GLOBAL OVERVIEW: WATER RESOURCES AND DISTRIBUTION ISSUES

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INTRODUCTION

IT IS APPROPRIATE TO EXAMINE the concept of water resource systems as a foundation for consideration of the distribution issues that impact human use of the resource throughout the world. One helpful approach is to consider a basic problem in the provision of water, namely the disparity between the distribution of available water versus the demand for the resource in a specific region or locale (Buras, 1972). There are three basic types of maldistribution of water resources. First, one may envision a geographical/ spatial maldistribution of the resource; the geographical area may be experiencing a flood condition (excess water) or a drought condition (insufficient water). In either case, the water availability fails to match the present demand. A second type of maldistribution of water is temporal. For example, the water may be available during the spring of the year following snowmelt in upstream areas. However, this water may not be available later in the growing season when it is needed for irrigation purposes. The third type of maldistribution of water as a resource is qualitative. The mineral, biological, and physical attributes of the water as it is available at specific locations may limit the use of the water for beneficial uses. For example, brackish water may be unfit for human and animal consumption and may have limited value for other purposes. One role for the field of water resource systems is to undertake the studies and research needed to enable sufficient water to be available within a specific locality or region in order to meet both present as well as future demands.

Traditionally, it has been the task of the water resource professionals to apply techniques of systems analysis to this type of maldistribution problem and to identify ways to overcome the maldistribution of water and to mitigate, correct, and provide the resource on an as needed basis. This approach is still valid; however, it needs to be broadened to consider ways to alter the demand

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side of the water need equation as well as meeting the supply side of the water need equation.

SYSTEMS ANALYSIS METHODS: MULTI-OBJECTIVE PLANNING

Normally one may expect a series of inter-related steps to be undertaken to accomplish a systems analysis of a problem of interest. Clearly, the methods of systems analysis may be applied to a wide spectrum of problems including but not limited to water resource problems and issues. The first step is to identify and quantify the objectives associated with the problem. For example, one objective may be to provide water of a specified quality and quantity to a specific region with a specified degree of reliability. A second related objective might be to provide this desired level of water service at minimum economic cost. Any problem that contains two or more objectives is considered a multi-objective problem. The solutions to this class of problem result in the identification of a range of potential solutions where the gain of one objective, for example, lower economic cost is achieved only through the trade-off against other objectives — i.e., less reliable water service in the example. Included in the problem definition portion of the systems analysis is the *definition of decision variables, for example, the location and the level of* treatment provided to achieve desired levels of water quality for the service area. In addition, the analysis requires the formation of constraints that describe the physical limitations associated with the problem at hand. The objective functions and the constraint equations which include the decision variables for the problem provide the analytical framework for the systems analysis to be undertaken.

A second step in the overall process is to collect data relevant to the problem. This data may be physical data, biological data, and/or chemical data that characterize the water resource in its present condition. Economic data including cost data is obtained which specifies information for this example on the costs associated with providing the desired level and reliability of water service. Simulation models and other techniques also may be utilized in order to calculate values of coefficients associated with the decision variables for the multi-objective optimization problem.

Having assembled the necessary data and identified the objective functions and associated constraint equations, the third step is to generate alternatives to achieve the desired objectives. In carrying out this third step in the overall systems analysis, one is identifying potential solutions in objective function space, which satisfy all of the constraints in the problem and identify optimum solution points for the objective functions in the problem. For example, if cost is to be minimized one may set different levels of water service to be provided and then find the least cost solution to provide that specified level of water service.

The fourth step is to evaluate trade-offs between the objective functions that are being considered in the problem at hand. It is very important for the decision makers to have this information before them so that it is clear what increased risk they may incur if they choose to implement lower cost solutions for the provision of water service. It is this explicit trade-off between objectives that is a critical and important element in multi-objective planning for water resource development and use. This fourth step leads directly to the fifth step, namely the selection by the decision-makers of a preferred alternative from among the large number of potential solutions to the problem.

The sixth and final step is the implementation and continued maintenance of the preferred and selected alternative. This step may be the most complex of all of the steps in the systems analysis process. The implementation step requires the commitment of sufficient financial resources to build and to operate the water project. The ability to secure and maintain these financial resources often requires a major political commitment from the multiple units of government served by the project. It should be clear from this brief presentation that the planning and management of water resources is a demanding task requiring the contribution of knowledge and professional skills of many disciplines including planners, engineers, policy makers, economists and others.

MAJOR PLANNING ISSUES: RESOLUTION NEEDED

In undertaking a multi-objective planning activity in the field of water resources, there are a number of major issues which need to be addressed and resolved in order for the planning to proceed in an effective way. First of these issues is to decide upon the desired scale of development. For example, is this water project to serve a limited locale or is it to serve a whole region or a whole watershed. Closely related to the scale of development is the sizing of the physical structural elements to be included in the project. This issue relates not only to the scale of development but also to the desired reliability to be achieved once the project is completed. For example, if the project is designed to protect human life, the reliability or safety factor associated with the project may require larger structures to provide the extra degree of protection of human life. If the water project involves certain control structures such as reservoirs then another issue that must be addressed is to develop a desired operating policy for these control structures so that they can perform their function with a high probability of success. A further dimension to be considered in the planning of major water projects is to minimize undesirable environmental impacts associated with the implementation and operation of the projects. Finally, it is essential to provide for the establishment of an adequate organizational structure to implement and maintain the water resource project. This organizational structure needs to have the capacity to ensure the physical, financial, operational, technical, political, social, and environmental integrity of the project. This issue is among the most complex and challenging of all the tasks facing the water resource planners.

GLOBAL OVERVIEW: KEY ISSUES

There are three major important issue areas that need to be considered to gain perspectives on global water problems facing the world as we move into the 21st century. These areas will be discussed and data will be presented to illustrate the impacts of these problems in certain areas of the world. The first key issue is the growth of global population against a relatively fixed supply of fresh water. The hard fact is simply that population growth is a driver that acts to increase the use of water to meet basic human needs. In addition to meeting the immediate individual need for water to sustain the individual, vast quantities of water are consumed through irrigation for the production of food and fiber to meet human needs. Additional large quantities of water are utilized for cooling purposes in the generation of fossil and nuclear energy. Given that the fresh water resources are not distributed uniformly across the globe, the increasing demand for the essential water resources requires that the water be used as efficiently as possible. Furthermore, it requires that means need to be found that will ensure the reliable provision of adequate food/fiber for those people living in water scarce regions.

A second key issue is the uncertainty associated with climate change and its potential impact upon the availability of fresh water resources in specific regions of the world. The risk of reducing the quantity of fresh water is of particular concern in regions that are already short of water needed to meet present needs. There can be increased evaporation as a consequence of global warming, soil moisture may decrease because of increased evaporation, and snowfall/snowmelt patterns may change. It is clear that the future will not be like the past; however, it is not clear what the future will bring other than change.

The third major global issue is that of sustainability and water resources. This topic is complex and not fully defined. The issue of population growth as a driver has already been discussed; it is important to attach a second driver to population growth and this second element is the standard of living. As the standard of living increases, increased demands are placed upon regional water resources to support the demands of people to achieve higher and higher standards of living. There are various technical means that may be utilized to augment existing water supplies. Desalination is very energy intensive and is applied in very special circumstances. Large scale, long distance transport of water has been practiced for many years to capture and move water from relatively water rich areas to areas where the demand exceeds the available supply. Diversion of water has increasingly come into question because once the water is diverted, it is highly unlikely that the receiving area will ever relinquish these augmented waters. There are a host of problems that emerge as one considers sustainability and water resources. These include water quality and health, ground water management and use, environmental protection of source waters, transport and flood protection, natural disaster problems that include the loss of essential water services when areas experience hurricanes or earthquakes or sea level rise. The problem of protecting against low probability events with severe consequences must receive additional attention. These elements of sustainability and water resources all have a common element, namely anticipation of change. Changes occur in water systems as the physical infrastructure ages. Changes are occurring in both the demand and supply of water resources. These changes will certainly continue into the future. It is very important that our water systems now and in the future incorporate the ability to adjust and remain viable in the face of unknown future stresses and changes.

GLOBAL OVERVIEW: RELEVANT DATA

Tables 1-4 contain representative data that illustrate a number of the issues discussed in this paper. Table 1 reports on the provision of water supply and sanitation for developing areas of the world between 1980 and 1990-the United Nations' Decade of Water Supply and Sanitation. Considering these regions as a whole, there have been dramatic increases in the percentage of populations in rural areas served for water supply and sanitation. There have been more modest increases in the percentage of urban populations now served for water supply and sanitation. While the absolute numbers of rural population not served by water or sanitation have decreased during this decade over the developing regions, the absolute numbers of population in urban areas not served by water supply and sanitation have actually increased. This outcome reflects the population driver as rural people leave the countryside to move to urban areas. The data for Africa is particularly important. It shows that the absolute numbers of unserved peoples in both urban and rural areas have increased over the past decade. In this region, the population driver has out-paced the provision of water and sanitation services. In the Middle East, the data shows that more progress has been achieved in the urban areas than in the rural areas.

Table 2 shows the fresh water withdrawn per year from the world and selected countries. It is important to note that Libya is withdrawing water at over 400% of its annual renewable water resources. This is clearly not sustainable; it is mining water from ground water under the desert and pumping it to the coast for human use needs. Table 2 also shows the high use of water for agricultural production, often in countries that are limited in their water availability. Examine the per capita withdrawn (cubic meter/person) in comparison with the overall world average. Egypt, Sudan, and China all use 87% or more of their water withdrawn for agricultural purposes.

Table 3 shows the annual internal renewable water resources for the world and selected countries. Here the population driver coupled with the relatively fixed fresh water supply is clearly evident. The data shows a range of 30 cubic meters per capita per year (Egypt) to 9,940 cubic meters per capita per year for the United States. In the case of Egypt, the country is entirely dependent upon the inflow of the Nile River from the Sudan. The countries in the Middle East all have in common a very limited annual internal renewable water resource. Water is the life-blood for these countries and effective shared management of this resource is essential for sustainability.

TABLE 1

Fresh Water Data

Water Supply and Sanitation Coverage for Developing Regions, 1980 and 1990*

Region Sector Year	Population (10^6)	Percent Coverage (%)	Number Served (10^6)	Number Unserved (10^6)
Africa				
Urban water				
1980	119.77	83	99.41	20.36
1990	202.54	87	176.21	26.33
Rural water				
1980	332.83	33	109.83	223.00
1990	409.64	42	172.06	237.59
Urban sanitation				
1980	119.77	65	77.85	41.92
1990	202.54	78	160.01	42.53
Rural sanitation				
1980	332.83	18	59.91	272.92
1990	409.64	26	106.51	303.13
Latin America and the Caribbean				
Urban water				
1980	236.72	82	194.11	42.61
1990	324.08	87	281.95	42.13
Rural water				
1980	124.91	47	58.71	66.20
1990	123.87	62	76.80	47.07
Urban sanitation				
1980	236.72	78	184.64	52.08
1990	324.08	79	256.02	68.06
Rural sanitation				
1980	124.91	22	27.48	97.43
1990	123.87	37	45.83	78.04

TABLE 1
(continued)

Region Sector Year	Population (10^6)	Percent Coverage (%)	Number Served (10^6)	Number Unserved (10^6)
Asia and the Pacific				
Urban water				
1980	549.44	73	401.09	148.35
1990	761.18	77	586.11	175.07
Rural water				
1980	1823.30	28	510.52	1312.78
1990	2099.40	67	1406.60	692.80
Urban sanitation				
1980	549.44	65	357.14	192.30
1990	761.18	65	494.77	266.41
Rural sanitation				
1980	1823.30	42	765.79	1057.51
1990	2099.40	54	1133.68	965.72
Western Asia (Middle East)				
Urban water				
1980	27.54	95	26.16	1.38
1990	44.42	100	44.25	0.17
Rural water				
1980	21.95	51	11.19	10.76
1990	25.60	56	14.34	11.26
Urban sanitation				
1980	27.54	79	21.76	5.78
1990	44.42	100	44.42	0.00
Rural sanitation				
1980	21.95	34	7.46	14.49
1990	25.60	34	8.70	16.90

TABLE 1
(continued)

Region Sector Year	Population (10^6)	Percent Coverage (%)	Number Served (10^6)	Number Unserved (10^6)
Totals for these region				
Urban water				
1980	933.47	77	720.77	212.70
1990	1332.22	82	1088.52	243.70
Rural water				
1980	2302.99	30	690.25	1612.74
1990	2658.51	63	1669.79	988.72
Urban sanitation				
1980	933.47	69	641.39	292.08
1990	1332.23	72	955.22	377.00
Rural sanitation				
1980	2302.99	37	860.64	1442.35
1990	2658.51	49	1294.72	1363.79

**Water in Crisis*, Gleick, Peter H. (Editor), Oxford University Press, 1993, p. 188.

Finally, Table 4 provides an indication of a major downside impact resulting from irrigation in arid and semi-arid regions. Increasing salinity of irrigated croplands, results from the high evaporation of irrigation water applied in these areas. The salts are left behind as the irrigation water evaporates. As the salinity increases, the soil becomes less productive and it requires crops with a high tolerance for salinity.

TABLE 2

Fresh Water Withdrawn Per Year[1]
(Selected Countries)

Country	Annual Renewable Water Resources (km^3/yr)	Fraction of Annual Renewable Withdrawn (%)	Per Capital Withdrawal (m^3/person/yr)	Use of Water Withdrawn
WORLD	40,673.0	8	660	
Algeria	18.9	16	161	
Egypt	56.4	97	1,202	88% - Agri.[2]
Libya	.7	404	623	75% - Agri.
Sudan	130.0	14	1,089	99% - Agri.
U.S.	2,478.0	19	2,162	42% - Agri. 46% - Ind.[3]
Peru	40.0	15	294	72% - Agri.
China	2,800.0	16	462	87% - Agri.
Israel	2.15	88	447	79% - Agri.
Jordan	1.1	41	173	65% - Agri.
Lebanon	4.8	16	271	85% - Agri.
Syria	36.0	9	693	61% - Agri.

[1] *Water in Crisis*, Gleick, Peter H. (Editor), Oxford University Press, 1993, pp. 374-378.

[2] Agri. = Agricultural.

[3] Ind. = Industrial

TABLE 3

Annual Internal Renewable Water Resources*
(Selected Countries)

Country	1990 Populations (millions)	Total (km^3/yr)	1990 1000 (m^3/yr/capita)	River Inflow (km^3/yr)	River Outflow (km^3/yr)
WORLD	5292.20	40673.0	7.69		
Algeria	24.96	18.9	.75		
Egypt	52.43	1.8	.03	56.5	
Libya	4.55	.7	.15		
Sudan	25.20	30.0	1.19	100	56.5
U.S.	249.22	2478.0	9.94		
Peru	21.55	40.0	1.79		
China	1139.06	2800.0	2.47		
Israel	4.60	1.7	.37	.45	
Jordan	4.01	.7	.16	.40	
Lebanon	2.70	4.8	1.62	0	.86
Syria	12.53	7.6	.61	27.9	30.0

* *Water in Crisis*, Gleick, Peter H. (Editor), Oxford University Press, 1993, pp. 374-378.

TABLE 4

Salinization of Irrigated Cropland
(Selected Countries)*

Country	Irrigated Lands Affected by Salinization (%)
Algeria	10-15
Egypt	30-40
Sudan	<20
U.S.	20-25
Peru	12
China	15
Israel	13
Jordan	16
Syria	30-35

* *Water in Crisis*, Gleick, Peter H. (Editor), Oxford University Press, 1993, p. 272.

OBSERVATIONS

There are a number of important observations that we may draw from the information presented in this essay. These observations include the following:

- It is imperative that we seek and implement the most effective and efficient use of water to meet human and environmental needs.
- Additional resources need to be committed to provide water to meet basic human requirements for health and survival.
- There is an important need to address issues of equity in terms of the use of limited water resources.

- It is important to recognize the uncertainty that exists regarding the potential adverse impacts of global climate change on fresh water resources.
- It is imperative to educate and train the water resource professionals who will provide the knowledge, skills, and leadership to meet the multiple water resource challenges of the 21st century.
- It is very important to educate the public as to the value and worth of water in society.
- There is a great need to utilize the watershed approach on an appropriate scale to ensure the most effective planning and management of water resources in the watershed.
- In order to build the necessary trust to implement important water projects, the stakeholders must be involved in meaningful ways in the planning and decision processes.
- It is critical to provide the most effective and innovative institutional arrangements possible to ensure effective implementation and sustained operation of key water resource facilities.

REFERENCES

Buras, Nathan, *Scientific Allocation of Water Resources,* New York, American Elsevier, 1972.

Gleick, Peter H. ed. *Water in Crisis,* New York, Oxford University Press, 1993.