SYSTEMS APPROACH
TO WATER RESOURCE PLAN FORMULATION

G. T. Orlob, Ph.D.

Presented to the Inter-Agency Task Force

Comprehensive Study of Puget Sound and Adjacent Waters

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INTRODUCTION

The early history of water resource development began with a single source-single project-single use concept exemplified in the Western United States by the efforts of the growing metropolitan centers to meet their needs for adequate supplies of high quality drinking water. These projects, which supplied water from the Cedar River to Seattle, the Hetch Hetchy to San Francisco and the Owens to Los Angeles, were marvels of engineering, even by today's high standards. They were gradually expanded by adding components--another reservoir, a pumping station, or a transmission line--or by tapping additional sources so that they grew into complex "systems" by a sort of evolutionary process. Priorities for use of the water they developed were of the highest order, so they did not suffer from too much competition (although the early farmers of the Owens Valley who stood off Los Angeles' engineers at gun point might debate this). Also, funds were usually available; hence economic restraints were not too imposing as obstacles. Yet while the number of elements of the project increased, a single use priority was honored and most of the development was confined to a single watershed.

The Reclamation Act of 1902 and the need of the metropolitan

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complexes for power stimulated even larger scale developments, often transcending hydrologic boundaries until whole rivers systems were embraced. At first, since the choicer sites for project development were considered and the benefits were distributed over relatively large areas only a limited number of beneficial purposes were identified with each project. Most often a single use dominated; the project was oriented toward either irrigation, power, flood control or water supply. Occasionally a secondary use became primary, as in the Central Valley of California where irrigation interests shifted to the power business. Gradually, as the choicer sites began to disappear, projects were justified only by a multiple-use concept but still on a project-by-project basis.

As our society met its basic needs for water--to drink, to irrigate, to produce power--it began to turn to protecting itself from the ravages of flood water and to conserving its resources--water, land, wildlife, and fisheries. Finally, and only with real emphasis during the last decade or so, it has focused increased attention on esthetic and recreational enjoyment. Belatedly, it has found, particularly in the Eastern United States, that it had failed to "plan ahead". New York city suffered nearly disastrous water shortages, whole fisheries resources were lost, and pollution was detracting from esthetic and recreational use of whole reaches of eastern rivers. In some arid regions ground water reserves were being depleted and sea water was intruding.

In many of these situations so-called "comprehensive" plans were conceived, largely to solve the localized problems of shortage. Several of the more notable of these envisioned redistribution of water resources on a grand scale, from areas of surplus to areas of demand. Few enjoyed the luxury, as the Pacific Northwest generally does, of an abundant supply, and envious eyes were turned northward and westward. Large demands, acute shortages, "abundant supplies", and long distances called for imaginative plans and many practical engineers (and some not so pragmatic) turned their hand to planning. With only a few provincial exceptions most of the visionaries included the Columbia with its vast resources as a major source of all the good that water brings.

If any real benefit to the planner developed from these efforts at "grand planning" except to "think big" it was the realization that the planning problem is complex. Not only is the system of water storage and conveyance elements complicated in the physical sense but the sources are displaced from the points of demand, qualities vary widely, and uses are manifold. Moreover, the supply which once seemed limitless is in reality finite, and the questions of benefits derived, where, when and how much, are of paramount importance. The universal question to be answered is "Given fixed resources distributed in some known manner in space and time, how can we best utilize them and preserve them for the maximum net benefit of all potential users." This is not a simple question and the answer is accordingly complex. However, the question is germane to our present discussion. It is the essence of the planner's dilemna. The systems approach which we are going to outline and illustrate briefly offers a fundamental methodology which can assist in achieving the answer.

THE SYSTEMS APPROACH

We have seen that water resource planning has moved from considering singleness of purpose, source, and project toward consideration of multiple purposes, multiple sources, and complex physical systems. Further, the task of planning is no longer an activity to be practiced by a single agency. All levels of governmental agencies and many private interests may and should be involved. Add to this picture, in which the planner occupies the spotlight, the many forces which modify the decision process and one can begin to appreciate the near hopelessness that the planner may feel in seeking the elusive "comprehensive plan".

The primary objective of the planner is to formulate from that array of alternatives which may be presented to him, a single plan which has the greatest likelihood of being "optimal". The concept of optimality as we choose to use it here means obtaining the maximum net social and economic benefits for the beneficiaries of water resource development. In other contexts it may be taken to mean maximum benefit/cost ratio, maximum absolute benefits, or minimum cost to achieve certain specified goals.

If one reflects for a moment on the large number of possibilities which might be presented to the planner of an "optimum" plan for utilizing the Puget Sound Basin's water resources, it becomes clear that some positive assistance in methodology is needed. The so-called "systems approach", a derivative of space age technology, offers to make the life of the planner somewhat easier in several ways. These are summarized as follows:

1. Identify the configuration of the system to be optimized

A system may be composed of any number of separate components, each with specified functions and each having some definable relationship to all other components of the system. It may be composed of physical parts for conveyance and storage of water and be comprised of dams, reservoirs, pumping stations, canals, natural watercourses, etc.

It can even be a set of actions which vary in their degree of independence from each other but which collectively describe a greater activity. The formulation process with which we are here concerned is such a set of actions.

2. Define the functions of each system component

Physical components must be characterized by their properties of size, shape, mass, deformability, etc. A reservoir may be described by its location, elevation, depth-area-volume relationship and the position of inlets and outlets.

Actions can be defined by the rates at which they take place, the direction and sense given to them, and by their duration. As will be seen later, the limits imposed by our ability to define the behavior of system components accurately may limit our potential for achieving an optimal solution to a problem.

3. Identify interfaces between components

The relationship between each system component and those with which it is directly linked must be defined. These linkages may be either a physical or a functional connection, or both. The interfacial connections define the position or orientation of each component within the system.

In plan formulation an interface prescribes a point in time or in the sequence of events when an action must occur between two adjacent activities. Most often the action is manifested as an input or output of information. The flow of this information and the organized storage and retrieval of it is another special area of application of the systems approach termed data management.

4. Prescribe the restraints under which the system must operate

Upper and lower limits of tolerances on size, rate, quantity, quality, position, and time can be stipulated as they may be set for the problem to be solved. In a water conveyance system the lower limit of flow in a certain stream may be a restraint on operation, i.e. no operation would be acceptable if it would permit a lower flow.

5. Describe the objectives for optimization

The objectives for optimizing may be related either to the physical character of the system or to its functional properties. An objective of maximum net benefits is common for resource development. Once the system is found which would yield such benefits, an objective might be to operate it such that the resource is allocated to points of use at least cost.

It might be desirable to optimize the plan formulation process itself. In such instances the objectives for optimization might be set in terms of time, funds, manpower, number of alternatives to be examined, or combinations of these.

6. Obtain a "near optimum" system

It is true that there can only be one truly optimum solution to a given system analysis problem. It is also true that there are an infinite number of other less attractive solutions. Because of the complexity of water resource systems we are usually confronted only with the practical problem of finding the most satisfactory near-optimal solution, that which is as close to the optimum as possible within our available time and human capabilities.

The process of finding the "near optimum" water resource system is one in which the methodology of the systems approach is coupled with a considerable amount of judgment to examine "systematically" the greatest number of potentially attractive alternatives. This process is further facilitated with certain tools of the space age such as the mathematical model and the digital computer.

REGIONAL PLANNING - PUGET SOUND STUDY

The systems approach just outlined becomes increasingly valuable as the scale and complexity of the plan formulation problem increase. Consider the task of the team that must draft a comprehensive plan for development and utilization of the water resources of the Puget Sound Basin.

Within the boundaries of the basin there have been identified thirteen individual planning units. For convenience in dealing with the sources of available water, these units have been described along hydrologic boundaries, although it must be recognized that such subdivisions of the major planning unit are not necessarily those which best serve the needs of economic analysts, governmental planners, and legislators, all of whom must be integrated into the planning process.

Further, for each subbasin at least eight major categories of water use or concern have been identified. They are:

Municipal and Industrial Water Supply*
Irrigation

* Water Quality Control, sometimes treated as a use of water, is recognized here on a par with water quantity control. Both quantity and quality are dimensions of the total water resource; both are to be regulated to serve the prime planning objectives.

Navigation
Power
Recreation
Fish and Wildlife
Flood Control
Drainage and Land Stabilization

Consider also that in addition to the State of Washington with 10 participating state agencies, the Bureau of Reclamation, the Corps of Engineers, the Federal Water Pollution Control Administration and other federal agencies, there are no less than 12 county organizations which are either actively involved in the resource planning process or acutely concerned with the product that will emerge from the Study.

Recognize further that technological factors alone are not sufficient to guide the selection of the most attractive "near-optimal" system but that economic, financial, social, and political feasibility must be treated and that the two latter types of feasibility are not so easily dealt with in the quantitative terms which the engineer finds essential. Add to this a large dose of subjectivity occasioned by the public's acute concern for esthetic enjoyment of the resource environment. It is small wonder that the intrepid planner of projects has not long since given up against overwhelming odds.

Clearly he must accept that there can be no really "optimal" plan which he can describe with mere paper and ink. What he must seek is the most attractive alternative which may be achieved by critical examination of all those presented to him, all of which he may conceive by his own effort, and all of which may be developed from the separate components and features of those alternatives to which he has access. The process of selection by the planner involves a subtle game of "trade-off" in which benefits in one use category or subregion are traded for benefits in another, the goal being a net increase in benefits for all uses or for the total region.

As a practical matter the "best" plan has several desirable characteristics:

1. It is most likely to have emerged from the greatest number of alternatives which can be devised within the limits of time and human resources.

2. Having been selected as the "most attractive", the plan is presumed to be nearest the optimum of all those considered according to the objectives or criteria prescribed.

3. It is supported by a limited number of other alternatives which may possess superior characteristics in some details but which are less attractive in others.

4. It recognizes competition for a limited resource by diverse uses, at various locations and at various points in time.

5. It is inherently flexible; it recognizes changing technology, the inexactness of prognostications, and the fallibility of planners. It is not the sole, inviolate blueprint for the future, but a viable structure designed to be improved and adapted to changing times.

6. It recognizes plans of broader geographical consequence which may have preceded it, may supersede it in the future, or which may be developed in parallel with it. It seeks to be integrated, logically, into a larger framework of comprehensive planning.

The Puget Sound Study must seek to develop a plan which will have all of these characteristics. No less an objective should be considered for a comprehensive Washington State Water Plan.

SYSTEMATIZED FORMULATION

The formulation of a comprehensive plan for the Puget Sound Basin is taking place in three major phases:

Preliminary single purpose plan formulation is being carried out by technical committees organized according to categories of water use. Objectives of these committees are:

a) Assemble basic data and information which identifies the system as it now exists by subregions.

b) Define restraints on water resource development by use and by subregion.

c) Describe the benefits to be derived at various levels of water resource development or water quality management.

d) Describe preliminary alternative plans which might best serve the needs of the subregion for the particular category of use concerned.

Phase I formulation is concerned with the evaluation of alternative plans by subregion for all of the various uses considered. Its major goal is the attainment of a limited number of attractive alternatives which have the greatest potential for achieving the subregion objectives as well as the overall regional objectives. Beginning with several dozens of single use alternatives, the planner endeavors by a systematic process to set aside those which are too narrow in their service to all uses, too costly in relation to benefits, clearly infeasible on technological grounds, politically unacceptable, or out-of-bounds with respect to the full spectrum of restraints imposed.

With those alternatives which remain after this preliminary screening he enters the bargaining process, "trading-off" between plans to find the most likely candidates. Part of this process is objective; that is, it may be done with some rigor, applying predetermined rules. The criterion that net benefit measured in dollar values must increase for a change in scale to be valid is an example. However, much of the process may be subjective and requires the exercise of judgment based on experience. The final products of these efforts, as few as three or four solidly conceived alternatives, are next presented for scrutiny at the regional level.

Phase II formulation is directed to finding a limited number of regional plans which satisfy regional goals as well as subregional objectives. Trade-offs made at this level of planning are largely between subregions, tempered by criteria established according to use on a regional basis. In the final analysis the most important trade-offs are those which are made in the legislative arena. By the time the recommended plan is received by the legislature the planner should be certain of its technological feasibility, confident of its economic attractiveness, and assured of its social importance. Other forces than he has mustered in the formulation process now must be brought to bear on his product. If he has done his job well, examined critically the alternatives, and weighed carefully the consequences, his recommendations should move forward toward implementation. If not, his report will stand in the company of many others, gathering dust rather than attention.

SUMMARY AND CONCLUSIONS

The "systems approach" provides a methodology which can be usefully applied in the planning for water resource development on a regional scale. It is particularly applicable when the number of components in the system is large, when there are many competing uses for water and when it is desired to consider the greatest possible number of alternatives. To a considerable extent it is a disciplined approach which sets a somewhat formal pattern for each step that is taken and for weighing the consequences of each action. Its ultimate aim is an optimized system comprised of physical components or actions or both. While the systems approach provides for formal mathematical optimization, the complexity of real systems often precludes this degree of rigor and subjective judgments must be introduced. Nevertheless, the techniques available facilitate greatly the number of complex systems which can be examined and in this way allow the designer greater latitude in seeking alternatives which lie close to the true optimum.

It may be generally concluded that through a concerted effort to utilize the systems approach the following advantages could accrue to the Puget Sound Study and to the planning activities concerned with formulation of a comprehensive Washington State Water Plan:

1. The collection, storage, retrieval, interpretation, and utilization of essential data and information can be managed efficiently to serve all resource development activities--planning, design, implementation, operation, and monitoring

2. The staging of the planning sequence, the flow of essential information, the scheduling of events, and

the allocation of manpower can be optimized within limits of time and budget

3. Equity between competing uses for a limited resource can be established according to rationally defined criteria and prescribed restraints on flow, storage volume, and quality

4. Complex water resource development alternatives can be examined expeditiously at all levels of scale, local, subregional and regional

Judiciously applied, the systems approach offers additional insurance that the maximum net social and economic benefits will accrue to the people of the State through the orderly, planned development and preservation of its water resources.