment and valuation of water resources projects. For example, trial methods were developed by the U. S. Geological Survey, U. S. Army Corps of Engineers, and U. S. Bureau of Reclamation for use in water resources project planning (Nichols and Hyman, 1982).

As early as 1962, U. S. national water resources planning principles and standards gave some consideration to preservation and enhancement of natural systems (U. S. President's Water Resources Council, 1962). Following enactment of NEPA, the U. S. Water Resources Council made successive revisions during the 1970 s of these principles and standards in order to incorporate environmental quality as a national planning objective. The most recent version of these principles and standards was issued by President Reagan in 1983 as guidelines for planning by federal water resources agencies. National economic development was established as the official planning objective, but an environmental quality account was included so that effects on environmental quality could be considered when decisions were made on project authorization and funding (U. S. Water Resources Council, 1983).

U. S. knowledge and experience with environmental impact assessment methods were drawn upon by developing countries during the 1970 s as they began to establish some forms of environmental assessment requirement. Help was also received from international donor and technical aid agencies (World Bank, regional development banks, UNEP, FAO, WHO) in the form of environmental assessment guidelines. In fact, no less than 92 guideline documents for environmental assessment in developing countries had been identified as of 1983 (Horberry, 1983).

Although increasing concern for the environmental effects of water resources projects has led to great expansion of environmental assessment activity in developing countries, with a few important exceptions (Hufschmidt, 1985 a) advances in methodology have been disappointingly small. This underscores the importance of examining the methodological dimension of environmental assessment, which is the subject of this paper.

2. CONCEPTS AND METHODOLOGIES

This discussion of environmental assessment methodologies in water resources development will proceed in the following sequence:

1. A conceptual framework for water resources management will be introduced in order to provide a structure for the appropriate consideration of environmental aspects in water resources management.

2. The methodology for the planning phase of water resources management will be examined in some detail to show how environmental effects, whether beneficial or detrimental, can be assessed and valued along with economic development aspects throughout the planning process.

1 The terms natural systems and environmental quality, as used in this paper, refer to the physical-chemical-biological environment. Taken together, the terms are synonymous with the general term environment as used in much of the environmental literature. The term natural system refers to ecosystems of various types--aquatic and terrestrial--in various degrees and types of management and use--watershed protection, agricultural, fisheries, forest, grazing, and water resources. The objectives of natural systems management are the maintenance of the renewable resource base and of ecosystem productivity, and the preservation of species and habitats. The term environmental quality refers to the state of the air, water, land, and human artifacts as affected by human activities and natural processes. The concern here is with the effects of changes in the state of the environment on receptors, including humans, plants, animals, and materials (Hufschmidt et al. 1983, pp. 2).

3. Using the conceptual framework for management and the methodology for planning as guides, an outline for identifying and quantifying environmental effects will be presented and the role of models discussed.

4. Finally, approaches and techniques for economic valuation of environmental effects will be presented within the context of efficiency-oriented benefit-cost analysis.

(1) Water resources management: conceptual framework

Conceptual frameworks for analysis of water resources management in general and watershed management in particular have been presented by the author elsewhere (Bower and Hufschmidt, 1984 and Hufschmidt, 1986) and will be only briefly summarized here[2]. As a start it is useful to look at water resources management as a system in which natural and human inputs are processed to yield useful outputs and, as a consequence of this processing, environmental and natural systems effects are generated. Historically, emphasis in water resources planning has been on the desired outputs of the management system, with little attention paid to unplanned-for effects such as erosion, sedimentation, pollution, channel degradation, waterlogging, and salinity buildup with consequent deterioration of ecosystems. The schematic shown in **Fig. 1** includes such environmental and natural systems effects, as a direct consequence of management of the system, along with the desired outputs. The logical consequence is that the water resources management system should be operated so that these environmental and natural systems effects,

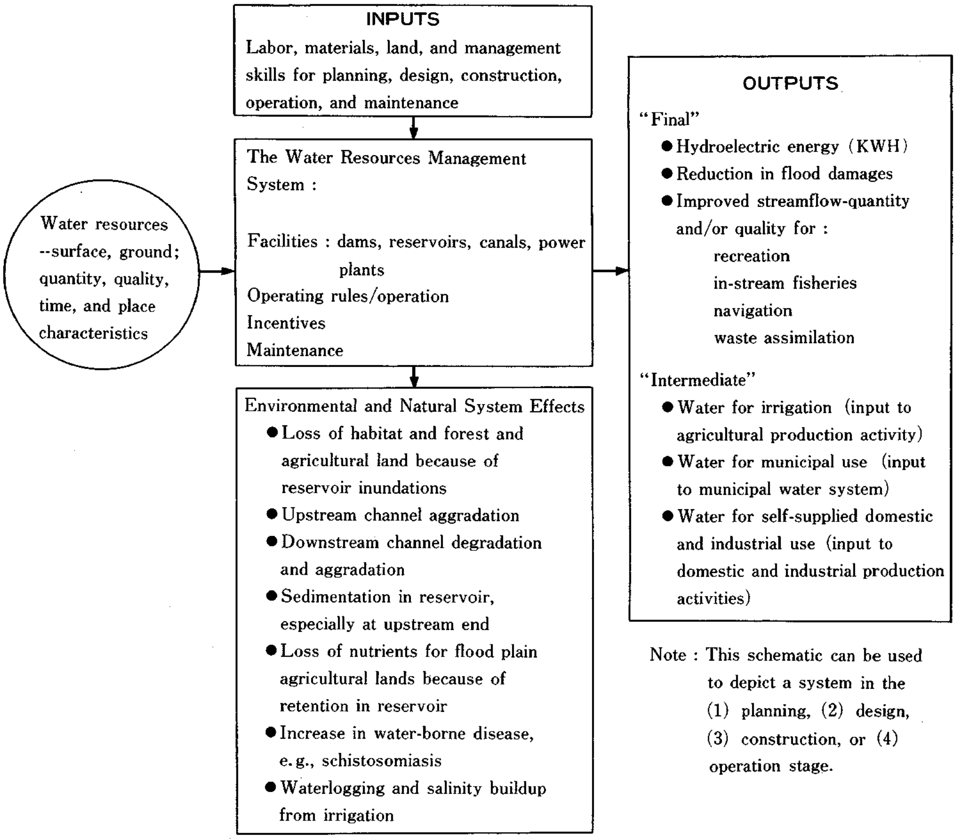

Fig. 1 Schematic of a generalized water resources management system (Bower and Hufschmidt, 1984).

2 Many other conceptual frameworks exist in the voluminous literature on water resources systems analysis and management. An important closely related example is that developed in the Netherlands under the project named "Policy Analysis for the Water Management of the Netherlands" (PAWN) (Goeller et al. 1983). Simplified versions of this methodology are contained in Koudstaal and Pennekamp (1983) and as lectures in the proceedings of a regional seminar on systems analysis for water resources development held by ESCAP in Bangkok, Thailand in November 1984 (ESCAP, 1985).

whether beneficial or adverse, are identified, quantified, and evaluated, and so that mitigating or compensating measures are taken to reduce or eliminate any adverse effects.

Three dimensions for analysis. Turning to the water resources management system or activity itself, one can identify three dimensions that are useful for analysis :

1. Management process which includes the sequential steps of project planning, design, construction or installation, operation and maintenance. Often these steps are combined into two : planning and implementation. It is clear that environmental and natural systems aspects should be included at every step of this management process. An example of how this would be done within the context of project planning and implementation under Asian Development Bank funding is shown in Fig. 2 (adapted from Rees, 1984). In this example, environmental and natural resources aspects are considered early in the process of project identification and are an integral part of the preliminary planning and detailed design stages of planning. Following project appraisal, environmental and natural resources covenants are incorporated in loan agreements. During implementation, environmental protection measures are included in construction or installation and operation and maintenance. Effectiveness of these measures is monitored and evaluated during implementation, and lessons learned are applied to new projects being developed.

2. Management system elements consisting of (a) management actions including physical facilities to be built and operated, (b) implementation tools, and (c) institutional and organizational arrangements for building and operating the facilities and applying the implementation tools. An example of this dimension as applied to watershed management is shown in Fig. 3 (Hufschmidt, 1986). In this example, the planned system includes not only resources management actions such as installing agricultural practices including contour plowing and strip cropping, but also the tools--regulations, technical help, subsidies--required to get the farmers to take these actions, and the institutional arrangements--legal codes, tenure systems, extension services--needed to apply the tools and make them effective. Two important points are revealed here : (a) that the separation of implementation tools ("ways of getting things done") from management

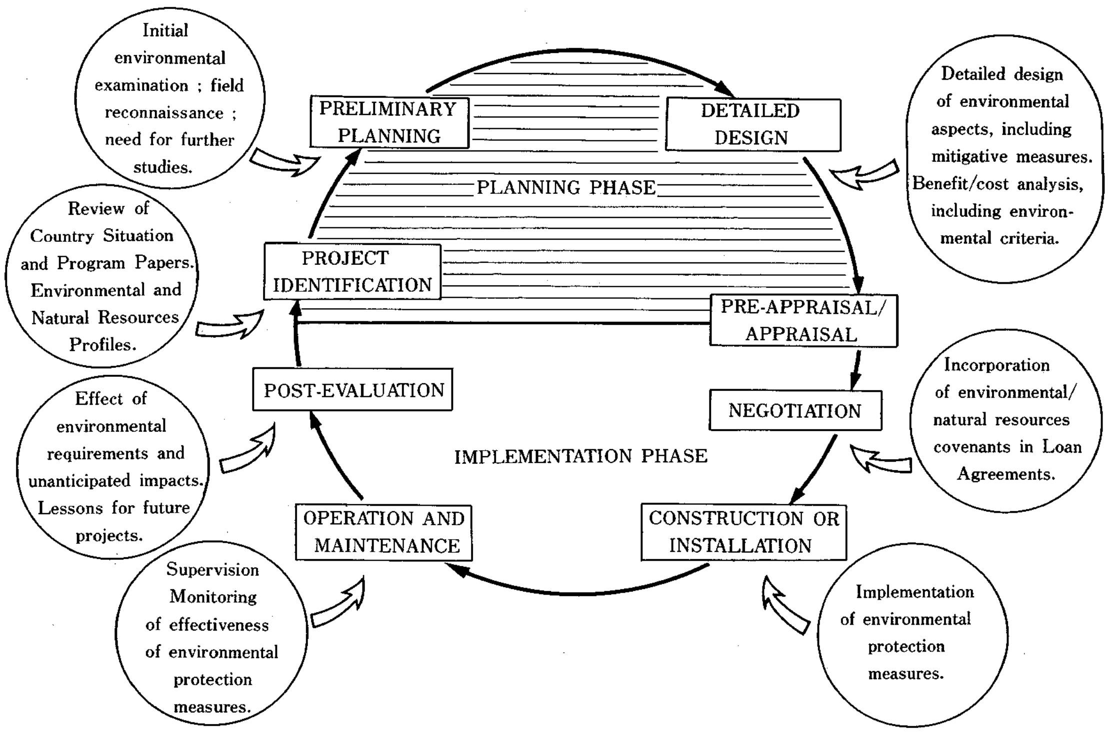

Fig. 2 Development project cycle showing environmental and natural resources inputs (Adapted from Rees, 1984).

actions ("things to be done") calls attention to the need for explicit consideration of designing implementation tools at the planning stage of watershed management; and (b) by specifically including institutional arrangements--both "rules of the game" and organizational--emphasis is placed on the key role that institutions play in the success or failure of watershed management. These points are especially important for successfully incorporating environmental quality and natural systems aspects into water resources management, because often special implementation tools and institutional arrangements are required for this purpose.

3. Management as a set of linked activities and tasks, which for analytical purposes can be identified as a number of specific steps that management agencies or other actors must perform in order to obtain the desired outputs and deal with the environmental and natural systems effects as illustrated in Fig. 1. For example, as shown for a surface water irrigation system with reservoir storage in Fig. 4, the upstream watershed must be managed; water must be stored, released from storage, transported to the irrigated area, allocated to subsidiary canals and to individual farms, and applied to the land with other factor inputs

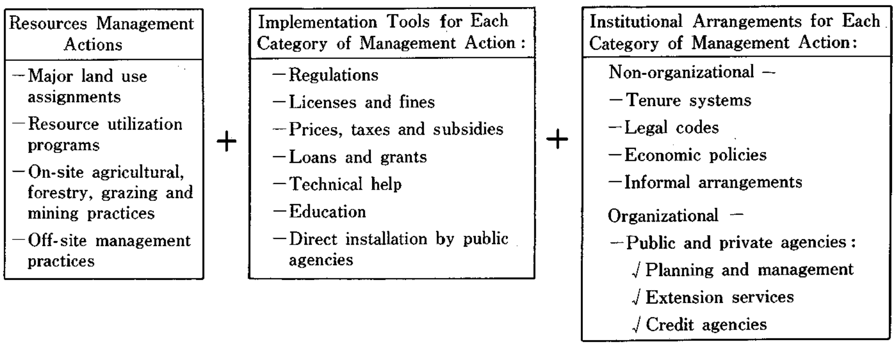

Fig. 3 Watershed management as a planned system (Hufschmidt, 1986).

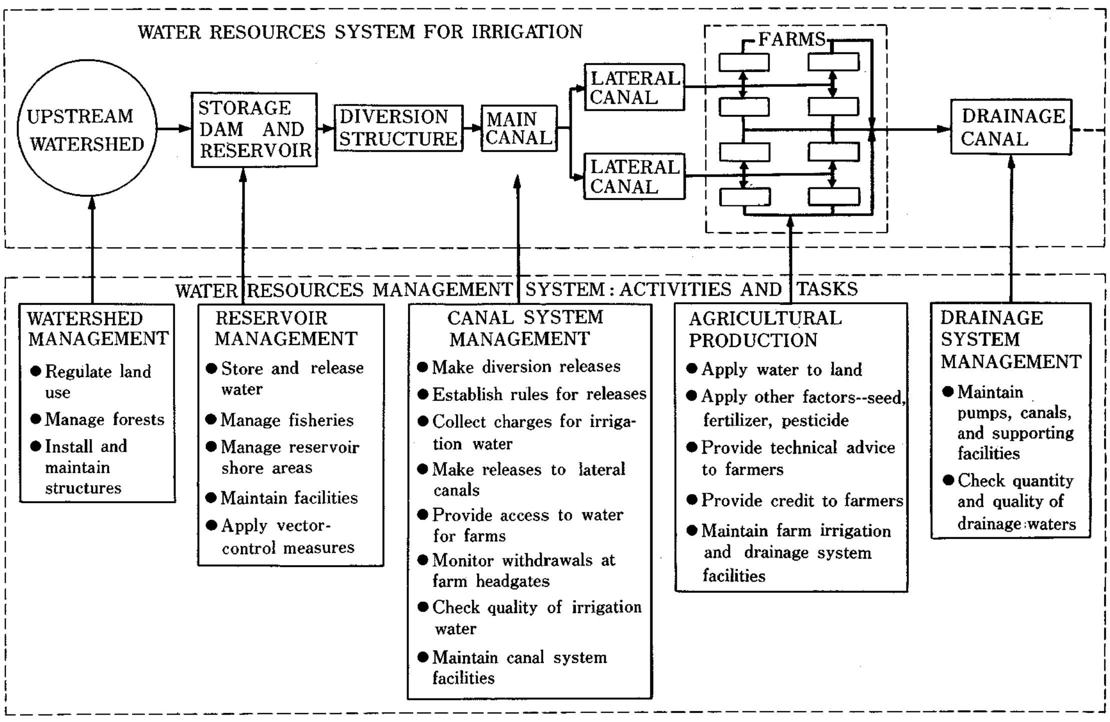

Fig. 4 Water resources management activities and tasks for a surface water irrigation system (Bower and Hufschmidt, 1984).

such as seed, fertilizer, and pesticides; and the irrigation return flow must be managed. Each of these steps consists of activities and tasks that require management action (Bower and Hufschmidt, 1984). This dimension of management can serve to highlight the specific management activities and tasks required to handle environmental quality and natural systems aspects. For example, erosion and sedimentation can be reduced by proper watershed management, water-related diseases can be controlled by applying vector control measures, and waterlogging and salinity caused by operation of an irrigation system can be dealt with by proper operation of the on-farm irrigation system and downstream drainage system.

This three-dimensional analytical framework for water resources management can be used both as a diagnostic and a planning tool. It can be applied by disaggregating management into specific tasks that are analyzed along each of the three dimensions. For example, as shown in Fig. 5, the reservoir relocation activity sssociated with a proposed water storage project can be analyzed at the planning stage, in terms of the management measures, implementation tools and institutional arrangements required to achieve the objectives of reservoir relocation (Hufschmidt and McCauley, 1988). Thus a reservoir relocation plan would include not only management measures such as the development of one or more new communities for the people being relocated, but also implementation tools such as subsidies and technical help, and institutional arrangements such as permanence of tenure and creation of a special technical aid agency to

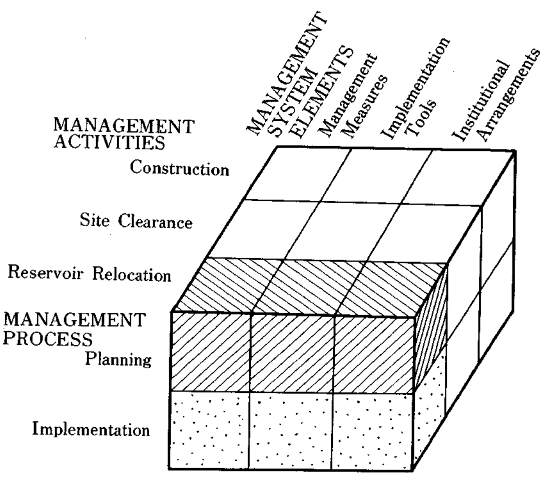

Fig. 5 Reservoir relocation as an activity of water resources management (Hufschmidt and McCauley, 1988).

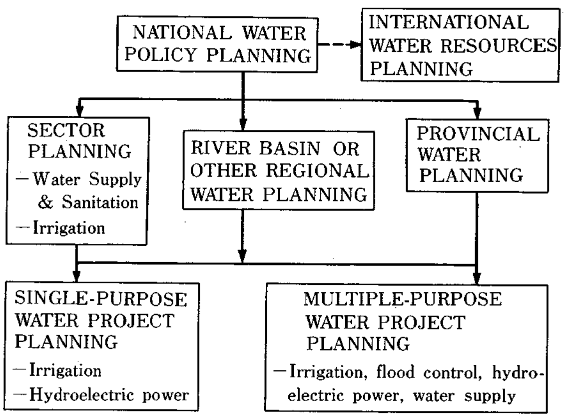

Fig. 6 Various contexts of water resources planning in developing countries.

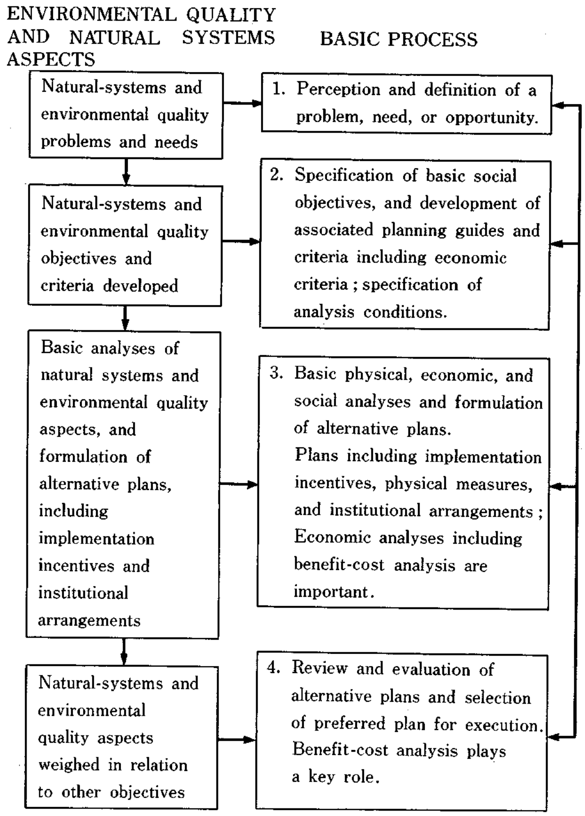

Fig. 7 Water resources planning process including environmental quality and natural systems aspects (Adapted from Figure 2.2 in Hufschmidt, et al., 1983).

help the relocated people make a proper adjustment to their new environment.

(2) Building environmental aspects into water resources planning

It is clear from the above that the planning stage of water resources management is a strategically important point of entry for environmental inputs to the management process. In fact, as illustrated in Fig. 2, environmental factors should be considered throughout the management process beginning with the earliest steps of planning.

Planning for water resources in developing countries occurs in a number of different contexts. At the broadest level (aside from international water resources planning) there are national water policy plans such as the one recently prepared in Bangladesh (Bangladesh Ministry of Irrigation, Water Development and Flood Control, 1986). In addition, as shown in Fig. 6, national sector plans are prepared for special aspects for water resources, such as agricultural/irrigation and urban and rural water supply and sanitation. At the sub-national level, there are regional/provincial water resources plans or river basin plans. At the most specific, detailed level plans are prepared for single-purpose or multi-purpose projects, often for irrigation, hydroelectric power, flood control, and water supply.

For each of these types of planning it is necessary to include an environmental dimension to the plans and policies that are products of the effort. How this can be done is illustrated in Fig. 7 in terms of a general water resources planning process (Hufschmidt et al., 1983). Planning usually starts with the basic recognition and definition of one or more water resources problems (floods, drought), needs (urban and rural domestic water supplies) or opportunities (hydroelectric energy, navigation, irrigation). Environmental problems such as erosion, sedimentation, water pollution, salinization can and should be defined at this early stage. The next step is to define the areal scope of planning (national, regional, river basin, project area), time scale and budget. In addition, basic social objectives (national economic development, regional development, equity) are defined at this step, along with the associated planning guides and criteria, including economic criteria related to application of benefit-cost analysis. At this stage, it is necessary to include environmental quality and natural systems objectives and related criteria. In the United States, these are included in the 1983 version of the Water Resources Council's Principles and Guidelines.

The core of the planning process is contained in the third step in which basic physical, ecological, economic, social, and financial studies and analyses are undertaken and alternative plans are formulated. As discussed in the earlier section on the conceptual framework, these plans are not limited to physical measures (dams, canals, power plants) but also include implementation tools (subsidies, extension services, regulations) and institutional arrangements (tenure systems, cooperatives) to help carry out the plan. Economic analysis plays an extremely important role in formulation of these plans.

The essential environmental and natural systems studies and analyses should be an integral part of this planning step. As each alternative plan is formulated, the effects on the environment and natural systems are identified, quantified, and valued in economic terms. Total monetary costs and benefits are assembled along with effects that cannot be quantified and monetized, for summary evaluation.

In the final step as shown in Fig. 7 the alternative plans are reviewed and evaluated and a preferred plan is selected for implementation. At this stage, all relevant information on the environmental quality and natural system consequences of the plans should be available. This will allow the environmental/natural systems consequences to be balanced with the economic development effects in the ultimate decision-making which occurs at this final stage of the planning process.

3. IDENTIFYING AND ASSESSING ENVIRONMENTAL EFFECTS

As pointed out by Lohani (1985), there are numerous manuals, guidelines, and other publications dealing with identifying and assessing environmental effects of development projects. Many of them, however, have limited applicability to developing countries where data are scarce and costly to obtain and trained manpower and finances are in short supply. Some water resources environmental assessment approaches specifically applicable to developing countries are those of the Organization of American States (1978) ; Interim Committee for Coordination of Investigations of the Lower Mekong Basin (1982) ; Tippetts, Abbett, McCarthy, Stratton (1980) on the Mahaweli Development Program, Sri Lanka; Engineering Science, Inc. (1983) on the Han River Basin, Korea, Environmental Master Plan; and Lohani (1985). Some of these are summarized in Hufschmidt (1985 a).

A useful approach is to look at environmental and natural systems effects of development as a causal chain in which human activities that use, affect or are affected by natural systems lead to changes in natural systems involving renewable natural resources and environmental quality which in turn lead to impacts on human health and economic and social welfare (Carpenter, 1983). When this approach is applied to a land-water system such as a river basin, the effects of human activities (such as a multiple-purpose water development project) on natural systems and receptors (humans, animals, materials) are identified and quantified, and the impacts of these changes on human health, the economy and social welfare are, in turn, identified and quantified.

Identifying the effects of water resources developments on natural systems at early stages of planning is often approached through use of checklists or networks such as the Leopold matrix and Sorenson network described in Nichols and Hyman (1982). A simplified checklist of this type is shown in Fig. 8 (Hufschmidt, 1985 b). Here, human activities that affect natural systems are listed in two broad categories :

1. Activities on land that affect water resources, and

Natural System Effects / Human Activities	Soil					Surface Water									Ground-water		
	Erosion	Salinization	Alkalization	Waterlogging	Nutrient Loss	Pollution-Salinity	Pollution-Toxics	Pollution-Organics	Flooding	Low Flows	Sedimentation	Depletion	Stream Aggradation	Stream Degradation	Depletion	Pollution	Salinization
A. On Land-Affecting Water																	
Forest-Commercial	×				×				×	×	×	×					
Forest-Protection	×				×				×	×	×	×					
Grazing	×				×			×			×						
Wildlife																	
Parks																	
Agriculture	×	×	×	×	×	×		×	×	×	×	×			×	×	×
Mining	×						×				×				×	×	×
Transport	×										×						
Industry	×						×				×				×	×	
Urban	×						×		×		×				×	×	
B. Involving Water-Affecting Land (and Water)																	
Dams and Reservoirs									×	×	×	×	×	×			
Hydro Power Plants													×	×			
Levees and Dikes									×		×						
Channel Works									×		×						
Irrigation Canals										×							
Navigation Canals										×							
Navigation Locks										×							
Harbors																	
Drainage Works		×	×	×		×			×						×		
Groundwater Pumps				×		×									×		×
Check Dams	×								×								
Fish Sanctuaries																	

Fig. 8 Illustrative natural systems effects of human activities (Hufschmidt, 1985b).

2. Activities involving water resources that affect the land as well as water.

This classification has the advantage of identifying all relevant human activities in terms of either or both land uses and water uses and technologies. A useful basis is thus provided for constructing more detailed checklists and networks and for undertaking detailed quantitative analysis of effects (Carpenter, 1985).

(1) Quantitative analysis of natural systems effects

In order to analyze the interaction of human activities with the natural system so that the results can be used in the detailed planning of alternatives, it is necessary to use models that portray the physical-chemical-biological processes at work. In the early stages of planning, these models can be relatively simple depictions of links in the causal chain, with indication of the direction of effects--increase or decrease. In the example shown in Fig. 9, increased agricultural production leads to higher rates of soil erosion which, in turn, (a) reduce the depth of soil on the agricultural land, and (b) contribute sediment downstream, which via the deposition and transport processes, increases stream bed deposition and suspended sediment load. These changes, in turn, can raise the level of nutrients in the stream, the level of primary production of biota and, ultimately, the level of fish production, with consequent effect on the fisheries activity (Hufschmidt 1985 b).

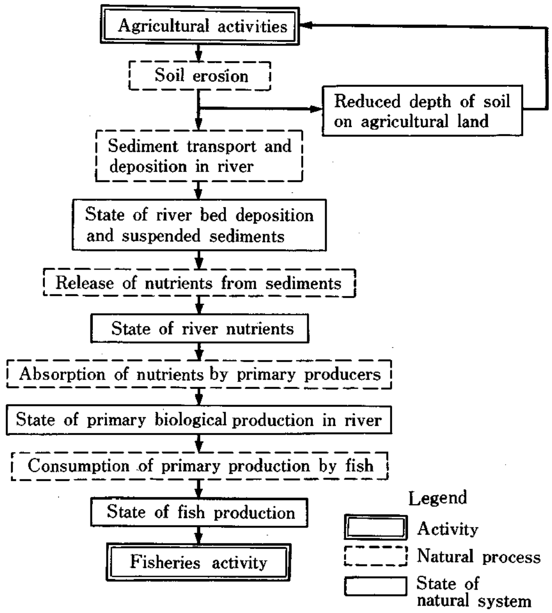

Fig. 9 Flow diagram of effects of agricultural activity on the natural system, including agricultural land, streams and fisheries (Organization of American States 1978).

Similar network diagrams, tracing the effects of human activities on other elements of the natural system and on other human activities can be developed for other phenomena including flooding, water pollution, waterlogging, and salinization. Examples of such diagrams are included in Hufschmidt et al. (1983), pp. 116 and 137, and in Organization of American States (1978), Appendix C, pp. 80-88.

(2) Natural systems models

As water resources planning proceeds and specific alternative land use patterns (e. g., agriculture, forest and grazing) and physical control measures (e. g., dams, canals, levees, pumping plants and wastewater treatment plants) are identified, it becomes necessary to quantify these natural systems effects in order to be able to estimate their impact on human health and welfare. For this purpose it is necessary to use more elaborate models capable of handling cause-effect phenomena in quantitative terms. Such models have long been in use with respect to hydrology in conventional water resources planning (Chow, 1964) but only in the past 20 years have models been developed to cover a broad range of natural system phenomenon (Basta & Bower, 1982).

Useful classifications of natural systems models are contained in Basta & Bower (1982) and Hufschmidt et al. (1983). Most modelling of natural systems uses one of two approaches, or a combination of them. These are (a) the statistical or "black box" approach, and (b) the conservation of mass and energy approach.

The statistical approach views the natural system as a "black box" in which the inputs are independent variables, the outputs are dependent variables and the internal workings of the black box remain unspecified. Examples of operational black box models are the Universal Soil Loss Equation and

Hydroscience Simplified Water Quality Models (Basta & Bower, 1982).

The conservation of mass and energy approach is the most common method for analyzing natural systems. The approach involves developing a set of equations for keeping account of the flow of mass or energy in a natural system. These mass-balance and energy-balance equations indicate that for any size volume in space--in air, water or soil--the change of mass or energy over any given time must be accounted for by either or both (a) inputs to or outputs from the volume and (b) transformations in the form of mass or energy within the volume. Analyzing a natural system according to these principles entails dividing the system into volume segments and tracing the movement over time of material and energy flows from segment to segment using mass- and energy-balance equations. Important examples of the conservation of mass and energy approach are : Stanford Watershed Model, Streeter-Phelps Dissolved Oxygen Equation, and the Agricultural Runoff Model. A comprehensive listing and summary descriptions of natural systems models are contained in Basta & Bower (1982).

4. VALUATION OF ENVIRONMENTAL EFFECTS

The outputs of the analyses using natural systems models will be quantitative and qualitative information on changes in natural systems and effects of such changes on receptors including humans. The next step is to estimate the significance of these changes and effects in terms of human health and welfare. Benefit-cost analysis is an extremely important technique for measuring the economic dimensions of welfare. Accordingly, the U. S. Water Resources Council has taken the position that to the extent possible, all environmental effects be monetized and thus accounted for under the "national economic development" objective (U. S. Water Resources Council 1983, pp. 103). Effects which cannot be readily monetized will be evaluated under the "environmental quality" account.

Valuation of environmental effects in monetary terms poses special problems that are beyond those encountered in conventional benefit-cost analysis. These problems arise largely because markets do not usually exist for the services of natural systems, e. g. , the gene pool characteristics of tropical forests, and some of the natural systems goods and services such as air and water quality improvements are "collective, " and cannot be exchanged in markets. In spite of these problems, considerable progress has been made, largely in the United States, in developing and applying economic valuation techniques to natural systems effects (Hufschmidt, et al. 1983; Dixon et al. 1988). The U. S. Water Resources Council (1983) has codified a number of such techniques in its principles and guidelines for water resources planning and the U. S. Environmental Protection Agency (1983 and 1988) has been promoting the use of such techniques in its regulatory activities. The U. S. General Accounting Office (1984) has reported that, although major problems still exist in applying economic valuation techniques to natural systems effects of development, the state of the art is sufficiently advanced that benefit-cost analysis has become a useful tool for guiding national decisions concerning natural systems and environmental quality.

Useful classifications of such economic valuation techniques are contained in Hufschmidt, et al. (1983) pp. 66-67 and in Dixon et al. (1988). A modified version is shown in Table 1, where the techniques are classified in terms of use of actual market prices, surrogate market prices, or hypothetical valuation via surveys and games (Gregerson, et al. 1987).

For example, the on-site effects of soil erosion, including the loss of agricultural, grazing and forestry productivity can be valued by applying market prices to the lost productivity. Similarly, the off-site effects of soil erosion involving loss of reservoir capacity via sedimentation can be valued by using market value of consequent reduction in hydroelectric energy, irrigation water and fishery productivity (Dixon and Hufschmidt, 1986, Chapter 8; Briones in Easter, et al., 1986, Chapter 15). Market prices can also be used to value the costs of preventive measures such as desilting structures or check dams, or replacement costs such as for pumps and turbine blades.

Surrogate market prices can be used to estimate the recreational value of streams, lakes or reservoirs

Table 1 A Typology of Selected Valuation Techniques.

	Valuation Technique	Examples of Applications	
		Valuing Costs	Valuing Benefits
1. Using Market Prices	(a) Changes in value of output	Decreased crop production due to erosion, siltation, contaminated water, or re-allocation of land ; change in value of fish catch.	Increased crop production due to decreased soil erosion ; crop increases from sediment enriched soils.
	(b) Loss of earnings	Value of productive services lost through increased illness and death caused by water borne diseases, e. g., shisto-somiasis.	Earnings losses avoided.
	(c) Preventive expenditures	Cost of intake water treat-ment, resiting of water in-takes, desilting structures, check dams.	Expenditures avoided.
	(d) Replacement cost	Cost of replacing damaged turbine blades ; cost of pump replacement ; compensation for production foregone.	Cost avoided.
	(e) Cost effectiveness analysis	Least cost way of achieving given water quality level or attaining certain erosion level.	——
2. Using Surrogate Market Prices	(a) Property or land value approach	Decreased land values due to erosion, sedimentation, or flooding	Increased property value due to increased producti-vity from reduction of erosion or flooding.
	(b) Travel cost approach	Recreational value lost if resource is harmed.	Value of a recreational fishery, lake, or beach.
	(c) Wage differential approach	——	Estimation of willingness of workers to trade wages for improved environmental quality.
	(d) Acceptance of compensation	Compensation for damage to crops or to health (e. g., Minamata disease).	——
3. Hypothetical Valuation	(a) Direct questioning of willingness to pay (or willingness to accept compensation)	Estimate of willingness to accept compensation for loss of use of a beach, pond or reservoir.	Estimate of willingness to pay for use of a reservoir fishery.
	(b) Tradeoff games	——	Estimate value of improved water quality or decreased soil erosion.

Source : Gregerson et al. (1987), pp. 60−61.

by applying the travel-cost approach which analyzes recreationists' travel behavior to estimate their willingness-to-pay for water-based recreation. Another example of surrogate market prices is the use of change in property or land values to estimate the economic losses associated with erosion, sedimentation, flooding or pollution (or alternatively, the economic benefits associated with reduction of these adverse effects).

Hypothetical valuation techniques have come into increasing use in the United States to estimate the benefits of water-based recreation via interviews and questionnaires (U. S. Environmental Protection Agency, 1983). An example of application of this approach to an urban public park in Thailand is contained in Chapter 7 of Dixon and Hufschmidt (1986). Because these approaches do not use market prices, the results require careful interpretation. In general, hypothetical valuation would be used only where market-price approaches are not practicable.

5. SUMMARY

Developing countries are becoming increasingly concerned with the adverse effects that water resources developments have on the environment and natural systems. However, few environmental assessment methodologies suitable for the special circumstances of developing countries are available. The need for appropriate methodologies and guidelines for developing countries has been pointed out by Lohani (1985) and others.

To develop an appropriate environmental assessment methodology for water resources developments requires a thorough understanding of the important dimensions of water resources management. To this end, an overall conceptual framework for the analysis of water resources management is presented in three dimensions : management process, management system element, and linked activities and tasks as shown in Fig. 5.

Environmental assessment begins at the earliest stages of the planning stage of water resources management. Although water resources planning in developing countries can take place at any or all of the national, provincial, sector, river basin, and project levels, environmental assessment needs to be incorporated in the planning in each case. Environmental problems must be identified, environmental objectives and criteria developed, and, as alternative water resources developments are formulated, environmental effects must be identified, quantified, and valued in economic terms. At the final stage when alternative plans are evaluated and a preferred plan is selected, environmental and natural systems consequences can then be weighed along with the economic development effects.

A useful approach to identifying and assessing environmental effects is to assume a causal chain in which human activities lead to changes in environmental quality and natural systems which in turn lead to impacts on human health and social and economic welfare. Using such causal chains, one can first identify environmental effects by means of checklists or networks, and then quantify the effects through use of appropriate natural systems models.

The final step is the valuation of environmental effects in economic terms. For this purpose, a number of valuation techniques using market prices, surrogate market prices, and hypothetical valuation methods have been developed and applied with some success, largely in the United States. The applicability of these valuation techniques to projects in developing countries is now being examined, and various guideline publications have been prepared including ones for the Asian Development Bank and the Food and Agricultural Organization (Hufschmidt et al. 1983; Dixon and Hufschmidt, 1986; Gregerson et al. 1987; Dixon et al. 1988).

In those cases where environmental effects cannot be valued in economic terms, they would be reported in quantitative terms where possible and evaluated in ecological, cultural and aesthetic terms for consideration along with economic valuation in the decision-making process.

Finally, conceptual frameworks and methodologies for environmental assessment and valuation represent only one step in the long process of assuring that environmental and natural systems considerations are appropriately handled in water resources management in developing countries. Many other actions are needed, including the application. testing, and evaluation of various frameworks and methodologies in actual planning and implementation situations.

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