WATER AND RELATED LAND RESOURCE SYSTEMS

Edited by

Y. HAIMES and J. KINDLER

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WATER AND RELATED LAND RESOURCE SYSTEMS

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The Editors

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PREFACE

This IFAC Symposium addresses myriad water and land resources problems and issues, as well as methodologies and procedures for respective solutions. Central to the Symposium's theme is the realization that these specific problems and complex issues transcend international, state, and political boundaries; and that improvement of the transfer of knowledge in water and related land resources is paramount to the well being of mankind.

Generic natural resources involve multiple use and need. Ever-increasing competition for water and land resources in agriculture, urban development, mining, energy, industry, et.al., necessitates more refined understanding of the hydrologic cycle, and various impacts that needs accommodation has both upon ground and surface water quality and quantity, and land use.

The systems approach -- through the use of modeling, simulation, and optimization methodologies -- has, over the last decade, markedly contributed to an appreciation of the distinct causal relationship between human activities and nature's response. This advance has consequently, led to better planning and management of water and land resources. In spite of such achievements, however, the systems approach has not yet commensurably, reached its potential.

Numerous explanations and reasons for this effect may be cited. Amont the dominant factors influencing this phenomonen are:

(a) Water and land resources models are not sufficiently credible.

(b) Water and land resources models are often developed without close collaboration with potential users, and thus, are neither realistic, useful, nor usable.

(c) An adequate system of technology transfer, maintenance, and user assistance for water and land resources models is unavailable.

(d) An appropriate training mechanism -- whereby managers, at all levels, acquire essential appreciation and understanding of model's capabilities and limitations -- is virtually non-existent.

This IFAC Symposium is aimed at alleviating the above critical problems by providing a proper forum of scientists and engineers, economists, political, and social scientists, public officials, consultants, and policy makers -- all interested or involved in water and land resources. Three designated plenary sessions, 14 technical sessions that feature 50 invited papers, three intensive workshops, various social activities, and field trips -- all symposium elements are structured to enhance dissemination of knowledge, know-how and operational information; and to lessen differences between the state-of-the-art in water and land resource systems, and actual use and implementation strategies.

Symposium Proceedings are organized in accordance with the technical program. Each session is identified by a letter, a numeral and a letter. The first letter denotes the day -- e.g., W for Wednesday, T for Thursday, and F for Friday -- the second letter denotes time of day: A for morning and P for afternoon. Finally, a numeral designates the session number within that specific part of the day. For example, W1A denotes the first session of Wednesday morning.

The Editors express appreciation to the IFAC Committee on Systems Engineering (SECOM) for sponsoring the Symposium and particularly to its Chairman, Dr. I. Lefkowitz; the IFAC Secretariate; IFAC-SECOM Working Group on Water Resources; the American Geophysical Union for cosponsoring and organizing the Symposium; Case Institute of Technology of Case Western Reserve University for cosponsoring and hosting the Symposium, particularly to Dr. M.A.H.Ruffner; The International Water Resources Association, the World Environment and Resources Council for cosponsoring the Symposium; to the International Program Committee and, particularly, its Chairman, Dr. Y. Sawaragi; to the National Organizing Committee, the Local Organizing Committee; to Pergamon Press; to all Symposium contributors, and to the Session Chairmen and Vice Chairmen.

Y.Y.Haimes and J. Kindler
Symposium Co-Editors

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BEYOND RESOURCE SYSTEMS

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Abstract. The paper has a twofold objective:

First, to point to the deficiencies of the orthodox, resources- or solution-oriented planning approach of resources systems, which focuses exclusively on economic benefits.

Second, to outline an alternative paradigmatic approach, the goal- or problem-oriented planning approach, conceiving of man, his culture and institutions, as well as of natural resources, as one complex super-system of interacting subsystems, with man-related optima of its own. Under this approach, the main problem would be the *transformation* of man, his culture, his values and his institutions, and the satisfying of his non-material needs--without disrupting the equilibrium of the symbolic environment--hand in hand with the satisfaction of man's material needs and the maintaining of sustainable steady states in the physical environment. *Resource systems development is seen as one of the principal vehicles for effecting this transformation.*

SCOPE AND TENOR

In choosing the topic of this address, I felt that the key to composing a key-note address ought to be that of an examination of the coupling of natural resource systems, the subject of the symposium, with the broader social, cultural and political context, in which they are embedded. I approach the presentation of this broader context, which encroaches on a number of disciplines that are not strictly within my own province, with some trepidation, in the hope that the loss of focus and resolution may be compensated by the insights that such a meta-systemic analysis might offer. The purpose of this paper is twofold.

First, to point to the deficiencies of the orthodox planning approach of resource systems, which focuses exclusively on extracting the greatest economic benefits from a resource system, while maintaining viable steady states. Under this approach, the socio-cultural and political dimensions are conceived of as an unavoidable "friction," which lowers the economic efficiency of the utilization of the resources system.

Second, to outline an alternative paradigmatic approach, conceiving of man, his culture and institutions, as well as of the natural resources, as one complex supersystem of interacting subsystems, with man-related optima of its own. Under this approach, the main problem would be to reduce the growing gap between the regulative requirements of rapidly changing society and the sluggish growth of its regulative capacity. To achieve this end, transformation--i.e. substantive change of man, his culture, his values and his institutions--and the related satisfying of man's non-material needs--without disrupting the equilibrium of the symbolic environment--will have to become major development objectives, going hand in hand with the satisfying of man's material needs and the maintaining of sustainable steady states in the physical environment. Development, conservation and utilization of natural resource systems--the basis for a substantial part of economic growth--*is seen as one of the principal vehicles for effecting this transformation, and it is therefore the duty of the planner to fully exploit this opportunity.*

I hope to show why in the LDCs (the less developed countries) a paradigmatic shift of this nature has become a *sine qua non* for convergence upon fundamental socio-economic goals, and why a similar shift is needed to enable DCs (developed countries) to move into the post-industrial era.

THE TWO PARADIGMS OF PLANNING

Two paradigmatic attitudes to analysis and planning can be distinguished: resource or solution-orientation and problem or goal-orientation.

The point of departure of *resources or solution-orientation* planning is a knowledge of resources and possession of ready-made solutions to harness these resources to supply man's material needs, by *promoting growth, without changing the existing structure and values of society*. Once such solutions are identified, the analyst will scan the planning space for situations matching solutions, and rank matches according to economic criteria. The inputs of solutions are natural and other economic resources; the outputs, the increase of the national product. The ranking criterion will be the volume of incremental product per unit of inputs.

The point of departure of *problem or goal-orientation* planning is identification of the problems that most weigh on society, and that impede growth and social innovation where they are most needed. Once these problems are identified, the analyst will proceed to devise specific solutions that promise to solve or attenuate them. Inputs will comprise, in addition to natural and other economic resources, interventions of change agents and participation of the mobilized target population; *outputs will include--in addition to well-distributed income streams--socio-cultural transformation and the satisfaction of man's non-material needs* that this implies. The ranking criterion will be the achievement of adequate need-satisfaction, together with the creation of capacities to facilitate future development and sociogenesis.

Resources or solution-orientation may be an acceptable short-cut as long as the conditions for which solutions were designed do not differ materially from those encountered, i.e. in periods of incremental change. But in situations calling for a radical transformation, or where the kit of solutions has been transposed from one socio-economic and political order in which it had been developed and tested, to a diametrically different one, it is doomed to failure.

My thesis is that the *major transformations taking place in the world now call for corresponding paradigmatic shifts*. The need today is for planning that is *problem-oriented, yielding new prototype solutions to match the problems* that have arisen in both the less developed and the developed parts of the world. DCs are under pressure to move out of the disorder and confusion of the late-industrial era, into the so far uncharted era of post-industrial society. LDCs are driven to make the even more radical switch from traditional passivity, to the dynamism of a transitional economy. Moreover, the growing interdependence within and between the North and South calls for supranational cooperational and synchronization on an unprecedented scale.

Becoming problem-oriented means raising one's voice for man and his needs, material and non-material alike. *In my presentation I will attempt to relate the analysis of natural resource systems--especially water and land resources--to associated social contexts, using the problem and solution-oriented approach.* This broader view has now become a necessity because the main problem is no longer one of developing resources to achieve maximum economic growth within existing societal frameworks, but rather *utilization of the resource development process to generate modifications in societal frameworks and motivation* that can promote a course of action satisfying both material and non-material needs, while maintaining sustainable steady states.

THE SOCIAL DIMENSIONS IN PLANNING

Planning for the needs of man means coupling a relatively well-structured natural resource system with an amorphous need system: the universe of discourse of man and society within which we have to consider human needs, differs from the natural resource system, above all, in nature and extent of uncertainty and of *inherent indeterminacy* in psychological and societal processes. Uncertainty may be reduced somewhat by future improvements in the state of the art; indeterminacy has to be accepted as a permanent characteristic of the planning space calling for flexible planning.

In planning the development and management of the physico-chemical dimensions of a resource system, we can clearly define an initial state and its inherent dynamics, the desired target state and the interventions (means) needed to reach it. When dealing with societal systems and the symbolic environments* which they create, the concepts of initial state, goal and means become blurred. The constructs used by social and behavioural sciences to interpret the symbolic environment are, unlike those of the natural sciences, subject to controversy and difficult to define rigorously.

To characterize the *initial state* of a societal (or a mixed) system and its inherent dynamics, we have to refer not only to directly observable facts, i.e. to the prevailing cultural, socio-economic and political situation, but also to what the biologist L. L. Whyte has called the evolutionary "*record*" [Whyte, 1962], that is to the historic trajectory on which society has travelled and which has become condensed into culture, customs, habits and personality. Human and societal systems are, *par excellence, "memory systems." Hence we cannot remain indifferent to the means we employ, the trajectory we choose, to achieve economic aims. Different trajectories will leave different "records," and different "records" spell different potentialities of future development for man and society.*

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*The term "symbolic environment" refers to the culture-specific social and psychological ambience that molds us and from which we receive most of our external stimuli.

Neither can *goal* or *target* in societal systems be defined deterministically; targets are a societal product and will thus change as society changes, while progressing towards goals. "Proper goals are always unachievable. They are an arrow and not a point" [Mack, 1971]. Moreover, the incorporation into resource planning of targets related to a particular "profile" of man's non-material needs implies the definition of the "good society" and the type of man we aspire to create through development. This raises two fundamental problems: how can our chaotic society presume to define the nature of Utopia? and how can the delegation of authority to define Utopia be legitimized? Finally, resistance to change is likely to arise from the "record" of a "memory system," and the cost (in material and non-material terms) of change will be related to the departure from the "record."

The problem of "Utopia" will be less difficult, as long as we deal with "negative goals," i.e. as long as we "adopt the method of searching for, and fighting against, the greatest and most urgent evils of society, rather than searching for, and fighting for, its greatest ultimate good" (positive goals) [Popper, 1966]. However, when the basic needs are satisfied to some extent, the problem of defining "Utopia" will become troublesome. In the words of the German poet Hoelderlin: "What has, at all times, turned the state into hell is man's desire to make it his heaven." Most of the difficulties and risks associated with Utopia can be avoided by replacing planning based on rigid ideological commitment by *social experimentation, steered by performance feedback*; there is no better criterion to judge performance and relevance than acceptance by the target population.

The concept "means" in the societal context suffers from a similar indeterminacy. Means aimed at the satisfaction of one need will create contexts which will either promote or obstruct the prospects of satisfaction of other needs in a not fully predictable way, thereby creating strong (positive or negative) synergistic complementarities. Capacity constraints are often found to be relaxable by appropriate interventions. These dynamic characteristics will have to be taken into account in the scheduling, sequencing and phasing of interventions.

As a consequence of the imperfection of tools to define in advance, with any degree of accuracy, the initial status, the goals and the means to be used in planning complex development, the monitoring and review process will assume a dominant role. The deterministic blueprinting of the engineer will have to give way to an *open-ended sequential decision-making process* with built-in monitoring and review procedures. Development will assume the form of a *directed social experiment*.

OPERATIONAL OBJECTIONS TO THE INCORPORATION OF THE SOCIAL DIMENSIONS IN RESOURCE DEVELOPMENT PLANNING

The technocrat in us may interject here: "It is difficult enough to attempt to define sustainable steady states in natural resource systems and the regimes to maintain them. Why make the job impossible by dragging in the amorphous and abstruse socio-psychological dimensions?" We have to look for an answer to this objection in two directions.

In the first place, the prime concern of development is man and his material and non-material needs, and the creation of individual and societal response patterns to facilitate the acceptance of programs for the achievement of these needs, of sociogenesis and of social stability. After so many years of planning with an economic growth bias, it would not be a bad idea at all to stand the development paradigm on its head and gear development planning to man instead of man to development planning; to consider, for some time to come, the "growth" of man and institutions as the primary development goals, and economic growth as "reinforcers" (in the sense given to this term in behaviouristic psychology). In the formulation attributed to Pericles:

> States should not merely be evaluated in terms of their ability to function efficiently as states, but far more in terms of the types of personality and character they produce among their citizens and of the opportunities they offer to all citizens for individual development.
> [Quoted in Deutsch, 1966]

Properly planned development programs provide the only effective opportunity to achieve this molding influence by engendering the relevant learning functions. Without such development, every attempt to substantially modify culturally-rooted response patterns and speed up sociogenesis must remain empty rhetoric. In this respect, Marx's thesis of dependence of the cultural "superstructure" on the economic underpinning is valid. However, there also exists an inverse relationship, completing the loop connection between the cultural superstructure and the production system. It may be true that an effective society cannot be built on social ethic alone; but without it, it cannot be built at all [Hirsch, 1978].

The other argument for incorporating the *socio-psychological dimensions in resource planning* is the almost universal evidence that the performance (even in purely socio-economic terms) of programs that have neglected these dimensions is inferior to that of programs that have fully incorporated them.

In actuality, the incorporation of the social dimensions into the planning process will prove less formidable than it would appear at first sight. What we have to ensure is not to pass through fully defined target "points" in the social space, *but to steer the target population and economy towards zones in which the desired adaptation* will become more probable, and to create appropriate *incentives to promote adaptation. Transdisciplinary aspects* of planning can be confined to *strategy formulation* and coordination. Detailed planning and implementation, within these strategic confines, can be entrusted to existing institutions, and can be conducted with the rigour and resolution that can be achieved in every discipline. We can simplify the planning task by employing the *"mixed strategy"* recommended by Amitai Etzioni [Etzioni, 1968].

THE LIMITS OF SELF-REGULATION

A different type of objection will be voiced by the *economic profession.* Neo-conservatives will caution us against burdening the inefficient public sector, especially in the less institutionalized LDCs, with additional complex and sensitive duties. They will claim that too little trust is placed in spontaneous adaptation and in the market mechanisms. Up to a point the argument is justified. Public intervention cannot match the flexibility and variety-processing capacity of market self-regulation. When facing a failure of the unregulated market, our first thought should, therefore, be to provide a set of corrective incentives to convert Adam Smith's "invisible hand" into what Fred Hirsch has called a "guided invisible hand," rather than imposing rigid controls [Hirsch, 1978].

Exclusive reliance on passive adaptiation and the market mechanism, however, has its limitations. Firstly, uncritical champions of the market tend to compare the Platonic "idea" of a "perfect" market--rather than its actual indifferent performance--with the grey reality of public sector performance, obviously an unfair and misleading comparison. Secondly, a number of important situations can be identified in which the market mechanism operates only very imperfectly.

Generally speaking, the market is an excellent instrument for producing reactive adaptation; it is much less effective in producing future-oriented changes, which might involve great uncertainty, long time horizons or might require *major restructuring* in the production process, the public attitudes or life styles. To use biological terminology, market self-regulation excels in *adaptive specialization* to existing "niches"; it will not give rise to *adaptive generalization*, i.e. the capacity to adapt to radically different conditions [Dunn, Jr., 1971]. Exclusive reliance on adaptive specialization and failure to maintain adaptive generalization is liable to end up in "evolutionary traps."

Two closely related examples of recurrent failure of the market mechanism in the development of resource systems illustrate the need for collective action predicated upon major social, economic, institutional and political restructuring as well as changes in social ethos. The first example comes under the category of "Tragedies of the Commons," the second under the category of "The Prisoner's Dilemma."

<u>Tragedies of the Commons</u>, as they have been called, are, of course, the most conspicuous example of a market failure in situations in which the yield of collectivley exploited, but unregulated, natural resource systems is limited. Exploitation beyond capacity is liable to result in a degradation of the system and its yields. Here Adam Smith's "invisible hand" will not guide individual decisions of self-interest to produce social optima, but will result in the cumulative deterioration of the "commons" (i.e., of collectively owned environments*) which will, before long, backfire on those responsible for the deterioration. One "Tragedy of the Commons" situation, for example, is overfishing, which, although rational from the individual fisherman's short-term point of view, will in the long run deprive him of his means of survival. The commons, degraded because of lack of collective restraint, may be the physical environment sustaining us; it may be the state with its competing social groups organized around a special interest; it may be other states in the same nation-bloc, or in another bloc; it may be the next generation [Wiener, 1979]. To avoid a "tragedy of the commons," we need not necessarily replace individual by planned collective action, but we have, at least, to produce through public intervention such incentives, disincentives or constraints as would orient individual self-interested decisions in the desired direction.

<u>The Prisoner's Dilemma situation</u> is another illustration of the failure of self-regulation. Simply put, this dilemma shows:

> . . . the rational individualist, in situations of social interdependence [in which he] knows that he does best when everyone else cooperates and he does not, for example, in ducking his contribution to a community project; he is then a "free rider," carried along on the cooperation of others. He does worst when only he cooperates, that is, when everyone else is trying to free ride. It follows that in the absence of coercive or self-enforcing arrangements to impose the cooperative lines of action on everyone except himself, or as a second best on everyone including himself, he will take the third best course of

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*The name derives from the "commons," the traditional, collectively managed, grazing ground of the English village.

> non-cooperation; this being individually rational (because it is superior to the fourth best outcome when only he cooperates) even though socially irrational. [Hirsch, 1978]

In the contemporary scene, one of the most conspicuous illustrations of behaviour patterned on the prisoners' dilemma is the leap-frogging of wage claims irrespective of their obvious counterproductive inflationary effect.

Such and similar failures of market regulation are typical for eras of transition in which the social morality which had sustained the operation of the "invisible hand" has disintegrated and no new ethos has yet arisen [Hirsch, 1978].

There can be no doubt that we are now entering such an era. Serious imbalances have developed in our resource systems and in the ecology of our physical, economic, symbolic and political environments. Technological developments, and especially those in the information processing, communications and microbiological fields, have been creating revolutionary changes at a rate that could not be matched by social adaptation. The neglect of man's non-material needs has eroded social cohesion, exacerbated social strife and induced attitudes patterned on prisoners' dilemma games. In DCs, national politics have blocked adaptation to the needs of global interdependence, and the all-important symbolic environment is in disarray. In most LDCs, the political regime--whose interest usually lies in the modern sector--impedes the stagnant traditional sector's progress towards a transitional economy, which would promote self-sustained economic growth, social equity and sociogenesis.

THE ROLE OF IDEOLOGY

In 1960, Daniel Bell pronounced the end of ideology [Bell, 1960]. Twenty years later, while accepting the fact that the old ideologies have lost most of their relevance, one would still have to insist on the indispensability of ideology, especially for the motivation of transformation. In the words of the French anthropologist, Claude Lévi-Strauss:

> One of the cruxes of our political thinking is that we continue to live against an ideological backdrop devised in the past to fit either theoretical societies or real ones--none of which were comparable, either in degree of complexity or in order of magnitude, with the societies to which we ourselves belong . . . All societies contain a vast irrational element and it would be as absurd as it would be dangerous to choose to ignore this and to get down on paper the outlines of a totally rational society. Societies cannot be like that, no society ever has been, and we have to come to terms with this. [Lévi-Strauss, 1979]

The ideology we now need to halt and reverse the "tragedies of the commons," resolve the prisoners' dilemmas, and induce anticipative future-oriented adaptation, is an ideology of *social and international responsibility* made possible by rising levels of consciousness in the structuring of social and political regulation and control [Vickers, 1979]. This would represent the rational face of the new ideology. However, as Max Weber has stressed, to strike roots, ideology must contain both goal-rationality and charisma, in a combination in which each element would reinforce the other [Aron, 1970]. Only such a "hybrid" ideology could generate the values and the symbols to mobilize the whole of man, and this is, as history testifies, the secret of success.

THE ROLE OF LEARNING PROCESSES IN THE DEVELOPMENT OF RESOURCE SYSTEMS

The engineer or agronomist will be familiar with ways of effecting physical changes in water and land resource systems. He might, perhaps, also be aware of the need to disseminate new technology, but he will usually be oblivious of the need to induce complex *learning processes* creating "behaviour-organizing behaviour pressed into the service of designing and implementing new behavioural modes" in the social, cultural, institutional and political spheres [Dunn, 1971].

In situations in which the effective development and utilization of resource systems depends on major societal transformations (and this is the case in most development programs in LDCs), learning processes, and especially those related to the non-technical dimensions, assume special importance. Learning has to be induced at a number of levels [Bateson, 1972].

Learning to learn, what Kurt Lewin has called the "unfreezing phase" of transformation [Lewin, 1964], and Gregory Bateson *zero-learning*, means creating readiness to learn by overcoming the inertia rooted in habit, custom, culture and ideology. In the LDCs, the most effective locus to apply zero-learning has been demonstrated to be the grass-roots level.

Primary learning, i.e. learning in the narrower sense of the word, Lewin's "moving" phase, comprises mainly transfer of technology, skills and knowledge. Since people learn by doing, it has to be a highly participative process, with built-in "reinforcements" in the form of benefits generated by applying the new skills.

Every sequence of zero and primary learning will create new social contexts which will encourage *secondary or context learning*, Lewin's "freezing" phase of learning, comprising the adaptation in the social, cultural, institutional and political dimensions. *Appropriate contexts for secondary learning and provisions to promote, support and reinforce it will have to be part and parcel of the development program.* The adaptation of the social and cultural to the technical dimensions achieved through secondary learning will not only decisively advance the attainment of economic objectives, but it will also promote social organization associated with these objectives and, in time, also political cooptation.

"Evolutionary experimentation is the fundamental character of the process of social learning" [Dunn, 1971]; its inherent indeterminacy will, from time to time, make it necessary to re-orient learning processes, in according with performance feedback. Bateson has called this level of learning *"tertiary learning."*

The inducement of goal-oriented multi-level learning processes will make new demands on development institutions and on change agents. It will require the drafting of new planning procedures, employing the social and hehavioural, as well as the technological and economic disciplines. It will call for new prototypes of programs and routines, and new types of performance monitoring and program revision.

In spite of recent changes in development rhetoric, the radical restructuring of planning and implementation envisaged is liable to encounter the resistance of the professional establishment. However, perhaps the time has come to shape planning methodology according to the needs of the people, rather than the preference of academe and professional guilds. We technocrats are in the habit of complaining about the shortsightedness of the political process, but we refuse to acknowledge that the political process has often been misled by solution-oriented and tool-deformed technocrats.

ILLUSTRATIONS OF THE APPLICATION OF THE GOAL-ORIENTED APPROACH IN DCs

Whatever social ethic we adopt within the confines of Western morality, *we shall have to posit man, and the satisfaction of his material and non-material needs, as the ultimate goal of development.* Yet in the economic calculus that dominates the political decision-making process, man is considered solely as one of the inputs--along with capital, technology, raw materials and land. Our educational system, our work design and our economic decisions are tailored to shape man, his skills and his motivation to maximize the input/output relationship.

In the past, the need to survive physically has forced society to adapt man to the requirements of an efficient production process and to tolerate the deformation this implies. Should we not now in the developed countries consider the opportunities for the self-actualization of man and the quality of society as the primary objective? An example from Australia's development history of water and land resources can illustrate the argument.

Some years ago, when the world market prices for Australia's main agricultural exports were at an unprecedented low, a heated argument arose on the subject of whether substantial federal funds should be allocated for further development of irrigated agriculture or used for further development of rainfed farming, although this would have meant a reduced rate of growth of agricultural exports. Economic analysis limited to the water and related land resource system concluded that, under prevailing conditions, further development of irrigation would not be justified on purely economic grounds. However, even a superficial understanding of the situation indicated that such a long-term problem deserved a much broader type of analysis. The more extensive nature of rainfed agriculture would obviously involve a more costly infrastructure (transportation, power, communication, education, health, etc.); it would result in a different settlement pattern, in a different conditioning and in a different micro-culture. A valid comparison would have to take all this into account. Before arriving at a conclusion on such a complex problem, we should not only compare the respective economic input-output ratios of the production systems proper, but also potential changes in the ratios as a consequence of anticipated developments in the world market, infrastructural investments involved, and above all, the type of man, the type of institutions and the type of communities the two alternative production modes might yield.

Similar problems have recently come into the limelight in some DCs in connection with the justification or desirability of maintaining family-size farm units and developing technologies and institutional patterns which could keep them viable. In spite of legislation of the European Common Market to the contrary--promoting a fading out of this type of agriculture--the French government has recently launched a program of rehabilitation of family-size farms. Some re-thinking on similar lines is also evident in the U.S.A.

The most conspicuous illustration of the need to look beyond the resources space when establishing strategies for resource development is found in the energy domain. This domain also illustrates the kind of evolutionary trap that an unguided market economy will tend to manoeuvre itself into. If and when dispersed energy systems comprising a substantial share of renewable energy sources should become viable, our whole philosophy of concentration of industrial facilities, economy of scale and settlement patterns will have to be reconsidered in the light of new economic, social and political objectives and of the availability of new information-intensive technology.

The necessity for a paradigmatic shift is even more evident in the LDCs, as the following illustration will show.

ILLUSTRATION OF THE APPLICATION OF THE GOAL-ORIENTED APPROACH IN LDCs

The engineering, *solution-oriented approach* that was dominant in the development of water and land resources in the LDCs during the first 30 years after World War Two (and which can still muster considerable support in professional circles), has had a chequered record, apart from a few success stories. By and large, concentration on resources and hardware aspects and neglect of supporting services to generate social learning in the cultural and institutional dimensions, have led to overlong gestation periods, low utilization rates of facilities and unsatisfactory production levels. While transferring the solution-oriented approach from DCs to LDCs, the fundamental fact was disregarded that the effective development of resource systems on a broad national scale, would above all be conditional on improving the symbolic environment and institutions to the requirements of the modernization process--without unduly disturbing the ecology of this all-important environment.

To refer to the narrower subject of this symposium, irrigation projects designed and implemented by the orthodox approach will only rarely offer the most attractive options to attenuate substantially the acute problems confronting LDCs, i.e., low productivity and incomes of the mass of the population, high birth rate, excessive rural-urban migration, unemployment and underemployment, and high balance of payment deficits. The high concentration of capital, human and institutional resources involved in major irrigation projects and the long gestation period mean leaving the majority of the rural poor outside the foreseeable development coverage.

A problem- or goal-oriented development strategy would attempt to use available resources on a broad population front in projects that could--at a lower cost in terms of capital, human and institutional resources and with little delay--significantly improve productivity, both in areas permanently intended for rainfed farming and areas into which irrigation is to be introduced later. Low-cost, quickly completed projects of this type will engender zero, primary and secondary (and in the later phases also tertiary) types of learning--and stimulate the *requisite cultural and institutional responses, concurrently with the improvement of production methods*. When later reached by irrigation projects, areas which had enjoyed the benefits of this predevelopment approach would soon adapt to irrigated farming; this would substantially reduce maturation costs. Given some government help, such areas would also be ready to embark on the other comprehensive development endeavours, such as basic social services, the generation of non-farm employment, development of the basic infrastructure, and improvements in the quality of life.

Learning processes of this type have a tendency to induce self-sustaining and self-exciting growth, so that, *within a relatively short time, the whole economy may be transformed, culturally-rooted attitudes changed, the political power balance modified and the whole socio-economic system upgraded*. A loop connection exists between transformation and modernization: transformation is a precondition for modernization, and modernization is the chief opportunity to induce transformation.

Major projects of this type have been initiated in a number of LDCs, and more are about to be started under World Bank financing. It might still be too early to reach conclusions on their overall systemic performance; but even in their initial stages--the ones that are notoriously difficult in other types of projects--their success has been outstanding.

In addressing the Board of Governors of the World Bank, Mr. McNamara recently (October 1979) made the statement that, even under mildly optimistic assumptions for the next two decades, the global population subsisting at or below the poverty level by the year 2000 will still be 600 million [McNamara, 1979]. His conclusion was that more capital transfer and more inter-block trade would be needed to reduce this number. But prospects for an improvement in the outlook for LDCs are, in his judgement, slim, while a deterioration cannot be excluded. To prevent *there being 600 million or more of this globe's population barely living above subsistance level by the year 2000, a much more radical switch of resources and efforts to the problem-oriented approach is needed.*

CONCLUDING REMARKS

We might not yet be in a position to define the types of man, the types of society and the types of economy that we are planning for; it is possible, however, to define the direction that we now have to take. As Ruth Mack has said

> The new orientation requires a shift from emphasis upon the "decision proper" to a "decision process." Decision itself . . . is only an incident in a life history . . . (what is now needed are) decision rules that may prove useful in guiding decision processes in unstructured and open-ended decision contexts. [Dunn, 1971]

Ruth Mack calls this "quasi-optimizing." She sets as the proper objective *"progress* *towards rather than the achievement of goals."* In a process of directed social experimentation the indeterminacy of the future course of development need not disturb us overmuch: if we keep the process participative and open to feedback, the final judge of performance and the source of corrective feedback will be man and the new grass-roots institutions he will create. In E. S. Dunn's formulation:

> The hazards of evolutionary experimentation will be diminished if we can make it less haphazard. To attain this we must find ways to (a) improve the efficiency of evolutionary experimentation and (b) improve its directed character. [Dunn, 1971]

We have come a far way from the orthodox concepts of development and management of resource systems. We have found that only by fitting planning into the broader context of the socio-psychological and political space and by *achieving harmony between transformation of the physical and the symbolic environments can we hope to realize socio-economic objectives, while building the society of tomorrow.*

To quote Dunn again, in conclusion:

> If social development serving human development becomes the goal, the ultimate resource, the basic means for achieving this end is the ability to develop new ideas that improve the relationship between social system goals and control operating in a mixed physical and social environment. . . In a basic sense then, the means for fulfilling the aims of development is the ability to generate new ideas in action. This creative capacity is the ultimate resource in meeting human objectives. . . *Social development requires, additionally, the activity of men and social organizations that "know how to learn" and who are able and willing to test what they learn against fundamental human values."* [Dunn, 1971, (Author's emphasis)]

The engineering and economic professions, by themselves, are not equal to this challenging task. The future will have to show whether the social and behavioural sciences are in a position to supplement them and establish a fruitful dialogue. Only through their common effort can the necessary perspective be achieved to inspire a more comprehensive vision of the development of natural resource systems and of their coupling with the socio-political systems and the symbolic environment. Such a vision has now become a necessity if we wish to maintain a balanced growth of man's material and spiritual welfare and to promote the rise of a stable society.

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A MAN-MACHINE INTERACTIVE APPROACH TO A NONLINEAR MULTIOBJECTIVE OPTIMAL PLANNING PROBLEM ON WATER MANAGEMENT OF A RIVER BASIN

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Abstract. A man-machine interactive optimal planning model is developed for a problem of constructing wide-area public sewage treatment systems of a river basin. The water supply planning problem is also taken into consideration by assuming that highly treated waste water can be reused for industrial purposes. The problem is formulated as a multiobjective nonlinear optimization one by minimizing (1) the total cost of both construction and operation necessary for sewage treatment systems and (2) the BOD concentration at the furthest downstream point. Adopting the surrogate worth trade-off method, a decision-making system is built to determine the preferred solution from the set of Pareto optimal solutions derived by the generalized reduced gradient algorithm.

Keywords. Computer-aided systems design; multiobjective optimal systems; nonlinear programming; sewage treatment system; water pollution; water resources.

INTRODUCTION

Up to the present, many optimal planning models for long-term, wide-area water management are developed for many river basins in Japan, but most of them treat water resource and environment problems separately. By considering the foreseeable shortage of water resource and the increasing discharge of water pollutants, it is essentially necessary to reuse highly treated waste water as available water resources.

An integrated water resource and environment management model was built for the Yodo river basin in Japan by Suzuki and his collaborators (1978), in which it is assumed that waste water treated by public tertiary treatment plants can be reused for industrial purposes. The linear programming technique was adopted in the process to determine the optimal water management strategy in this model. As a huge amount of capital investments is necessary to construct sewage treatment systems, it is requested to consider water management problems more precisely by developing more complete planning models.

The primary objective of this study is to develop a man-machine interactive planning model for a long-term, wide-area water management of a river basin, in which the optimal planning problem of constructing public sewage treatment system is mainly formulated together with the water supply planning problem as a nonlinear multiobjective optimization problem.

In this study, the Pareto optimal solutions for proposed multiple objective functions will be derived by using the generalized reduced gradient (GRG) algorithm (Lasdon, 1974), and a man-machine interactive decision-making system will be built adopting the surrogate worth trade-off (SWT) method (Haimes, 1975) to determine the preferred solution from the set of the above-obtained Pareto optimal solutions.

A NONLINEAR MULTIOBJECTIVE OPTIMAL PLANNING MODEL FOR WATER MANAGEMENT OF A RIVER BASIN

Basic Structure of The Model

In the water management planning model developed here, a whole river basin to be considered is divided into M regions, and let m be the variable which identifies each region. In the positive study for the Yodo river basin, the total area is divided into $M = 7$ regions. Furthermore, in order to reflect the local differences of socio-economic activities and regional characteristics in the model, the habitable area of each region mentioned above is divided into urban and rural areas.

Moreover, each urban area is divided into densely inhabited district (DID) and non-densely inhabited one (non-DID).

The total planning period is fixed from 1975 to 1995, and it is divided into N planning stages denoting each planning stage by the variable n. In this model, the short-term plan is made for every 5 years; that is, the initial year of 1975 is denoted as $n = 0$, $n = 1$ identifies the year of 1980, and $n = N = 4$ the year of 1995.

Forecasting future socio-economic activities of the basin, future water pollution loads are estimated first by adopting the indicator of biochemical oxygen demand (BOD). Pollution loads generated from the residential and the commercial sectors are considered together, and they are divided into amounts of BOD from night soil and from other waste water. Concerning the industrial sector, it is assumed that there exists no industrial activity in rural areas of the Yodo river basin; in other words, no industrial waste water is assumed to be exhausted in these areas. Let us denote amounts of BOD in units [ton/day] exhausted into each district or area of the region m for the n-th planning stage as

- $G_{m,n}$: total amount of BOD exhausted,
- $G^{r}_{m,n}$: amount of BOD generated by residential and commercial sectors,
- $G^{r_1}_{m,n}$, $G^{r_2}_{m,n}$, $G^{r_3}_{m,n}$: amounts of BOD from residential and commercial sectors generated within DID, non-DID of urban area, and rural area, respectively,
- $G^{f}_{m,n}$: residential amount of BOD which is exhausted from industrial sector,
- $G^{f_1}_{m,n}$, $G^{f_2}_{m,n}$: residual amounts of BOD from industrial sector exhausted into DID and non-DID of urban area, respectively, and
- λ_n: the ratio of BOD from night soil to the total one in residential and commercial sectors.

In order to prevent the deterioration of water quality of rivers, the construction problem of public sewerages and sewage treatment plants (i.e., public sewage treatment systems) should be investigated in the model. In the Yodo river basin, it is assumed that public sewage treatment systems will be constructed only in DID through the total planning period.

In the long-term, wide-area public water treatment planning problem, main variables to be determined for the n-th planning stage are the following ones;

(a) the coverage rate of public sewerage systems in DID of each region,
(b) the ratio of waste water treated by primary and secondary treatment plants to the total waste water in DID of the region m, say $\alpha_{m,n}$,
(c) the corresponding ratio of (b) concerning tertiary treated waste water denoted by $\beta_{m,n}$.

Here, it is assumed that waste water discharged into public sewerages is purified at least at primary and secondary treatment plants. In other words, it is assumed that the rate of (a) is equal to $\alpha_{m,n}$ of (b).

As regards the night soil from the residential and the commercial sectors which is not discharged into public sewerages, it is assumed to be disposed at night soil treatment plants and then its residential pollution load flows out into main rivers.

After operations by public sewage and night soil treatment plants and processes of self-purification by tributary rivers, pollution loads of BOD flow down main rivers. Local authorities are executing environmental standards of water pollution at monitoring points located at downstream points of all regions to check water quality in main rivers.

Next, in addition to the water treatment planning problem mentioned above, the water supply planning problem is also taken into consideration in the model by assuming that highly treated waste water by public tertiary treatment plants can be reused by industry. In the positive study for the Yodo river basin, water demands are estimated taking account of the improvement of the quality of life and the technological progress. Water demands in units [m^3/day] at each sector for the n-th planning stage in the region m are denoted as

- $Q^{d}_{m,n}$: total amount of water demands,
- $Q^{dr}_{m,n}$: drinking water demand for residential and commercial sectors,
- $Q^{dr_1}_{m,n}$, $Q^{dr_2}_{m,n}$, $Q^{dr_3}_{m,n}$: amounts of $Q^{dr}_{m,n}$ in DID, non-DID of urban area, and rural area, respectively,
- $Q^{df}_{m,n}$: water demand for industrial sector, and
- $Q^{df_1}_{m,n}$, $Q^{df_2}_{m,n}$: amounts of $Q^{df}_{m,n}$ in DID, and non-DID of urban area, respectively.

In order to meet these increasing water demands, it becomes necessary to develop new water resources. Let $\Delta Q^{s}_{m,n}$ express the amount of water in units [m^3/sec] which must be developed newly in the region m at the planning stage n. As $\Delta Q^{s}_{m,n}$ is generally determined by local authorities from the political standpoint, this value is considered as a policy parameter given exogenously to the model; that is, this variable is not considered as the one to be determined by the model. Besides, it is assumed here that the highly treated waste water by public tertiary treatment plants will be reused for applicable industrial purposes. These water demand-supply relationships mentioned above are considered as constraint relationships in the model.

In this model, the optimal water management plan is made every 5 years by adopting the following two objective functions; that is, the total cost of both construction and operation necessary for public sewage treatment system, and the BOD concentration at the furthest downstream point. As the above-mentioned optimization problem has multiple objective functions, the optimal strategy for the n-th planning stage is not determined uniquely, but a set of solutions are derived which satisfy Pareto optimality. Here, a man-machine interactive decision-making system has been built by adopting the SWT method; by which the preferred solution of the decision maker is determined among the set of Pareto optimal solutions based on the results such as values of optimal solutions, trade-off relationships between multiple objective functions for various values of the policy parameter $\Delta Q^{s}_{m,n}$, etc.

After the best policy for the n-th planning stage is determined, it becomes possible to investigate the optimal planning problem for the next stage. Repeating these procedures sequentially until the final stage n=N, it becomes possible to study the long-term planning problem for water management of a river basin.

Mathematical Description of The Model

Following is the detailed mathematical description of the water management planning model.

Quantitative relationships of water flow. The quantitative flow diagram of water including demand and supply relationships in the region m ($1\leq m\leq M$) is illustrated in Fig. 1. Listed below are mathematical notations used in this figure:

- $Q^{s}_{m,n-1}$: amount of water within the region m developed before the n-th planning stage which excludes the amount of recycled water from tertiary treatment plants [m^3/sec],
- $Q^{re}_{m,n}$: amount of recycled water from tertiary treatment plants to available industrial usage [m^3/sec],
- $Q^{u}_{m,n}$: intake amount of water from main river [m^3/sec],
- Q^{tr}_{m}: amount of inflow from tributary streams [m^3/sec],
- $\bar{Q}_{m,n}$: mean discharge at the upper stream point [m^3/sec],
- $Q_{m,n}$: mean discharge at the downstream point [m^3/sec],
- $Q^{0}_{m,n}$: lower limit of water discharge permissible at the downstream of the intake point [m^3/sec], and
- δ: rate of loss in water usage processes.

From the definitions concerning amounts of water demands, the following relationships hold obviously; i.e.,

$$Q^{d}_{m,n}=Q^{dr}_{m,n}+Q^{dr}_{m,n},\quad Q^{dr}_{m,n}=Q^{dr_1}_{m,n}+Q^{dr_2}_{m,n}+Q^{dr_3}_{m,n},\quad Q^{df}_{m,n}=Q^{df_1}_{m,n}+Q^{df_2}_{m,n}. \tag{1}$$

To answer the increasing water demand by each region, the relationship

$$Q^{d}_{m,n}\leq Q^{u}_{m,n}+Q^{re}_{m,n} \tag{2}$$

should be satisfied. As it is assumed here that the tertiary treated water can be reused only for available industrial purposes in DID of the region m, the following constraint should be imposed; i.e.,

$$Q^{re}_{m,n}\leq\rho_{m,n}Q^{df}_{m,n}, \tag{3}$$

where $\rho_{m,n}$ is the maximum rate of tertiary treated water applicable to the industrial water demand.

As the reused amount $Q^{re}_{m,n}$ cannot exceed the amount of tertiary treated waste water, it holds obviously

$$Q^{re}_{m,n}\leq\beta_{m,n}(1-\delta)(Q^{dr_1}_{m,n}+Q^{df_1}_{m,n}). \tag{4}$$

Furthermore, as there is the lower limit of water discharge permissible at the downstream of the intake point, the intake amount of

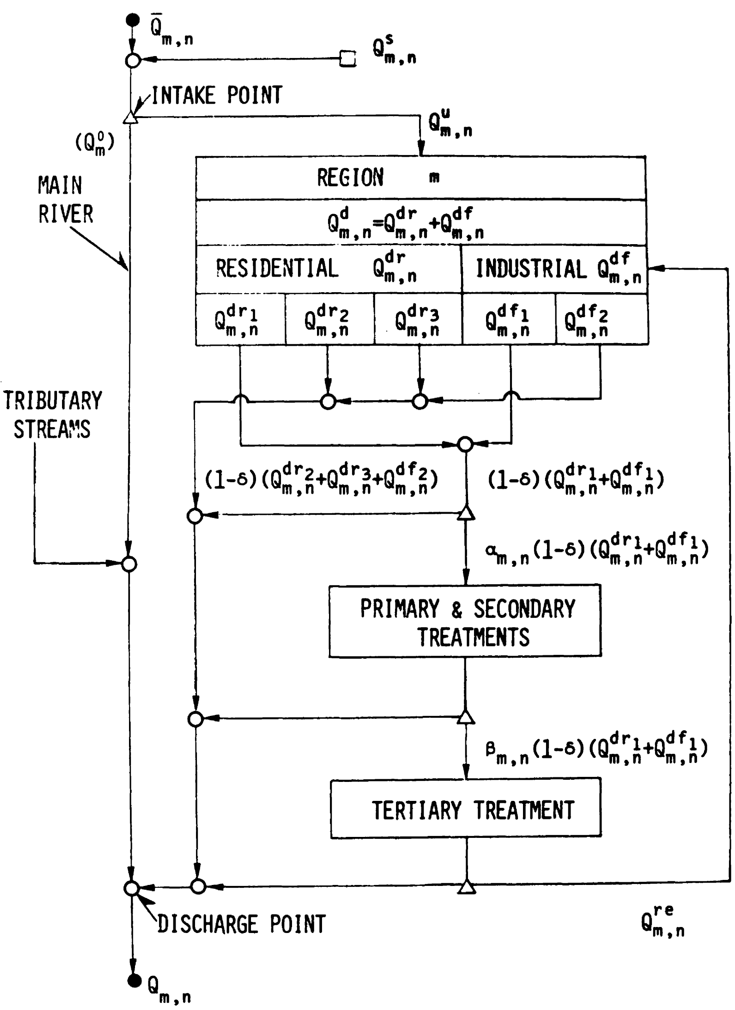

Fig. 1. Quantitative flow diagram of water in the region m ($1\leq m\leq M$).

water $Q^u_{m,n}$ is determined appropriately so as to satisfy the following relationship for each m; i.e.,

$$Q^u_{m,n} \leq \bar{Q}_{m,n} + Q^s_{m,n} - Q^0_m. \qquad (5)$$

Taking into account amounts of newly developed water, losses in water usage processes, and inflows from tributary streams, the mean discharge at the downstream increases as

$$Q_{m,n} = \bar{Q}_{m,n} + Q^{tr}_m + Q^s_{m,n} - \delta Q^d_{m,n}$$
$$= \bar{Q}_{m,n} + Q^{tr}_m + Q^s_{m,n-1} + \Delta Q^s_{m,n} - \delta Q^d_{m,n}. \qquad (6)$$

If the upper stream point is not the confluence of several rivers, then it follows easily

$$\bar{Q}_{m,n} = Q_{m-1,n}. \qquad (7)$$

It is possible to consider the similar relationships of Eq. (7) for the case in which several rivers are confluent at the upper stream point.

Quantitative relationships of BOD. Next, let us consider the treatment problem of the pollution load of BOD flow out in each region.

In Fig. 2, the quantitative flow diagram concerning BOD pollution load and its treatment in region m is illustrated, where the mathematical notations are as follows:

- B^{tr}_m; pollution load of BOD from streams [ton/day],
- θ: elimination rate of BOD at night soil treatment plant,
- R^{r1}, R^{r2}, R^{r3}: rates of run-off for other waste water of residential and commercial sectors in DID, non-DID of urban area, and rural area, respectively, caused by self-purifications in tributary streams,
- R^{f1}, R^{f2}: rates of run-off for industrial waste water in DID, and non-DID of urban area, respectively,
- γ_2: elimination rate of BOD by primary and secondary treatments,
- γ_3: elimination rate of BOD by primary, secondary, and tertiary treatments,
- $\bar{B}_{m,n}$: pollution load of BOD at the upper stream point [ton/day],
- $B_{m,n}$: pollution load of BOD at the downstream point [ton/day],
- T_m: travel time between upper and downstream points [day],
- t^{tr}_m: travel time between discharge point of tributary streams and downstream point [day], and
- t_m: travel time between discharge and downstream points [day].

From the definitions concerning variables of pollution loads of BOD in region m, it holds obviously

$$G_{m,n} = G^r_{m,n} + G^f_{m,n}, \quad G^r_{m,n} = G^{r1}_{m,n} + G^{r2}_{m,n} + G^{r3}_{m,n},$$
$$G^f_{m,n} = G^{f1}_{m,n} + G^{f2}_{m,n}, \quad G^{ri}_{m,n} = \lambda_n G^{ri}_{m,n} + (1-\lambda_n) G^{ri}_{m,n},$$
$$(i=1\sim 3) \qquad (8)$$

Let $P_{m,n}$ [ton/day] denote the amount of BOD purified within the region m for the n-th planning stage, the discharge amount of BOD to the main river expressed by $E_{m,n}$ [ton/day] is given by

$$E_{m,n} = G_{m,n} - P_{m,n}. \qquad (9)$$

As illustrated in Fig. 2, $P_{m,n}$ in Eq. (9) can be calculated as

$$P_{m,n} = \theta\lambda_n\{(1-\alpha_{m,n})G^{r1}_{m,n} + G^{r2}_{m,n} + G^{r3}_{m,n}\}$$
$$+(1-\lambda_n)\{(1-R^{r1})(1-\alpha_{m,n})G^{r1}_{m,n} + (1-R^{r2})G^{r2}_{m,n}$$
$$+(1-R^{r3})G^{r3}_{m,n}\} + \{(1-R^{f1})(1-\alpha_{m,n})G^{f1}_{m,n}$$
$$+(1-R^{f2})G^{f2}_{m,n}\} + \gamma_2\alpha_{m,n}(G^{r1}_{m,n} + G^{f1}_{m,n})$$

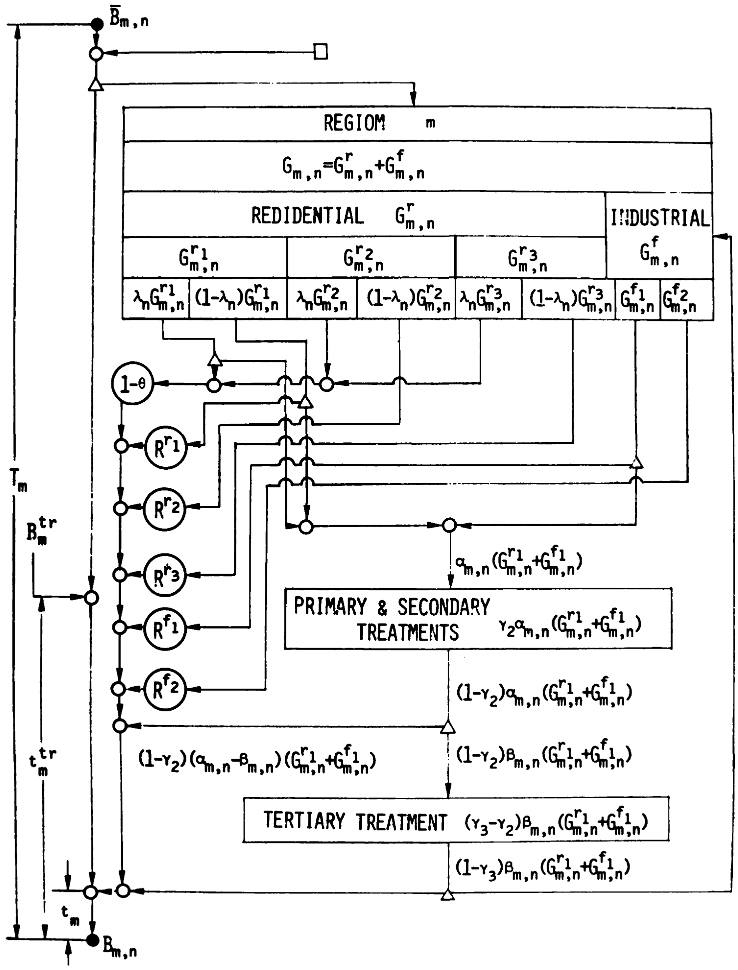

Fig. 2. Quantitative flow diagram of pollution load of BOD and its treatment.

$$+(\gamma_3-\gamma_2)\beta_{m,n}(G^{r1}_{m,n}+G^{f1}_{m,n})+(1-\gamma_3)(G^{r}_{m,n}+G^{f1}_{m,n})\{Q^{re}_{m,n}/(1-\delta)(Q^{dr1}_{m,n}+Q^{dr1}_{m,n})\}, \quad (10)$$

where the first term of the right side is the eliminated amount of BOD through night soil treatment, the second and the third ones are amounts of BOD decreased by the self-purification in tributary streams, the fourth one expresses the eliminated amount of BOD by primary and secondary treatments, the fifth term is the one by tertiary treatment, and the last one is the amount of BOD not discharged into the main river caused by the reuse of waste water.

Expressing the self-purification phenomenon in the main river by the relationship of Streeter-Phelps' equation, the pollution load of BOD at the downstream point is given by

$$B_{m,n}=\exp(-KT_m)\overline{B}_{m,n}\times(\overline{Q}_{m,n}-Q^{u}_{m,n})/\overline{Q}_{m,n}+\exp(-Kt_m)E_{m,n}+\exp(-Kt^{tr}_m)B^{tr}_m, \quad (11)$$

where K is the coefficient of self-purification in the main river.

If the upper stream point is not the confluence of several rivers, then it follows easily

$$\overline{B}_{m,n}=B_{m-1,n}. \quad (12)$$

When several rivers are confluent at the upper stream point, it is also possible to consider the similar relationship corresponding to Eq. (12).

By the local authorities of the Yodo river basin, the environmental constraint of BOD concentration expressed by $q^0_{m,n}$ [ppm] is imposed at the downstream point of each region. Then, the water quality of BOD at this point, say $q_{m,n}$ [ppm], must satisfy the relationship

$$q_{m,n}=B_{m,n}/Q_{m,n}\leqq q^0_{m,n}. \quad (13)$$

As the coverage rate of public sewerage system, $\alpha_{m,n}$, is not less than the value of the previous planning stage, it holds

$$\alpha_{m,n-1}\leqq\alpha_{m,n}\leqq 1.0. \quad (14)$$

Furthermore, assuming that the amount of tertiary treated waste water does not decrease its value from the one of the previous planning stage, the following relationship should be satisfied; i.e.,

$$\beta_{m,n-1}(1-\delta)(Q^{dr_1}_{m,n-1}+Q^{df_1}_{m,n-1})\leqq\beta_{m,n}(1-\delta)\times(Q^{dr_1}_{m,n}+Q^{df_1}_{m,n}). \quad (15)$$

Lastly, as it is physically impossible that $\beta_{m,n}$ exceeds $\alpha_{m,n}$, it holds

$$\beta_{m,n}\leqq\alpha_{m,n}. \quad (16)$$

Multiple objective function. In this optimal planning model, the following two objective functions are investigated:

The first objective function is to minimize the total cost of both construction and operation necessary for public sewage treatment systems through each planning period in the whole river basin. This objective function for the n-th planning stage is composed of the nonlinear cost functions as follows; i.e.,

$$J_1(n)=\sum_{m=1}^{M}\{f_{1,m,n}(\alpha_{m,n})+f_{2,m,n}(\beta_{m,n})+f_{3,m,n}(\alpha_{m,n})+f_{4,m,n}(\alpha_{m,n})+f_{5,m,n}(\beta_{m,n})\} \quad (17)$$

where

- $f_{1,m,n}(\alpha_{m,n})$: cost for constructing primary and secondary treatment plants through the n-th planning period in DID of region m,
- $f_{2,m,n}(\beta_{m,n})$: the corresponding one of $f_{1,m,n}$ concerning tertiary treatment plants,
- $f_{3,m,n}(\alpha_{m,n})$: cost for constructing public sewerages through the n-th planning stage in region m,
- $f_{4,m,n}(\alpha_{m,n})$: cost for operating primary and secondary treatment plants through the n-th planning stage in region m, and
- $f_{5,m,n}(\beta_{m,n})$: the corresponding one of $f_{4,m,n}$ for tertiary treatment plants.

The cost function of $f_{1,m,n}$ in Eq. (17) is assumed to be the nonlinear form of

$$f_{1,m,n}(\alpha_{m,n})=C_1\{\alpha_{m,n}(1-\delta)(Q^{dr_1}_{m,n}+Q^{df_1}_{m,n})-\alpha_{m,n-1}(1-\delta)(Q^{dr_1}_{m,n-1}+Q^{df_1}_{m,n-1})\}^{C_2}+C_{3,m}\{\alpha_{m,n}(1-\delta)(Q^{dr_1}_{m,n}+Q^{df_1}_{m-n})-\alpha_{m,n-1}\times(1-\delta)(Q^{dr_1}_{m,n-1}+Q^{df_1}_{m,n-1})\}^{C_4}, \quad (18)$$

where C_1, C_2, $C_{3,m}$ $(1\leqq m\leqq M)$, and C_4 are positive constants. The first term of the right side of Eq. (18) expresses the cost for constructing primary and secondary treatment facilities in region m which is the function of the increase of sewage treatment amount in the n-th planning stage expressed by $\alpha_{m,n}(1-\delta)\times(Q^{dr_1}_{m,n}+Q^{df_1}_{m,n})-\alpha_{m,n-1}(1-\delta)(Q^{dr_1}_{m,n-1}+Q^{df_1}_{m,n-1})$, and the second term is the cost necessary to purchase sites of treatment plants in region m.

In the same way, the function $f_{2,m,n}$ is assumed to be in the form of

$$f_{2,m,n}(\beta_{m,n})=C_5\{\beta_{m,n}(1-\delta)(Q^{dr_1}_{m,n}+Q^{df_1}_{m,n})-\beta_{m,n-1}(1-\delta)(Q^{dr_1}_{m,n-1}+Q^{df_1}_{m,n-1})\}^{C_6}+C_{7,m}\{\beta_{m,n}(1-\delta)(Q^{dr_1}_{m,n}+Q^{df_1}_{m,n})-\beta_{m,n-1}\times(1-\delta)(Q^{dr_1}_{m,n-1}+Q^{df_1}_{m,n-1})\}^{C_8}, \quad (19)$$

where C_5, C_6, $C_{7,m}$ $(1 \leq m \leq M)$, and C_8 are positive constants.

The function $f_{3,m,n}$ adopted here is in the form of

$$f_{3,m,n}(\alpha_{m,n}) = C_9(\alpha_{m,n} - \alpha_{m,n-1})S_m, \tag{20}$$

where C_9 is the cost of constructing public sewerages per unit land area, and S_m is the land area of DID in region m.

Both functions of $f_{4,m,n}$ and $f_{5,m,n}$ are assumed to be

$$f_{4,m,n} = C_{10}\{\alpha_{m,n}(1-\delta)(Q^{dr_1}_{m,n} + Q^{df_1}_{m,n})\}^{C_{11}} + C_{12}\alpha_{m,n}(1-\delta)(Q^{dr_1}_{m,n} + Q^{df_1}_{m,n}), \tag{21}$$

$$f_{5,m,n} = C_{13}\{\beta_{m,n}(1-\delta)(Q^{dr_1}_{m,n} + Q^{df_1}_{m,n})\}^{C_{14}}, \tag{22}$$

where C_{10} to C_{14} are positive constants.

All these relationships of Eqs. (18)∿(22) are derived from cost analysis of water treatment in the river basin, and all values of positive constants $C_1 \sim C_{14}$ are determined based on real data.

The second objective function adopted here is the BOD concentration at the furthest downstream point; that is,

$$J_2(n) = q_{M,n} = B_{M,n}/Q_{M,n}. \tag{23}$$

This value should be minimized so as to decrease water pollution load from the concerned river basin to the downstream one.

Summing up the optimal planning problem proposed in this model, the water management problem for the n-th planning stage can be reduced to the following mathematical optimization; that is, giving an appropriate value of the policy parameter $\Delta Q^s_{m,n}$ and a set of all initial and parameter values given a priori to the model, one can find the set of optimal solutions $\{\alpha_{m,n} = \alpha^*_{m,n},\ \beta_{m,n} = \beta^*_{m,n};\ m = 1 \sim M,\ n = 1 \sim N\}$ which minimizes two objective functions $J_1(n)$ and $J_2(n)$ of respective Eqs. (17) and (23) under the constraints of Eqs. (1)∿(16).

As these two objective functions are in conflict with each other, one cannot optimize both of them simultaneously. This optimization problem is one of multiobjective nonlinear programming problems, and a fundamental approach to multiobjective optimization problems is based on the concept of Pareto optimal solutions, also known as the noninferior solutions.

A Man-Machine Interactive Systems for Decision Support

In Fig. 3, the execution flow of the system model developed here is shown. In this system model, for the purpose of utilizing computer facilities effectively, two IBM computer systems are adopted; i.e., a time sharing system, CALL/370, and a multiple virtual storage (MVS) operating system.

First, the decision maker runs the GRGINIT program and saves various kinds of initial data concerning the river basin.

Second, the GRGPLAN program displays the initial data of the planning stage, and requests the decision maker to enter his alternatives. Then, he chooses values related to the future water supply planning $\Delta Q^s_{m,n}$ and several BOD concentrations at the furthest downstream point of the river basin which becomes ε-constraint values in GRG. GRGPLAN makes a job stream for the GRG program, and then the decision maker issues SUBMIT command to execute it under MVS.

Third, GRG executes as many times as the number of the alternatives given by the decision maker. After completion of GRG, the set of Pareto optimal solutions and various kinds of data are returned to CALL/370.

Lastly, the decision maker runs the GRGDSPL program, by which he can compare and investigate several alternative plans from different angles, e.g., the trade-off ratios between the objectives, and then he chooses his preferred solution using the SWT method. To support his decision making, GRGDSPL has 10 options which show the following information in answer to his request:

- Option 1: set of Pareto optimal solutions and trade-off ratios between the objectives,
- Option 2: graph of Pareto optimal solutions in the objective space,
- Option 3: ratio of primary and secondary treated waste water to the total one in DID,
- Option 4: ratio of tertiary treated waste water to the total one in DID,
- Option 5: ratio of Option 3 adjusted by population in the whole region,
- Option 6: ratio of Option 4 adjusted by population in the whole region,
- Option 7: ratio of primary and secondary treated waste water to the total one in the whole region,
- Option 8: ratio of tertiary treated waste water to the total one in the whole region,
- Option 9: BOD concentration at the furthest downstream point in each region, and
- Option 10: next execution selection.

When he cannot obtain feasible solutions from GRG or wants to investigate other alternatives in the same planning stage, he can repeat all over again. Otherwise, the decision maker proceeds to the next planning stage and reexecutes the GRGPLAN program.

Repeating these procedures described above, the decision maker can construct a long-term plan for water management problems.

STUDY OF THE YODO RIVER BASIN