INTEGRATED APPROACH

TO

IRRIGATED AGRICULTURE

by

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Overview of Irrigation

It is logical to assume that some of the first efforts of man to control his environment were to control water for various purposes--including the prevention of damage from flood waters following rains and during the melting of snows in the high mountains; and to put the water to use for his benefit as domestic drinking water for himself and his animals, and for irrigation of crops. Initially these steps were extremely simple and elementary in nature. However, there is evidence that these steps were being taken many thousands of years B. C., in such places as China, Iraq, India, and Egypt. It is quite likely that future studies and investigations will show that elsewhere in the world irrigation was practiced at a very early date.

These early civilizations were highly dependent upon irrigation water for the production of food and to provide water for domestic purposes. The success of the civilization was completely dependent upon the continued success of the water supply itself in the necessary quantity and with the necessary quality. Some of the systems were quite simple but others of the systems were complex and elaborate. Generally speaking the irrigation systems of the past were developed in arid regions where it was possible only for a nomadic civilization to exist without the development and use of irrigation water. Likewise, very little irrigation development took place in the humid regions where it was possible to obtain a livelihood from rainfall only.

In these early arid regions, water permitted the civilizations to bloom and flourish. Many of these flourishing civilizations of the past ceased to flourish when the system was unable to continue, due to failure from such factors as salinity and sediment deposition. These factors usually came to

prominence in a gradual way and unless they were corrected the civilization would eventually die out or move to another location.

The problem of salinity was usually due to a lack of drainage--which points out the necessity for combining drainage with any irrigation system. It is for this reason that irrigation and drainage must be considered as one. They cannot be separated. Unfortunately, the same problems have plagued recent irrigation systems throughout the world and have required careful and extensive study to solve the problems.

The total acreage of land irrigated in the world (Framji and Mahajan: 1969, Vol. 1) has been estimated at approximately 20 million acres in 1800. During the 19th century, large numbers of irrigation projects were developed, particularly in India and Egypt. By 1900, there were about 120 million acres of land under irrigation throughout the world including India, Pakistan, Egypt, the USA, the USSR, Japan, Spain, and Chile. The following table shows the estimated acreage in these countries at about 1900 (from Framji and Mahajan: 1969 Vol. 1).

Table 1. Irrigated Areas in 1900

Chile	0.8 million ha	(1.98 million acres)
India	11.66 million ha	(28.81 million acres)
Italy	1.3 million ha	(3.21 million acres)
Japan	2.72 million ha	(6.72 million acres)
Pakistan	3.85 million ha	(9.51 million acres)
Spain	1.00 million ha	(2.47 million acres)
U.A.R.	2.00 million ha	(4.94 million acres)
U.S.A.	3.01 million ha	(7.43 million acres)
U.S.S.R.	3.80 million ha	(9.39 million acres)

Since 1900 there has been an unprecedented increase in irrigated acreage throughout the world and by now it is probably a half billion acres of land. At the same time the nature and complexity of the irrigation projects has been expanded so that many other factors besides irrigation are considered--including flood control, navigation, recreation, domestic and industrial water supply, and the like. These projects are multiple-purpose projects in which basin-wide planning is done as well as interbasin development of the water resources.

Still more recently various techniques of optimization have been developed for giving balanced consideration to all of the different aspects of a water resource development including the socio-economic aspects as well as the physical and biological aspects.

Table 2 is a summary of the total irrigated area in comparison to the cultivated area and the total area in 103 countries of the world(Framji and Mahajan:1969,Vol. 1).

Table 2. Summary of Irrigated Area in the World

Name of country	Total area million ha	Area cultivated million ha	Area irrigated million ha	Percentage of cultivated area to total area	Percentage of irrigated area to total area	Percentage of irrigated area to cultivated area
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. Afghanistan	64.750	7.770	0.813	12.00	1.26	10.5
2. Albania	2.875*	0.501**	0.156*	17.43	5.43	31.1
3. Algeria	238.174	4.200	0.245	1.76	0.10	5.8
4. Argentine	277.666	27.200	1.147	9.79	0.41	4.2
5. Australia	769 500	13.961	1.271	1.81	0.165	9.1
6. Austria	8.385	3.935	0.004	46.93	0.05	0.1
7. Belgium	3 051	0.895**	0.009	29.33	0.30	1.0
8. Bolivia	109.858	0.728	0.040	0.66	0 036	5.5
9. Botswana	57.000	0.073	0.002	0.13	0.004	2.7
10. Brazil	851.196	70.000	0.141	8.23	0.017	0.2
11. Bulgaria	11.091	4 822	0.960	43.48	8.65	19.9
12. Burma	67.058	8.715	0.753	12.88	1.12	8.6
13. Cambodia	18.100	2.500	0.074	13.81	0.40	3.0
14. Canada	997.618	25.267	0.627	2.58	0.06	2.5
15. Ceylon	6.561	1.665	0.333	25.38	5.07	20.0
16. Chile	4.177	2.816	1.300	3.80	1.75	46.2
17. China, Mainland	956.100	109.354	74.000	11.44	7.73	67.7

* Figures from FAO Production Year Book 1968, Volume 22
** Arable land and land under permanent crops from FAO Production Year Book 1968, Volume 22

(1)	(2)	(3)	(4)	(5)	(6)	(7)
18. China, Republic of	3.596	0.896	0.537	24.91	1.945	59.9
19. Colombia	113.617	4.400	0.180	3.87	0.16	4.1
20. Costa Rica	5.070	0.622**	0.026	12.26	0.51	4.2
21. Cuba	11.452	1.970**	0.347	17.20	3.03	17.6
22. Cyprus	0.925	0.466	0.091	50.38	9.83	19.5
23. Czechoslovakia	12.780	7.21	0 140	56.42	1.1	1.9
24. Denmark	4.304	2.682	0.110	62.3	2.56	4.1
25. Dominican Republic	4.877	0.958	0.154	19.64	3.16	16.0
26. Ecuador	28.356	3.670	0.146	12.94	0.52	4.0
27. ElSalvador	2.100	0.600	0.020	28 57	0 95	3.3
28. Ethiopia	122.190	12.525**	0.030	10 25	0 025	0.24
29. Fiji	1.827	0.280	—	15 33		
30. Finland	33.701	2.746	0.009	8.15	0.027	0.33
31. France	55.000	20.000	2.500	36 36	4.55	12.50
32. Germany (Fed. Republic)	24.853	14.300	0.270	57.58	0.09	1.89
33. Ghana	23.854	2.850	0.007	11.95	0.03	0.25
34. Greece	13.194	3.800	0.560	28.8	4.24	14.7
35. Guatemala	10.889	1.47**	0.032	13.5	0.29	2.2
36. Guyana	21.497	0.304	0.188	1.41	0.875	61.8
37. Haiti	2.775	0.370**	0.047	13.33	1.69	12.7
38. Honduras	11.500	3.008	0.035	26.0	0.304	1.17
39. Hungary	9.303	6.928	0.205	74.55	2.20	3.0
40. India	327.634	137.91	37.640	42.0	11.5	27.3
41. Indonesia	149.156	14.000	3.797	9.38	2.55	27.1
42. Iran	164.800	6.843	3.107	4.15	1.89	45.4
43. Iraq	44.444	7.496**	4.000	16.87	9.0	53.4
44. Israel	2.070	0.407	0.153	19.66	7.4	37.6
45. Italy	30.122	27.540	3.150	91.5	10.5	11.4
46. Ivory Coast	32.246*	2.056**	0.009*	6.27	0.028	0.44
47. Jamaica	1.142	0.221	0.071	19.35	6.22	32.1
48. Japan	36.966	5.996	3.390	16.2	9.17	56.6
49. Jordan	9.661	1.140**	0.050	11.81	0.52	4.38
50. Kenya	58.265	1.696**	0.004	2.91	0.007	0.236
51. Korea (Rep. of)	9.850	2.312	0.763	23.47	7.75	33.0
52. Laos	23.680	2.000	0.023	8.45	0.097	1.15
53. Lebanon	1.004	0.306**	0.054	30.4	5.38	17.65
54. Libya	175.954	2.375	0.167	1.35	0.096	7.03
55. Malagasy Republic	59.579	1.000	0.900	1.68	1.51	90.0
56. Malaysia	33.263	3.458**	0.239	10.4	0.72	6.91
57. Malawi	11.759	1.308	0.002	11.1	0.017	0.15
58. Mali	120.162	1.221**		1.016		
59. Malta	0.032	0.016**	0.0015	50.0	4.69	9.38
60. Mexico	196.400	15.000	3.300	7.64	1.68	22.0
61. Morocco	44 505	7.858**	0.265	17.66	0.595	3.37
62. Nepal	14.080	2.023	0.059	14.37	4.2	2.91
63. Netherlands	4.100	2.570	0.051	62.68	1.24	1.983
64. New Zealand	26.868	0.809	0.081	3.02	0.3	10.0
65. Nicaragua	13.970	1.812	0.029	12.99	0.21	1.60
66. Nigeria						
(North-Eastern State)	27.195		0.0024		0.009	
(North-Western State)	16.835	0.0024	0.0024	0.014	0.014	100.00

(1)	(2)	(3)	(4)	(5)	(6)	(7)
67. Norway	32.422	0.845**		2.59		
68. Pakistan	94.671	21.770	11.971	30.39	12.65	41.6
69. Panama	7.565	0.564**	0.014	7.46	0.185	2.48
70. Peru	128.522	2.171	0.120	1.69	0.093	5.53
71. Philippines	29.968	8.296	0.960	27.65	3.20	11.57
72. Poland	31.252	15.435	0.209	48.39	0.67	1.35
73. Portugal	9.196	6.753	0.639	73.43	6.95	9.46
74. Puerto Rico	0.886	0.295	0.037	33.3	4.2	12.5
75. Rhodesia	38.936	1.631	0.034	4.19	0.087	2.1
76. Romania, Socialist Republic	23.75	10.500	0.600	44.2	2.53	5.71
77. Saudi Arabia	225.33	0.373**	0.162	0.166	0.072	43.4
78. Senegal	19.667	2.300	0.120	11.69	0.61	5.22
79. Sierra Leone	7.174	3.664**	0.0008	51.0	0.011	0.0218
80. Somalia	63.766*	0.957**	0.165*	1.50	0.259	17.24
81. South Africa (Union of)	122.100	12.058	0.607	9.88	0.497	5.03
82. Spain	50.475	20.482**	2.300	40.99	4.56	11.2
83. Sudan	250.581	7.100**	0.790	2.83	0.313	11.1
84. Suriname	18.145	0.055	0.025	0.303	0.137	45.5
85. Swaziland	1.736	0.138	0.028	7.95	1.61	20.3
86. Sweden	44.979	3.158**	0.025	7.02	0.056	0.792
87. Switzerland	4.129	1.059	0.023	25.65	0.558	2.17
88. Syria	18.518	3.127	0.507	16.89	2.74	16.2
89. Tanzania	93.970	11.702**	0.040	12.45	0.043	0.342
90. Thailand	51.400	7.300	1.900	14.20	3.70	26.0
91. Tunisia	16.415	4.334**	0.076	26.40	0.463	1.75
92. Turkey	78.058	23.539	1.724	30.16	2.21	7.32
93. Uganda	23.589	4.640	0.003	19.69	0.013	0.065
94. Union of Soviet Socialist Republic (USSR)	2,240.000	2.255	9.900	10.06	0.442	4.39
95. United Arab Republic (UAR)	100.000	2.940	2.94	2.94	2.940	100.00
96. United Kindom (UK)	24.281	7.330	0.113	30.15	0.465	1.542
97. United States of America (USA)	936.333	176.000	16.932	18.79	1.81	9.62
98. Uruguay	18.693	2.000	0.027	10.70	0.144	1.35
99. Venezuela	91.205	5.219**	0.362	5.72	0.397	6.94
100. Vietnam (Rep. of)	17.326	2.750	0.269	15.87	1.55	9.78
101. Yemen	19.500	—	—	—	—	—
102. Yugoslavia	25.654	7.507	0.150	29.50	0.585	1.98
103. Zambia	75.272	2.064	000.6	2.74	0.0080	0.291

Surface, furrow, border and subsoil irrigation have been the conventional methods of irrigation in the past. The trend of the last three

*Figures from FAO Production Year Book 1968, Volume 22
**Arable land and land under permanent crops from FAO Production Year Book 1968, Volume 22

From this table it can be seen that in such countries as India, Pakistan, Cyprus and Italy, there is 10 percent or more of their total area which is under irrigation. In contrast, this table shows that in most African countries only a very small percentage of the total area is under irrigation--usually a fraction of one percent.

Although the total of irrigated area throughout the countries of the world is impressive, there remain many millions of acres of land which can still be put under irrigation beneficially. Actually, we have literally only "scratched the surface" with respect to the irrigation potential for the world. This is especially true in the continent of Africa.

Nearly all of the irrigation developments of the past have used surface application of the water by gravity flow. In very recent years, however, there has been an increasing development of sprinkling irrigation where the value of the crop can justify the expense of installing and operating a sprinkler system. Other recent developments in irrigation include the extensive use of new varieties of seeds, fertilizers, and pesticides which have increased the production per unit of area several fold. These factors, together with others, have resulted in "the green revolution" which has taken place in a number of countries.

Perhaps the most serious problems which have confronted irrigation in the past and in the present are the problems of waterlogging and salinity. In nearly every case, these problems can be traced to inadequate drainage or inadequate control of sediment which is transported in the canals and ditches. Other problems have resulted from the impact of irrigation upon social and cultural factors and the inability of the people and institutions of the region or the country to adjust to these changing conditions caused by technological

advances. Consequently, irrigation cannot be considered as an unmixed blessing (Gulhati and Smith, 1967). These socio-economic factors are given detailed consideration by Vlachos, 1972--including the social and institutional structure necessary for efficient irrigation development. The following is a general summary and conclusions regarding the development of irrigation and drainage which have been stated by Framji and Mahajan; 1969, Vol. 1:

1. It is now well recognized that irrigation and drainage are complementary for successful permanent irrigated agriculture, and that provision of drainage should form an integral feature of every irrigation project, wherever the area served does not have adequate natural drainage facilities.

2. Pre-project investigations, such as complete soil and sub-soil survey, ground-water survey, a socio-economic survey of the area to be served and *adequate* hydrologic data, are prerequisites for the technical soundness of an irrigation or drainage project.

3. The most efficient and economical use of water for irrigation is getting recognized to be of overriding importance everywhere in view of the limited fresh water supplies of the world and the competing claims for its various uses.

4. Consolidation of holdings to form economically viable units is necessary for the efficient use of water; and where the problem of fragmentation or uneconomic holdings exists, there is urgent need for suitable ameliorative measures (legislative, social, etc.).

5. There is a continuing need of research in all fields to insure permanent successful irrigated agriculture and for maximizing production with the minimum possible inputs.

6. Extension service is very important for educating the farmers in new techniques and practices of irrigation and drainage, and for demonstrating at the field level the results of the latest researches relating to irrigated agriculture.

7. Good neighbourliness, mutual accommodation and the co-operative spirit are essential for solving interstate and international disputes so as not to hamper or delay the benefits of irrigation, etc., possible from unutilized available water supplies in interstate or international rivers. Direct negotiations and voluntarily made agreements and not adjudications and imposed-treaties have proved in practice to be the best means of arriving at enduring and satisfactory settlements for the good of all the beneficiaries.

Interrelationship of Resources

It is not possible to consider irrigation successfully in isolation from other uses of water resources, and it is likewise not possible to consider the water resource in isolation from other resources. For this reason, the following general considerations are presented. Table 3 (Albertson: 1972) states the various types of resources that are necessary for development to take place in a region or country of the world. These resources are divided between human resources and physical resources. The way in which these resources are interrelated is shown in Fig. 1, known as The Development Wheel (Albertson and Chaudhry, 1972; and Albertson, 1970).

Table 3. Resources Needed For Development

1. Human Resources
    a. Manpower resources (both quality and quantity)
    b. Institutional resources (organizations and groups)
    c. Information resources (including processes and systems)
    d. Cultural resources (including values and attitudes)
    e. Political resources
    f. Laws (legal resources)
    g. Social environment
2. Physical Resources
    a. Natural resources
    b. Financial resources
    c. Infrastructure (e.g. facilities, equipment, works, and energy resources)
    d. Physical and biological environment

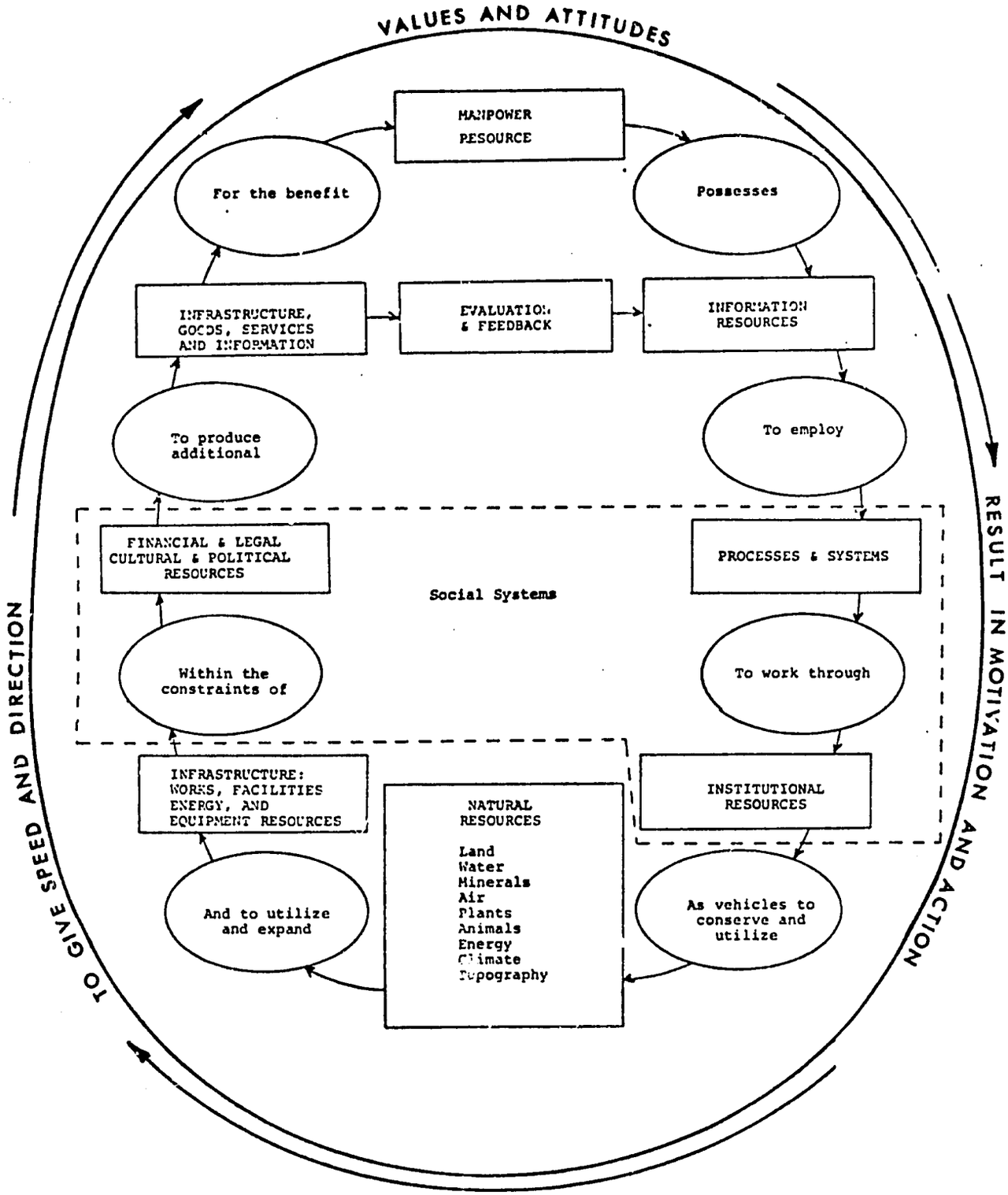

Fig. 1: The development wheel, illustrating the development process. (Adapted from Albertson, 1972).

The Development Process

From Fig. 1, it is evident that the resources which are used for development are interrelated and follow a sequence --each one depending upon the others for its own contribution and progress.

Man is at the heart of development. It is man who must cause development to occur and this development enures to the benefit of man. Any action which is taken by man, whether it helps or hinders development, depends upon his values and attitudes. These result in motivation and action which in turn give speed and direction (forward or backward) to the development wheel.

Schultz (1971) has clearly demonstrated the indispensable value of manpower (quality as well as quantity). If the manpower resource has the proper education, training, and experience, then he has the knowledge and ability for creating the necessary institutions with the required characteristics, and then using these institutions as vehicles to utilize the natural resources (whether indigenous or imported), infrastructure, and other resources to produce additional goods and services, information, infrastructure, and other resources -- all for the further benefit to man. Any water resource development follows this same pattern.

Water Resources

Water resources is one of the natural resources and it cannot be considered in isolation from the other natural resources and physical resources.

With respect to water resource development, Fig. 2 shows the hydrologic cycle, which illustrates the various routes that water can follow from the time

it is precipitated, through its travels over or under the earth's surface, to evaporation, transpiration, and sublimation into the atmosphere where it is again transported to the point of precipitation again.

The hydrologic cycle shows that the precipitation from the clouds can be in the form of rain, snow or hail which falls on the surface of the land and will soak into the soil (infiltration), run off the surface into a stream, or evaporate or sublimate before it even reaches the ground. The water which infiltrates into the soil can go into deep percolation, join the ground water table, or simply soak into the soil. The water which infiltrates into the soil but which does not go into the groundwater or into deep percolation can be taken up by plants or evaporated from the surface of the soil -- having been carried to the surface by capillary action.

The water which moves along the surface of the ground can be evaporated directly from the water surface of the stream or from the surface of the soil, or it can be taken up by the roots of plants. The final destination of some surface water is into streams where it eventually reaches the ocean. Water can be taken from the surface of the earth into the atmosphere by evaporation or sublimation. This evaporation can occur with rain drops falling to the earth before they strike the earth, evaporation from various water surfaces, evaporation from various solid surfaces (such as a leaf surface or the soil), or evaporation from the ocean. Transpiration from vegetation also moves the water from the surface of the earth into the atmosphere. Ice and snow which are falling can sublimate directly into the atmosphere before it reaches the ground or it may sublimate after it has reached the ground -- or it may melt and flow off as surface water or

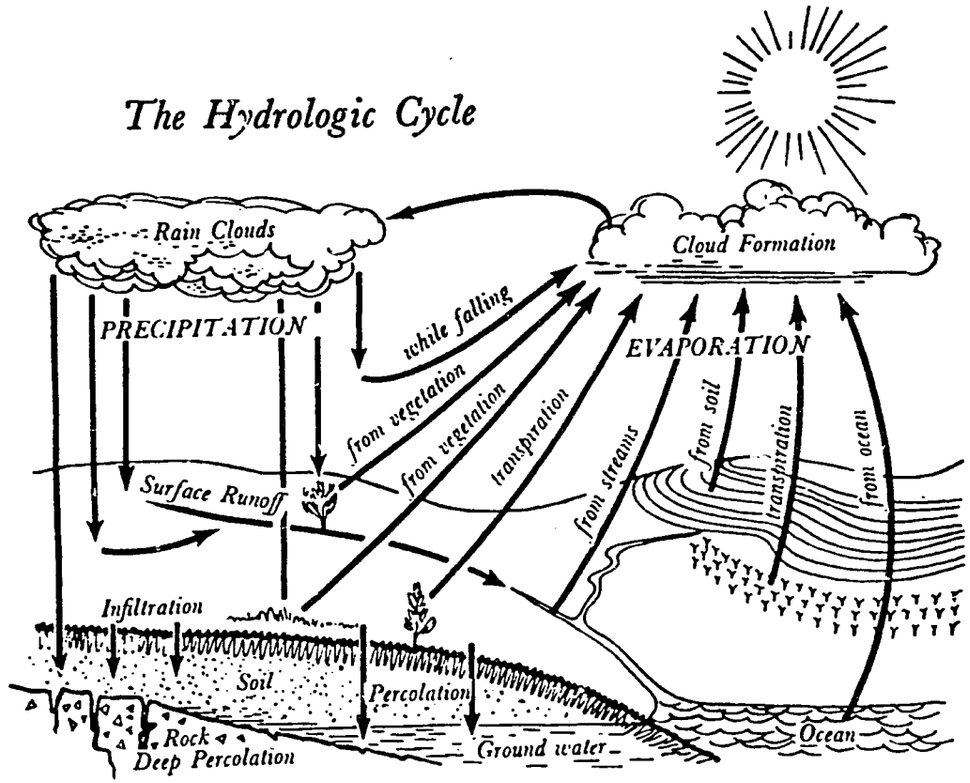

Fig. 2. The Hydrologic Cycle (From Newhall and Smith, 1965) American Society of Civil Engineers, Irrigation and Drainage Specialty Conference, Billings, Montana, 6-9 October.

ground water.

It can be seen from Fig. 3 that water resource development must be considered from a multiple-purpose viewpoint, and that irrigation is only one of these purposes. Furthermore, the development of water for irrigation cannot be considered in isolation from environmental considerations--including such factors as pollution and erosion.

Also from Fig. 3 it is evident that the development of a region can be much more complete by a balanced development and use of the water resources -- each factor in this balanced use contributing to the other. Irrigation will help the agricultural aspects of the economy and the culture, and at the same time urban and industrial development will help to balance the economy and the culture. In some situations hydropower is possible and, likewise, flood control may be needed. Increasingly, such activities as recreation will play a greater role with respect to water resource development. In some areas navigation is also of primary importance.

Water-Soil-Plant Relations

With respect to irrigation itself, it is not possible to divorce the relationship between the water, the soil, and the plant. There is actually a very delicate balance between these factors which will result in the maximum production of agricultural products. Climatic conditions will frequently permit the use of only a certain range of crops to be produced and likewise the characteristics of the soil and water--including both quality and quantity--will determine whether maximum production of these crops is possible. The agronomic aspects of these factors are considered by Kemper, 1972.

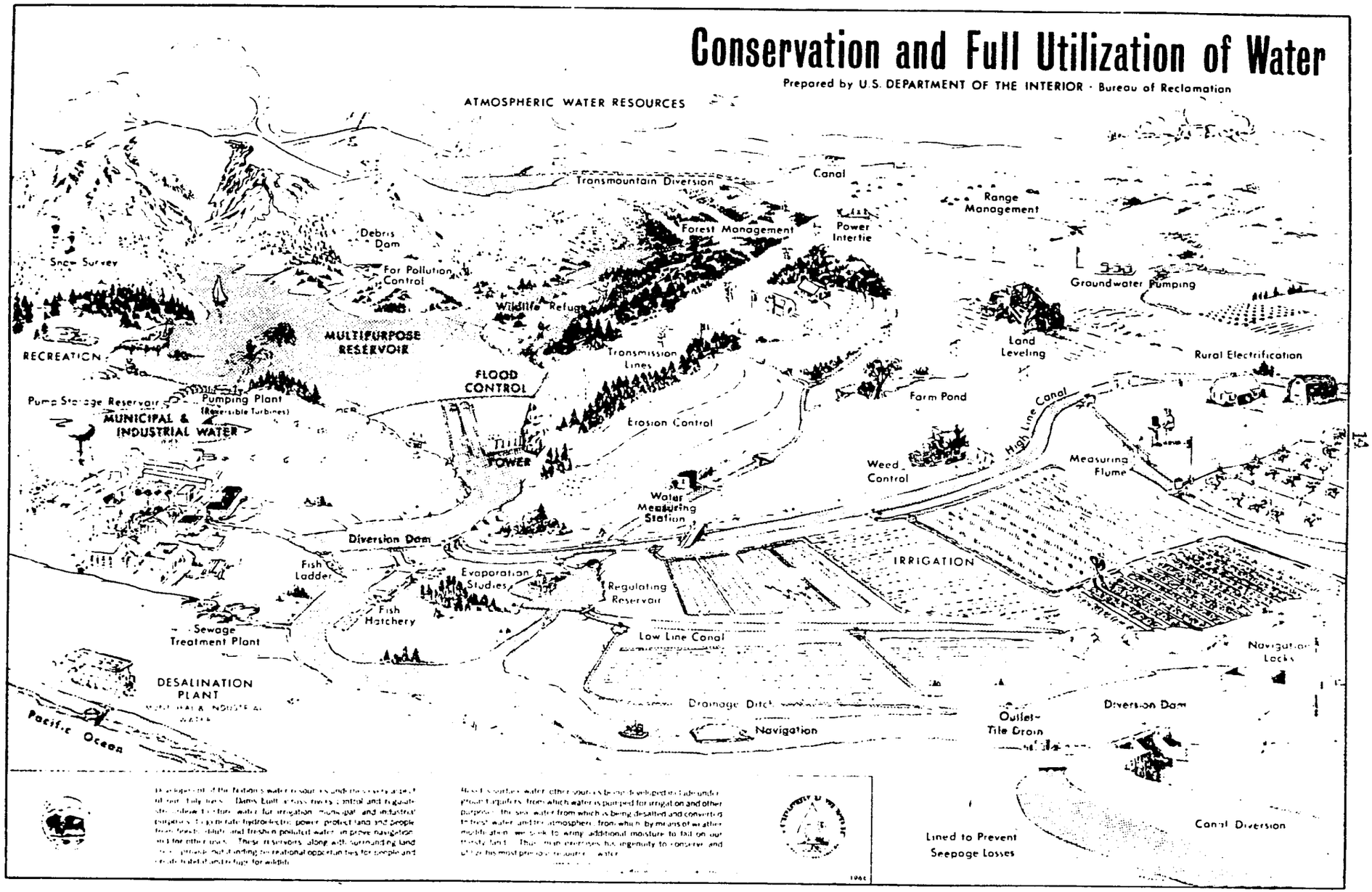

Fig. 3. Conservation and Full Utilization of Water

Importance of the Environment

In developing any irrigation project, it is necessary to consider the impact which the irrigation and drainage will have on the existing environment as well as the new environment which will result from this new program. Included in the environment must be such factors as problems of pollution, erosion, vegetative cover, general appearance of scars by land excavation and fill, air pollution, noise pollution, density of population, density and appearance of structures such as buildings, highways, dams, bridges, canals, green areas, etc. These factors are considered further by Vlachos 1972.

Planning for Irrigation

Proper planning for the development of irrigated agriculture requires an overview of the entire system--which necessitates the use of systems analysis for the most effective insight. Fig. 4 is a simple representation of a system involving inputs and outputs and the surrounding environment which has an impact upon the system and its operation.

When irrigation is added to an area, the entire system becomes much more complex--the population density increases, new and modified institutions are required, much more extensive infrastructure must be developed, and more intensive use of resources in general results. This is expanded by Vlachos, 1972; Hart, 1972 and Kemper, 1972.

Data Collection

The first step in the planning and design of a water resources development, such as irrigation, must be the collection of data, including climatic data, precipation data, runoff data, groundwater data, water

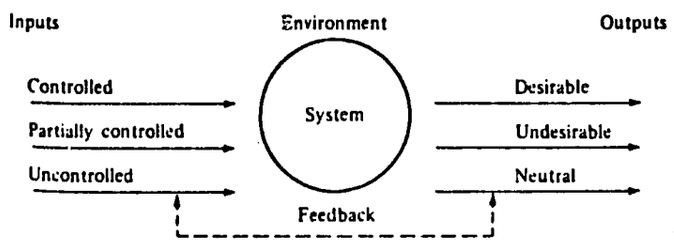

Fig. 4. The Concept of a System

quality data, and soil and crop data. Without these data it is not possible to plan and design a project or program which will achieve the intended objectives.

Most regions and countries of the world have at least some such data, but seldom are the data adequate in scope, quality, or quantity.

Regardless of the status and schedule of any irrigation or water resources project, a complete water resources data collection program should be initiated immediately so that the greatest length of record possible will be available. This fact cannot be overstressed.

Without adequate data, it is necessary to guess and make estimates in planning and design. These can result in errors and risks which are costly and intollerable, as well as setting into motion irreversable processes which are damaging.

The Water System

The flow diagram of a water system is shown in Fig. 5 involving the supply of water, its control, its conveyance and distribution, its utilization, and its disposal and reclamation. Also involved are the losses and the return flow which occur at various points along the system. This system is also represented in a water management matrix, Fig. 6, which includes the physical and nonphysical aspects as well as various levels of environmental components. These figures are closely related to the hydrologic cycle, Fig. 2.

From these illustrations, it is evident that: a water supply can originate from surface water or ground water; control of the water can be accomplished by storage above ground or under ground; conveyance and

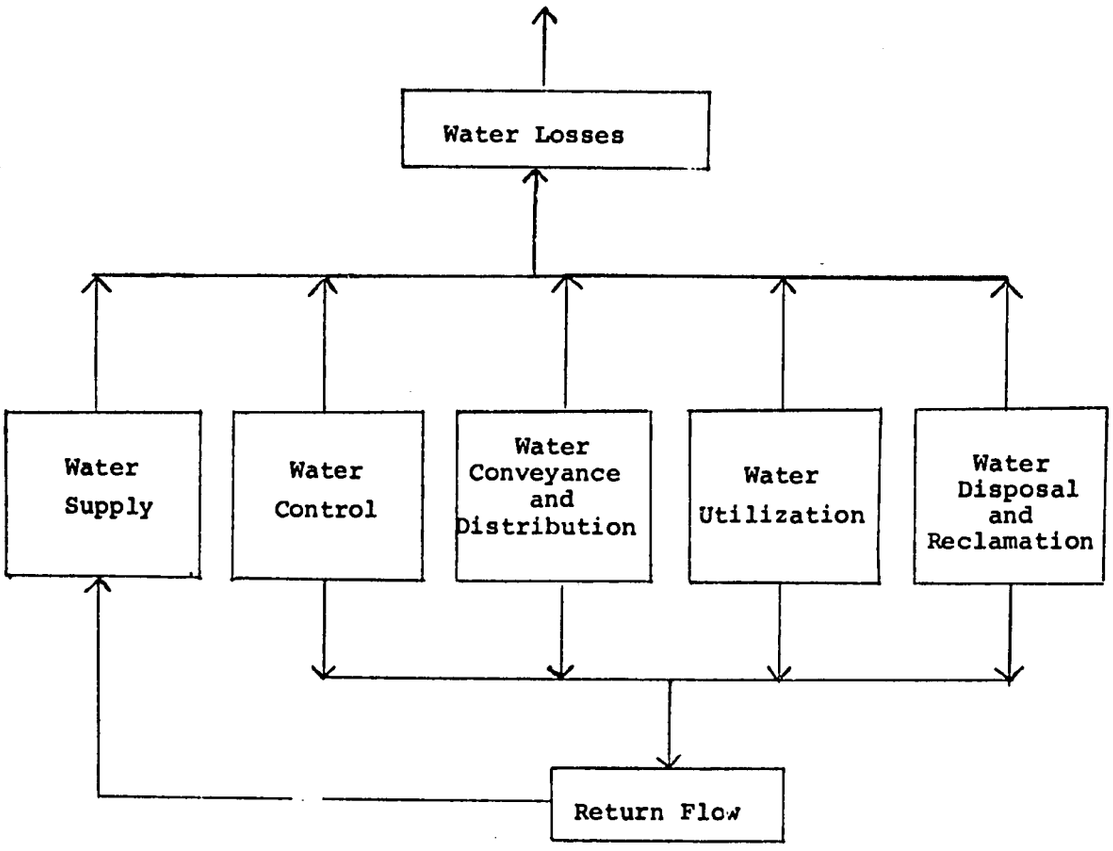

Fig. 5. Flow Diagram of a Water System

Micro-environmental (community, local, etc.)

Meso-environmental (regional, area, basin, etc.)

Macro-environmental (national, internation, bilateral, multilateral)

ENVIRON-MENT	SUPPLY	CONTROL	DISTRIBUTION	UTILIZATION	RECLAMATION	LOSSES
Physical	Precipitation River Flow Underground Surface Water Harvest	Reservoirs Wells Seepage Storage Surface Underground	Canals Pipelines Measurement Seepage	Agron. consid. Time & Amount Yield vs.Irrig. C.U.Consumptive use Farm irrig. systems	Surface water Ground water	Evaporation Transpiration Sublimation Deep percolation Consumption
Non-Physical Social Economic Cultural Demographic Legal Political Institutional Manpower						

Fig. 6. Water Management Matrix

distribution of the water is done by canals, pipelines or seepage; utilization of water is by agriculture, industry, municipalities, recreation, navigation, etc; reclamation of water can be to or from the surface water or the ground water; the losses can be any one or a combination of evaporation, transpiration, sublimation, deep percolation, and consumption; the nonphysical aspects involve the socio-economic, the cultural, the legal, the political, and the demographic; and all of these factors must be considered within the context of the size and scope of the environment (micro, meso, or macro). These concepts are also discussed by Vlachos, 1972.

Need for Regional and National Water Plans

It is becoming increasingly evident throughout the world that water is a very precious resource which is limited in either quality or quantity or both, and that the need for water is expanding exponentially. Unfortunately, in many countries these facts have been given serious consideration only recently. Fortunately, the multiple purpose and interdisciplinary nature of water resources development is now generally recognized and planning is increasingly taking these factors into consideration.

One of the first steps needed for the proper development of the water resources of a country or region of the world is a National Water Plan or a Regional Water Plan or both. This plan must consider all of the uses for which water is needed, or may be needed in the future, and the impact any new water development will have upon the environment and the people involved. If more than one nation is involved, the international implications must also be considered. This is discussed in greater detail by Vlachos, 1972.

These studies must include the various factors already discussed in this paper, together with the other aspects which follow.

Water Uses

The many uses to which water is put are illustrated in Fig. 7. This is also a flow diagram which shows the route taken by the water from the point of precipitation to the point of movement back into the atmosphere to be precipitated again. The numbers inserted in this diagram are for the

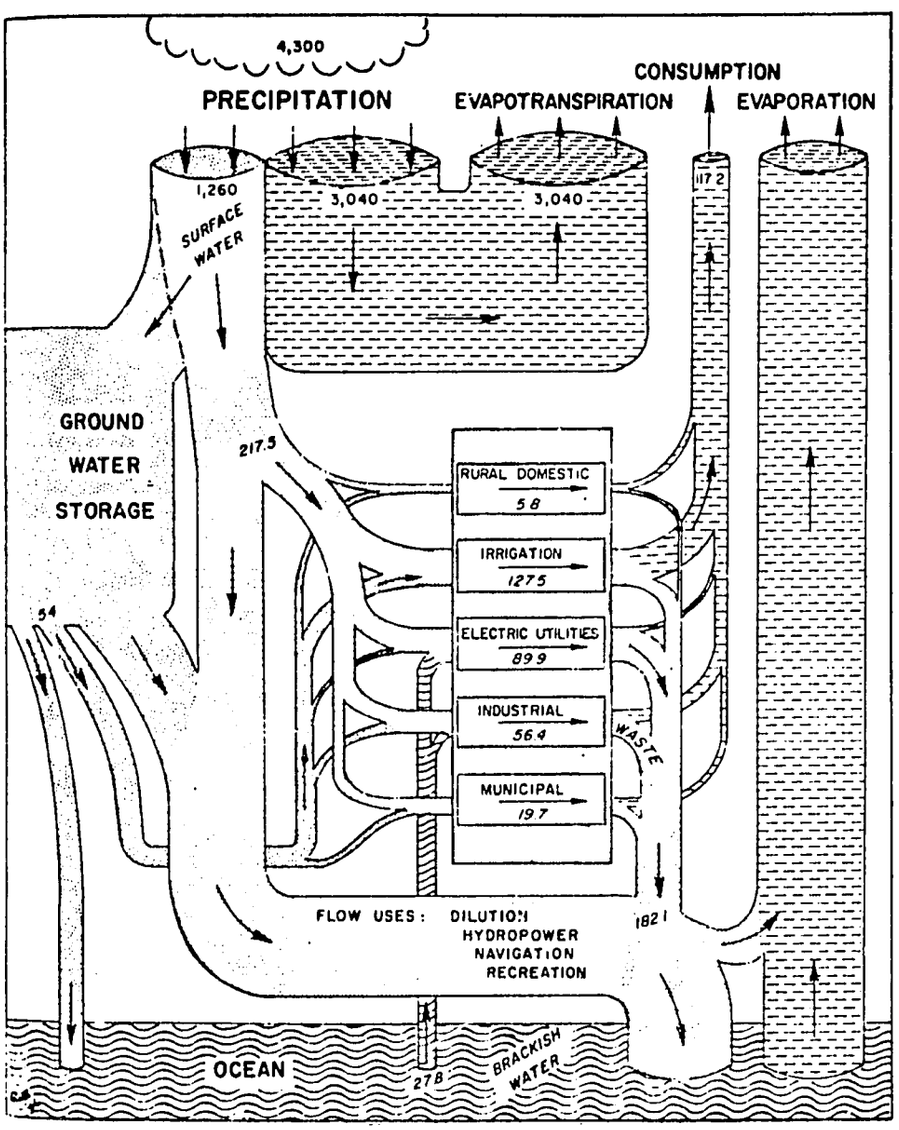

Fig. 7. Relative Amounts of Water Useage (Figures are estimated in billion gallons per day for the USA in 1958.)

USA in 1958. In this case the predominate use of water is for irrigation, with other uses falling considerably behind. Nevertheless, the other uses are very important and must be given full consideration in the preparation of a water plan.

Fortunately, the various uses of water are frequently compatable and cause little or no conflict, eg. irrigation and electric utilities. On the other hand, some uses do conflict, such as flood control through reservoir storage and hydro power. Through the proper systems analysis--which considers the value and importance of each use, and the impact on the environment and the people--it is possible to determine an optimum plan within the constraints imposed, eg. financial limitations.

Water Management for Irrigation

The management of water for irrigation involves water supply, water distribution, water application, and removal of excess water. These are discussed in detail by Hart, 1972, and Kemper, 1972.

Water supply can be obtained from several sources as illustrated by Figs. 2 and 3. Frequently more than one source is used. For example, in many areas the conjunctive use of both surface water and ground water is the most effective and efficient. This supply must be located, its quality and quantity determined, a control system devised, and program developed for release of this water supply into the distribution system.

The water distribution program includes the conveyance of the water from the point of storage to the point of use, such as an irrigated farm. This conveyance can be through open conduits, such as canals and ditches,

or through closed conduits such as pipelines. Underground flow can also be considered a means of conveyance where it is also a means of storing the water.

Water application to an irrigated area is done by flooding of level basins, irrigation between borders, furrow irrigation, subsurface irrigation, trickle irrigation, and sprinkler irrigation. Each of these methods has both advantages and disadvantages, depending upon the type and value of the crop, the topography of the land, the type and condition of the soil, the quality, quantity and availability of the water, the relative costs, availability, and quantity of equipment and labor, and the climate. These factors must all be given consideration in order to develop the most efficient and effective irrigation system of application.

Water removal is one of the most important aspects of an irrigation project. The removal of excess water must be considered to be just as important as the distribution and application of the water. Improper or inadequate removal of excess water (drainage) has caused many irrigation projects to fail, both in the present and the immediate and distant past. It causes flooding of crops, waterlogging of the land, and salinity. Not only must the drainage system be well designed and built initially, but the system must also be well maintained and operated.

Factors to be Integrated

In planning an irrigation project or program, it is necessary to integrate a number of factors. These include:

1. The various water resources uses
2. The various land resources uses
3. The environmental aspects
4. The physical and social aspects
5. The overall watersystem and its management
6. The overall agricultural program and system
7. The scale of the program (level of planning)
8. Data required for decision making.

These factors are considered in varying degrees in this paper, and in the papers by Kemper, 1972; Hart, 1972; and, Vlachos, 1972. Much more detailed information and consideration is necessary, however, when planning a water resources program such as an irrigation project.

Advantages and Disadvantages of Irrigation

When considering the development of an irrigation project, careful consideration must be given to both the advantages and disadvantages of the proposed project. Some of the advantages are the following:

1. Usually increases the number of crops which can be grown each year
2. Usually increases the variation of crops which can be grown
3. Increases the yield of the crops that are grown
4. Increases the economic base and the productivity of an area
5. Serves as a support base for other economic and social activities
6. Stabilizes an agricultural area

7. Ensures a good yield of crops each year (including the humid areas)
8. Changes an area from a one crop culture to a diverse and expanding culture and economy
9. Fertile land can be productive even with no rainfall
10. Permits more intensive use of given natural resources
11. Helps to diversify the economy of a region or nation and thereby increases independence and foreign exchange.

Included in the disadvantages of irrigation are the following:

1. A large initial capital investment is usually required
2. There are large costs for operation and maintenance
3. There must be a long term, renewable water supply -- which is not always available
4. The necessary drainage facilities may be difficult to provide or maintain
5. A high level of manpower ability is required.

Many case studies should be carefully evaluated when considering the advantages and disadvantages of an irrigation project and whether to proceed with its development.

Summary and Conclusions

1. Irrigation can be highly beneficial to a region or a nation, but many factors must be considered to be sure that it is successful.
2. The development of any area usually requires a great improvement in the quality of the manpower resource because new skills and concepts are necessary.
3. An irrigation program cannot be considered successfully in isolation from the other uses of water resources and other resources involved in development.
4. There is a vast store of knowledge available for considering and planning an irrigation program but this knowledge must be adapted to the local conditions which exist at the time.
5. A program of research, education, and extension, should be established to be an integral part of any new or expanded irrigation project.

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