Summary and Findings

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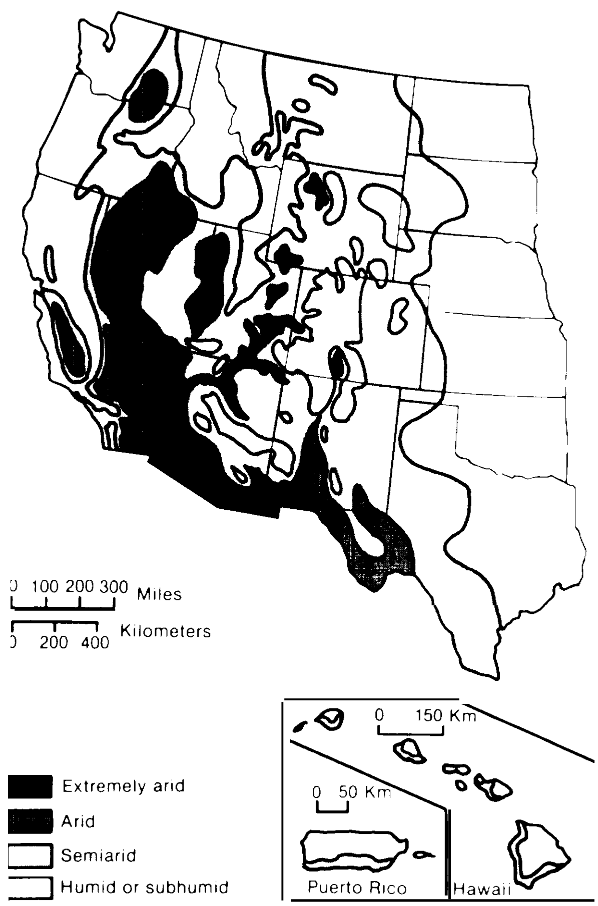
INTRODUCTION

As a Nation with bountiful resources, the United States has rarely faced natural resource limits. In the short history of this country, there have always been more lands and more resources to develop and a philosophy that technology could supplement natural resources when needed. Increasingly, however, some Western States are experiencing resource limitations related to water use and distribution that challenge the full capacity of existing social and technical institutions. The water problems to face this region and, therefore, the Nation in the 1980's and 1990's are likely to expand and intensify for agriculture. Stretching resources to accommodate the West's continuing growth while protecting existing patterns of water demand may require levels of technical input no longer economically feasible. Concerted Federal, State, and local action will be needed to help build a sustainable Western agriculture that is profitable for the Western farmer and rancher and that effectively addresses the complex and interrelated problems surrounding the agricultural use of Western water, A strong Federal role will remain fundamental to help bring about necessary changes.

This study assesses the role of present and emerging water-use technologies for sustaining the long-term agricultural productivity of arid/semiarid agricultural plants and animals and the renewable natural resource base on which agriculture depends. The study considers increased demands on the resource, concerns about water quality, and the capacity of existing institutions to respond effectively and equitably to growing demands. Congressional interest in this topic is important because the arid/semiarid West (fig, 1) makes significant contributions to this country's agricultural production, providing unique benefits not easily replaced by the other regions of the United States. Its large expanses of land nurture cereal grains and livestock. Its dry and disease-free

Figure 1.—Arid and Semiarid Regions of the United States



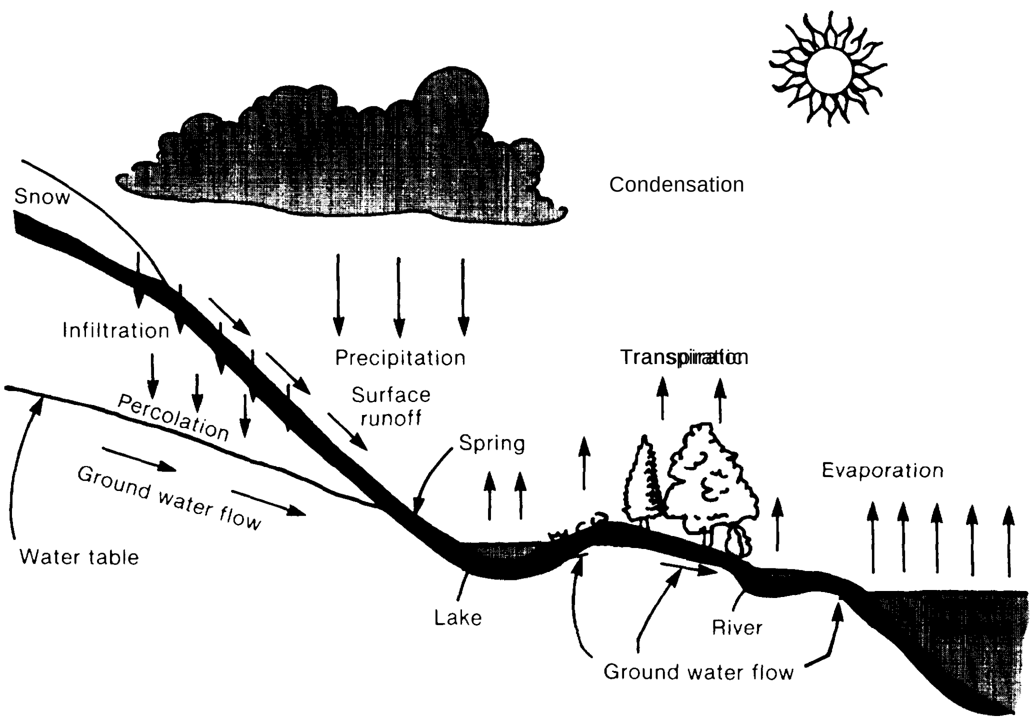
SOURCE: Carle Hedge (ed), *Aridity* and Man (Washington D C American Asso-elation for the Advancement of Science, publication No 74, 1963)

environment is especially suited to seed production and certain kinds of agricultural research. When irrigated, its soil, aided by low humidity and many cloud-free days, produces high-value specialty crops such as fruits, nuts, and table vegetables. Much of the research and development (R&D) of agricultural technology that now benefits the entire United States originated in the West, where water application could be carefully controlled.

This report is organized into two parts: background chapters on the state of the renewable resource base and associated water institutions (chs. II-V) and technology chapters containing assessments of near- and long-term technology potentials (chs. VI-XI). Technologies are organized in particular chapters according to the principal components of the hydrologic cycle [fig. 2) the technologies are meant to manipulate. Because water is a key factor dictating the types of agriculture that can be sustained in the water-short West, knowing the impacts of a particular water-related technology throughout the water system is critical. Benefits to one user upstream could mean losses to another user downstream in reduced flow, reduced quality, or altered timing of flow. Alterations in surface water at one site could affect ground water supplies at another hydrologically interconnected site. Moreover, technologies and land uses may overlap at particular sites.

As used in this report, the term "renewable natural resource base" includes soil, water, and all the physical, chemical, and biological components of agricultural resource systems. "Long-term," as used in this report, means more than one human lifespan (approximately *70* years) from the date of this report.

Figure 2.—The Hydrologic Cycle



Water passes continuously through this cycle from evaporation from the oceans into the atmosphere through precipitation onto the continents and eventual runoff into the oceans Human use of water may modify this cycle at virtually every point

SOURCE H Hengeveld and C DeVocht, Urban Ecology 6(1-4) 19, 1982

MAJOR FINDINGS

The following three major findings of this assessment are the synthesis of individual chapter findings which are discussed in more detail below:

- If agriculture in the Western United States is to be conducted in a sustainable fashion, a systems approach to decisionmaking regarding policies, plans, and programs affecting the agricultural resource base and water-related technologies is a fundamental need, one that generally is lacking throughout government.
- The goal of sustaining long-term productivity of the agricultural resource base in the western States is not being advanced effectively by some existing Federal activities.
- To ensure sustainable Western agriculture, users must be involved in and must perceive equity and fairness in decisionmaking about water-related technologies and resolution of conflicts over water use. Improved mechanisms are needed to expand this involvement.

Western Agricultural Production

Products of Western agriculture constitute a large share of the total income derived from farming and ranching in the United States. In 1980, cash receipts from marketing crops and livestock and their products in the Western States accounted for approximately $59.3 billion, or about 43 percent of the income derived from farming in the United States. Some 30 percent of this sum came from export markets.

Unlike the Eastern United States, much of the land in the West is federally owned:

	Federal	Non-Federal	Percent Federal
	(in millions	of acres)	
17 Western States	368	790	32
31 Eastern States	3-1	705	5

The amount of public land varies from State to State, from some 85 percent of Nevada to about 1 percent of Kansas and Nebraska. These public lands are used largely for livestock grazing and include major water-producing areas, The Federal ownership of these lands has generated Federal policies on use and management, policies that can substantially affect the sustainability of Western agriculture.

Of the three types of agricultural production (see box A) used in arid/semiarid regions, rangeland and dryland agriculture are the most extensive in area and rely on precipitation for water supplies. Rain-fed agriculture makes important contributions to the economy and lifestyle of the West and is likely to increase in importance. Present-day irrigation agriculture is especially significant because of the large amounts of energy and supplemental water involved. It allows crop production in areas where it might otherwise be impossible, and farmers who irrigate generally have higher and more stable yields and can risk growing crops of higher value. However, irrigation agriculture is the subject of particular controversy and concern at present. Some crops that are irrigated are surplus. Moreover, competition for these water resources is increasing from industries and municipal users who can afford to pay more for their water. Finally, depletion of ground water resources threatens agricultural producers and rural communities and diminishes the possibility of using this resource in the future. These factors lead many analysts

Box A

Three broad types of agricultural production are common in arid/semiarid regions:

- Rangeland agriculture—usually involves grazing domestic livestock on grasses, grasslike plants, forbs, and shrubs on lands traditionally considered unsuitable for cultivation.
- Dryland farming—involves crop production through cultivation of the land and relies on precipitation to supply plant-water needs.
- Irrigation agriculture—involves crop production through land cultivation and uses additional water to supplement normal precipitation.

to believe that in the future Western irrigation agriculture as practiced today will diminish in productivity and profitability in some areas.

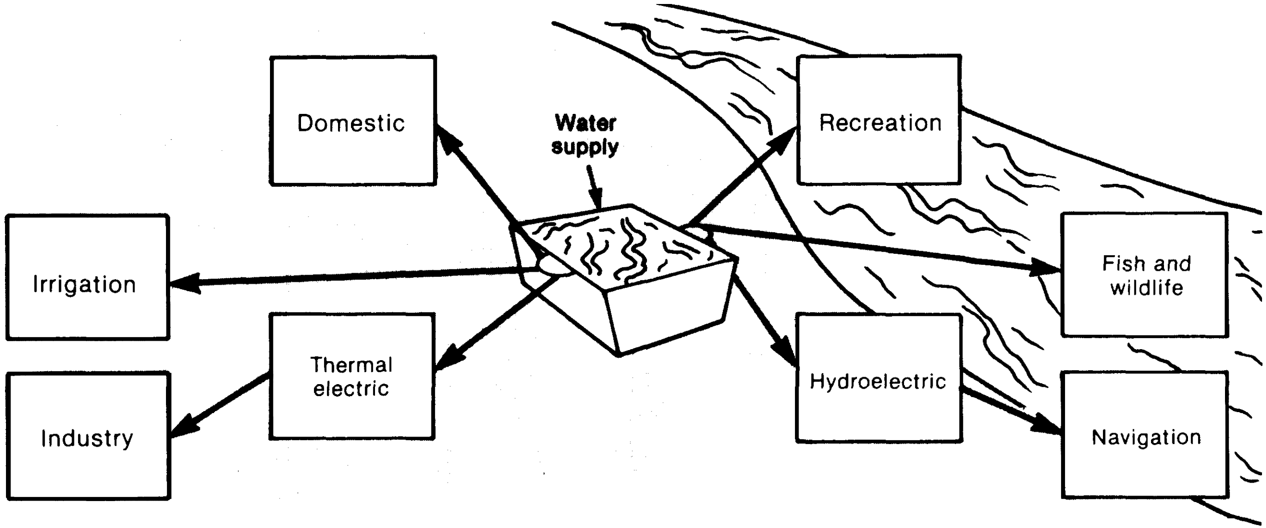
Water Supply and Use

Available estimates of water supply and use indicate that almost half of the Western United States is experiencing water-supply problems in relation to demand. Surface water shortages exist annually or seasonally in at least some portion of each of the major water resources regions of the Western States. In almost all cases, these shortages are offset by water reuse and ground water pumping. In much of the Southwest and southern High Plains, ground water is being withdrawn faster than it is replaced (often called ground water "mining") in order to sustain developed levels of use. Where water supply is not being consumed, competing nonconsumptive uses, such as instream flow requirements for hydroelectric generation, waste assimilation, recreation, and habitat maintenance, increasingly create scheduling conflicts for offstream uses (fig. 3). Present trends and experience indicate that every additional drop of water conserved, and thus available, enables more growth and development, raising demand levels further. Effective water-use management will necessitate attention to demand as well as supply aspects of water use.

The availability of water for agricultural use varies by location and over time. Water supply depends on variations in components of the hydrologic cycle—precipitation, evaporation, transpiration, infiltration, and runoff, Because these components interrelate, a change produced by technology in one component of the cycle will inevitably affect other components.

The potential for a given technology to produce additional water or to conserve existing supplies is difficult to evaluate and will remain so unless the quantities of water involved in the hydrologic cycle can be defined more accurately. Various responsibilities for

Figure 3.—Conflicts in Instream v. Off stream Use



SOURCE: U.S. Water Resources Council, *The Nation's Water Resources 1975-2000*, vol. 2, part III (Washington, D.C.: U.S. Government Printing Office, 1978), p. 129.

the collection, synthesis, and dissemination of hydrologic information are delegated among a number of Federal and State agencies (table 1), resulting in a variety of data bases and data interpretations that are often not compatible. Important gaps in data exist, and few regional syntheses of data have been made. Short-term climatic fluctuations affecting water supply can be accommodated in management and planning processes through statistical analysis of past trends; there is no reliable method for predicting long-term fluctuations.

The most important source of renewable surface water supplies in the Western United States is the mountain snowpack. When the snowpack melts in the spring and summer, it supplies an estimated 70 to 100 percent (depending on location) of the total annual surface runoff for all river basins except the Texas-Gulf region. Relatively little research attention has been given to the snowpack. Technologies such as weather modification and the forecasting of streamflow to improve reservoir management would benefit considerably from increased understanding of the snowpack's dominant role in renewing surface water supplies.

Water Quality

Water quality is determined both by the nature of a pollutant and by the concentration of that pollutant in water. The kinds and amounts of impurities in water depend on a number of environmental factors, such as the source of the water, the physiographic characteristics through which the water moves, and the effects of human activity on water. The types of water pollution can be categorized as follows:

1. municipal sewage and other oxygen-demanding wastes,
2. infectious agents,
3. synthetic organic chemicals,
4. mineral substances and inorganic chemicals,
5. sediments,
6. plant nutrients,
7. radioactive substances, and
8. heat.

Since the volume of water in the Western United States is lower than that in the more water-abundant Eastern part of the country, any given water use in the West has a greater

Table 1.—Federal Water-Data Collection Agencies[a]

	Government agencies						Independent agencies			
In-house data programs	USDA	DOC	DOD	DOE	DOI	DOT	EPA	IBWC	NRC	TVA
Surface water	X	X	X	X	X	X	X	X	—	X
Ground water	X	—	X	X	X	X	X	X	—	X
Water quality	X	X	X	X	X	X	X	X	—	X
Water use	X	X	X	X	X	—	—	—	—	—
Environmental impact	X	—	X	X	X	X	X	—	—	X
Ecology	X	—	X	X	X	X	X	—	—	X
Management effects	X	—	X	X	X	X	X	—	—	X
Basin studies	X	—	—		X	X	X	—	—	X
Real-time sensing	X	X	X		—	X	X	—	—	X
Remote sensing	X	X	X	—	—	X	X	—	—	X
Data sensing	X	—	X	X	X	—	X	—	—	X
Instream use	X	—	—		X		—	—	—	—
Water rights	X	—	—		X	—	—	—	—	—
Floods	—	X	—	—	X	X	—	—	—	X
Energy	—	—	—	X	X	—	X	—	X	—
Nuclear	—	—	—	X	X	—	X	—	X	—
Precipitation quality	—	—	—	—	X	—	X	—	—	x

KEY USDA—U S Department of Agriculture, DOC—Department of Commerce, DOD—Department of Defense, DOE—Department of Energy DOI—Department of the Inter! or, DOT— Department of Transportation, Independent agencies EPA— Environmental Protection Agency, IBWC— International Boundary & Water Commission NRC—Nuclear Regulatory Commission, TVA–Tennessee Valley Authority.

aFor the 1981.82 fiscal year 26 Federal agencies, representing six departments and four indepen[d]ent agencies collected 'water resource data

SOURCE U S Department of the Interior Geological Survey Off Ice of Water Data Collect Ion, Plans for *Water Data Acquisition by* Federal *Agencies Through F/sea/ Year* 1983 (Reston Va 1982) p 7 potential for causing water-quality degradation. The limited supply of Western water requires that each unit of water be more fully used, resulting in patterns of reuse in which each unit of water is used consecutively as it moves downstream. Thus, water may be removed from a river and partially consumed for irrigation; the return flow may be stored in a reservoir and subsequently reused to generate hydroelectric energy; and the remainder may be withdrawn by a municipality for human consumption. The return flows from each of these uses often have increasing levels of pollution that, left untreated, can threaten uses downstream, including agricultural uses.

Most water-quality problems appear to be site-specific. The data base describing the quality of water in the Western United States is incomplete, however, and few integrated analyses of water contamination as it affects water reuse, environmental characteristics, or public health have been performed.

The term "water quality" in agriculture refers primarily to the quality of water used for farm and ranch water supply, livestock watering, and irrigation. In evaluating the relationship between water quality and agriculture, two aspects must be considered:

1. the effect of agricultural uses on the quality of water for other uses, and
2. the effect of water quality on various agricultural uses.

The highest quality water required in agriculture is for domestic farm and ranch consumption. Much of the water used in this way is well water, which in many areas is not routinely monitored for quality nor subjected to any routine treatment prior to use. The quality of this water source is particularly susceptible to degradation because of the many potential sources of contamination in the farm and ranch environments.

The quality of water used in irrigation is also very important, When water applied in irrigation is lost to evapotranspiration during plant growth, salts contained in that water are left behind in the soil. Continued reuse of streamflows for irrigation without prior treatment has become a necessity in many of the water-sport areas of the Western United States. This reuse can result in the gradual buildup of salts and agricultural chemicals in the soil and in water that is ultimately detrimental to long-term agricultural productivity.

Agricultural water pollution can be reduced by using improved management practices and methods that result in fewer contaminants being released into the water supply, However, present monitoring and control measures may not be sufficient to prevent deterioration of water quality caused by Western water use for either agricultural or nonagricultural activities—e. g., municipal and industrial activities.

Institutions Affecting Western Agricultural Water Use

Distribution of water in the Western United States among uses and users responds to two major institutional forces—the legal system and the market system, The legal system defines rights and responsibilities regarding the use of water; the market system allows water to be bought and sold, and thus transferred between uses and users. The Western agricultural water user is, at best, moderately uncertain about water use and the adoption of technology affecting water use because it is unclear how legal and economic institutions might change as demands for water increase.

The Western State water institutions developed in response to the surrounding conditions of aridity and the initial character of Federal ownership of the water and land. Their focus was on allocating water-use rights to individuals as property rights. States deferred to Federal agencies for large-scale water-resources planning and development because of the Federal Government's financial and technical capabilities and its broad geographic jurisdiction that facilitated interstate river basin development,

At the time Western law doctrines (Federal, State, and interstate) were developed, the level of definition given to water rights and duties was adequate to address early development needs, water law divided the resource into water-supply categories, the major categories at the State level being surface water and ground water. I n recent years, water-quality programs have been developed with distinct bureaucracies and regulatory responsibilities separate from those programs related to water supplies. This treatment of water has caused conflicts and confusion among users within and between States and has made water planning and management problems more severe. As water-use demands increase and values change, more precise definition of such concepts of beneficial use will be required to allow the user greater assurance of return on investments in water "saved."

Growing demands are creating conflicts among agricultural, energy, industrial, municipal, Federal reserved water-right holders, environmental, and other uses and values and suggest that water in the West will become more expensive. Until now, Federal sponsorship of many development activities provided water at well below its "cost" or ''value' relative to much non-Federal water. This sponsorship has slowed the development of Western water markets and has shaped the character and patterns of agricultural water use in the Western United States. However, as demands for water for nearly all purposes increase and as the scarcity of water is recognized, pressures will mount to shift water to new uses and users. The rules of economic efficiency will support arguments that the development of water markets *may* be desirable. Making such changes, however, must be viewed in a context broader than the primary or first use of the water. whether the water is used for irrigation, navigation, recreation, or hydropower as the primary use, that water also generates secondary and tertiary incomes to local economics. Transferring substantial amounts of water to a new use will have a profound effect on the people and on the supporting resources that are left behind.

In the past two decades, States have begun to take a more active role in resolving these growing conflicts of water use and the associated social effects of the choices being made, However, direct Federal involvement to address Federal water issues, topics of broad geographical jurisdiction, international impacts, and equity concerns and to support and assist States' efforts will be necessary to ensure the sustainability of Western agriculture.

Technologies: Making Optimal Use of the Hydrologic Cycle for Arid/Semiarid Agriculture

Evidence suggests that some new and emerging technologies have potential for sustaining the long-term productivity of Western agriculture. These technologies are wide-ranging, and their effective application requires an understanding of their interrelated impacts on the agricultural resource base. Such technologies involve several natural and social science disciplines, including hydrology (understanding water-related impacts), plant and animal science (adapting plants and animals to resist environmental stress), engineering (improved irrigation-system management), agronomy (cultivation practices and planting techniques), and interdisciplinary sciences for integrated agricultural land and water management (multiple-use of rangeland and cropland, flexible cropping).

Water-related technologies for arid / semiarid agriculture are generally directed toward:

1. improving efficiency of use (and thus minimizing "waste" in such practices as irrigation),
2. augmenting existing supplies with additional water not previously available for agricultural purposes,
3. preserving water quality, and
4. improving supply and distribution,

Technologies Affecting Precipitation and Runoff

The renewable water resources of the West originate as precipitation from air masses moving across the region. Surface runoff represents that fraction of this precipitation not consumed by evapotranspiration or infiltrated into the soil and ground water. Three major classes of technology have evolved around modifying or anticipating the surface runoff fraction of the original precipitation: weather modification, watershed management, and water-supply forecasting. Each of these technologies has some potential on at least a local, site-specific basis. Evidence does not yet exist, however, to demonstrate that these are generally accepted operational technologies for sustainable agriculture,

Evaluation of any technology designed to modify or forecast precipitation and/or runoff from hydrologic environments in the region would benefit from a more integrated approach to the study of the hydrologic regimes of the Western United States than that which now exists. Moreover, hydrologic research activities and priorities should reflect the fact that most of the annual surface runoff and ground water recharge in the West comes from the mountain snowpack,

WEATHER MODIFICATION

Weather-modification technologies are designed to increase the amount of precipitation over that which occurs naturally. This is done by injecting artificial nucleating agents, such as silver iodide, into suitable air masses. The two weather-modification technologies that have received the most attention are those involving: 1) winter storms that cross the major mountain ranges of the Western United States, producing the snowpack of the mountain watersheds; and 2) the summer cumulus clouds that produce both rain and hail, often in large amounts over limited areas. Of the two, precipitation augmentation from winter storm systems by "cloud seeding" appears to show the most promise. This technology has been developed within a solid scientific framework creating a body of knowledge that should facilitate future advances.

WATERSHED MANAGEMENT

Two major classes of watersheds occur in the Western United States: 1) highland watersheds, located in the major mountain ranges and consisting of the unlimbered "alpine" zone (above the timberline) and the timbered "montane" zone; and 2) lowland watersheds consisting of grass- or brush-covered valleys and plains. Watershed-management technologies are designed to increase surface runoff by vegetation removal or replacement or by other surface modifications,

No proven technologies exist to increase water yield from the alpine zone. This area may be the most efficient and productive source of water in the Western United States, and a passive, conservative management approach may be the most beneficial and effective management technology at present for downstream users.

In certain situations in the montane zone, vegetation management through timber harvesting may produce local increases in water yield. It may be difficult, however, to detect increased yields at points downstream where arid/semiarid agriculture is practiced because such increases, when combined with the entire volume of watershed runoff may not be discernible using existing stream-gage technologies. Moreover, the ability to predict results of application on an unstudied watershed is difficult because of the range of hydrologic environments in the mountains of the West relative to that represented by existing experimental results. At some sites the effects of timber harvest on soil erosion, other components of the hydrologic cycle, or existing wilderness values may negate potential beneficial effects for downstream arid/semiarid agriculture,

Results of attempts to produce additional surface runoff from lowland watersheds have been varied because of the natural hydrologic variability of the lowland watersheds and the range of purpose of the technologies. Because practices are very site-specific, they have more local than regional significance, In most cases where the dominant vegetation consists of shrubs and grasses, management should emphasize forage production and erosion prevention rather than surface runoff production. Where surface runoff is collected and used for cultivated crops and animal watering (runoff agriculture), water-management practices can provide an important local water supply.

STREAMFLOW FORECASTING

Water-supply forecasting is one of the most important technologies related to precipitation and runoff in the Western United States for long-term sustainable agriculture. Improvements in the accuracy of these technologies will entail advances in understanding the impacts of weather modification and watershed management on the hydrologic environment. Improved water-supply forecasting could provide the link between the resource and the water user or planner because it directly relates to the timing and volume of water available to downstream or lowland agriculture.

A wide range of forecast models exists, from very sophisticated computer simulation technology to simpler statistical correlation models. Research has indicated that no single forecast model may be sufficient for all the hydrometeorological environments in the West. Research also suggests that progress in accurately forecasting streamflow for certain regions in the Western United States would reap considerable economic benefits for agriculture.

Technologies Affecting Surface Water Storage and Delivery

Natural streamflow and precipitation seldom meet agricultural demands for water in the western States. Three approaches make more surface water available when demand exceeds supply:

1. increasing the total amount of water in storage,
2. augmenting supplies with addit ional water, and
3. stretching existing water supplies by conservation.

Currently, opportunities to develop large sources of previously unavailable surface water or to augment existing supplies are feasible technologically but are limited by economic, environmental, legal, and social considerations. They are unlikely to add significant amounts of water to irrigation supplies in the future, Technologies that reduce water losses [i.e., conserve water) in storage and delivery systems can be applied relatively easily but tend to be expensive. In addition, their effects on the entire hydrologic cycle are often difficult to measure and their application, at times, can have unexpected, negative effects on riparian (areas of shrubs, trees, and grasses generally along streambanks) and wetland wildlife habitats.

TECHNOLOGIES THAT STORE AND AUGMENT WATER SUPPLIES

Technologies that increase the amount of water in storage include storage facilities, desalination processes, and interbasin transfers of water.

Storage Facilities.—The extensive and complex system of large and small reservoirs in the Western States represents about 79 percent of storage capacity in the Nation. These storage areas include a few reservoirs that contribute much to the total storage capacity, a sizable number of medium-sized reservoirs, and an even larger number of farm and ranch ponds. Storage facilities permit more convenient and efficient use of available water supplies by downstream agricultural users. Construction technologies for reservoirs are well developed, and technologies to manage reservoirs are advancing rapidly.

The Federal Government has a sizable investment (at least $26 billion) in completed water resource projects and owns some 2,000 dams, ranging in size from small reservoirs to large, multipurpose projects. While the benefits to irrigators and other users have been sizable, the costs have also been substantial.

Barriers to new, large-scale developments are not technological; they are physical, economic, and environmental. Because of these constraints, many experts expect that the Federal role in building and operating new, large-scale water-storage facilities will diminish markedly in the future. New storage facilities are likely to be smaller, and their construction may depend increasingly on private and non-Federal public investment, Innovative cost-sharing arrangements could be encouraged between private and public developers and among local, State, and Federal governments.

Desalination.— Desalination (removal of dissolved salts from brackish water, seawater, or salt-degraded water) is a technology that can supplement freshwater supplies. Desalination can be accomplished by many methods and has proven to be reliable for small amounts of water. High costs are the major current limitation to use of desalination; further development is needed before the process can produce low-cost freshwater. Brine disposal is also a problem. These considerations now limit production of desalted water to municipalities and industries and exclude most agricultural uses.

Interbasin Transfers.—In the Western United States, regional transfers of water from one river basin to another—e. g., the Colorado-Big Thompson project—have been in operation for many years. Current attention focuses on proposals to transfer water from areas of supposed surplus (e.g., Alaska and the Missouri River) to Western stream systems for irrigation use. Such transfers will present considerable problems for the foreseeable future. First, the cost of irrigation water from an interbasin transfer would probably be prohibitively expensive. Second, such transfers will present complicated environmental, political, legal, and institutional problems. Most important, however, surplus water may not be available for transfer since many areas are realizing the present and future values of their water onsite.

TECHNOLOGIES THAT CONSERVE EXISTING WATER SUPPLIES

Technologies that conserve existing water supplies have promise for meeting short-term needs for irrigation water. These practices include flexible delivery systems for irrigation water, seepage and evaporation control, and vegetation management.

Flexible Delivery Systems for Irrigation Water.—Timely delivery of surface water to irrigation users is a crucial element of effective water management. In most arid/semiarid regions, delivery systems are based on supply rather than demand because the water supply is limited. Delivery schedules are prepared in advance and are fixed for a preset time and length. Adjustment in timing, duration, or quantity of water application is limited. This system favors water distribution over crop needs.

A variety of technologies for improving water delivery flexibility is being examined. While the agronomic benefits of new water-delivery technologies are likely to be substantial, existing irrigation facilities and practices may require extensive modifications before these benefits can be realized.

Seepage Control.–Seepage occurs through the sides and bottoms of reservoirs and canals. Its extent depends largely on geology, soils, and topography. Water “losses” caused by seepage can be large enough in some areas to prevent reservoirs from filling; however, estimates of the problem’s magnitude are difficult to make and vary widely.

Seepage control can “save” water on a local basis, and its effects can vary widely in different locations. For example, water lost through seepage is not lost to the hydrologic cycle and is generally available for downstream users, for ground water recharge, and for plants and animals in wetlands and streams.

Although technologies to reduce seepage are available (e.g., soil sealants and methods that compact the earth), control is costly, a primary limitation to use. As the relationship between wildlife populations and standing water from inefficient irrigation is explored more fully, other limitations to use may be identified.

Evaporation Control.—In arid/semiarid lands, evaporation is high. In some regions, reservoir evaporation may reach about 40 percent of usable storage. In small reservoirs, stock tanks, and farm ponds, more water may be lost than is used productively. Since conserving collected water is one of the most economical methods of maintaining an adequate water supply, considerable research has been devoted to developing effective evaporation-control technologies. These technologies increase water supplies, in effect, by increasing reservoir capacity without new construction. They alter the processes that contribute to evaporation by:

- lessening the amount of energy that reaches the water surface to drive evaporation, and
- altering the ease with which vaporized water moves into the air.

Four methods of controlling evaporation have received attention: 1) surface area reduction, 2) reflective coatings, 3) surface films, and 4) mechanical covers. Results from use of evaporation-control technologies have been variable and often disappointing. Reflective coatings and surface film are unstable and ineffective if the water surface is not still. Small reservoirs arranged in clusters and of varying depths (frequently called "compartmented") experience substantially reduced evaporation when volumes are managed to minimize the exposed surface area. Mechanical covers show high potential for use on small reservoirs, stock tanks, and ponds.

Vegetation Management In and Near Surface Water.–Riparian zones constitute a small fraction of Western lands. They are significant to agriculture, however, and provide high-quality forage for livestock and are important in maintaining water quality. Many water experts believe that water "saved" by removing riparian vegetation remains in ground or surface waters for direct human use. However, recent research indicates that plant removal from riparian zones does not necessarily make more water available for other immediate uses. Consequently, less emphasis has been placed on vegetation eradication. Other technologies to manage riparian vegetation (e. g., chemical methods to slow plant-water use) are limited by high costs, unknown long-term effects on wildlife, and difficulty in application.

Aquatic plants present a special problem for irrigators because they interfere with water movement, disrupt control devices, cause leaks in canal linings, and lose water to evaporation at rates greater than would occur from open-water surfaces, As many as *85,000* miles of U.S. canals could be affected, and some water managers believe the problem is becoming more severe, These problems have a large economic impact,

Perhaps the most effective and least costly approach to aquatic-plant management is prevention. But where aquatic weeds are present, mechanical, biological, and chemical methods of control are available, Of these, the chemical methods are faster and easier; however, they involve problems of water pollution, Mechanical methods are expensive, time-consuming, and laborious, but are used by many water managers, using biological methods—insects, fish, and plants—is rare but generally effective, economical, and minimally detrimental to the environment,

Technologies Affecting Soil Water

Many opportunities for improving soil-water conditions exist, both where precipitation is used to supply crop- and forage-water needs (rangeland and dryland agriculture) and where additional water is supplied to fulfill crop-water requirements (irrigation). Technologies that conserve precipitation include practices that shape the soil surface, manage the soil cover, and change the physical or chemical properties of soil. Technologies that supplement soil-water supplies include drip irrigation, surface irrigation, sprinkler irrigation, and subsurface irrigation. Effective use of precipitation and irrigation water often requires the use of more than one technology and skillful management of plants, water, and soil.

The extent of soil-water increase that can be expected with the adoption of a particular technology or set of technologies is difficult to quantify, given the wide variability y in site conditions across the arid and semiarid region. Where water-conserving technologies are used on irrigated land, data that assess the effects of adoption on total water supplies are lacking. Similarly, information on economic and social consequences of technology adoption is generally not available.

Some water-conserving practices have been adopted by producers, but numerous barriers remain to their widespread application. First, many of these technologies are effective only under certain soil and/or climatic conditions. Where site conditions are not appropriate, application can yield little or no improvement in soil-water conditions. Second, some practices require large economic investments for equipment, fuel, and labor; application costs may outweigh their benefits in terms of higher farm or ranch profits. Third, the use of some technologies is hindered by Federal and State institutions. For example, mechanical land treatments on public rangelands by individuals are often prohibited; water saved by irrigators is often not allowed for their reuse. Finally, some practices are difficult to incorporate into existing farm and ranch operations and in some cases require new equipment or skills.

Soil salinization of irrigated lands and other effects of irrigation on natural resources (e.g., ground water depletion) lead many experts to believe that present irrigation agriculture is not sustainable and that existing practices will not make the contributions to agricultural growth that they have in the past. If a shift to limited irrigation or dryland or rangeland agriculture does occur, Western agriculture will face a period of economic and social readjustment which will be facilitated by development of a wide range of new opportunities for production.

Technologies Affecting Water-Use Efficiency of Plants and Animals

Agricultural production is handicapped on almost 35 percent of U.S. soils by either drought or salts, and much of this acreage is in the West, In the past, these lands were often ignored in the search for high-yielding crops that were adapted to more favorable conditions. The methods used to "improve" these lands—e.g., irrigation and drainage—are becoming less available and more expensive. Therefore, technologies that improve the efficiency with which plants and animals use water, yet do not entail extensive additions of extra water, are likely to make large areas more productive. These technologies include new and traditional methods of improving existing organisms as well as the use of plants and animals that have not been widely used in the United States previously or that are newly domesticated.

In arid and semiarid lands, the efficiency with which organisms use water has important implications for sustaining all types of agriculture, influencing the growth, distribution, and survival of plants and animals. Plants have evolved a number of different ways of coping with water shortages; no single factor completely controls the way plants respond. Plants may almost totally escape drought by germinating, growing, and reproducing before water becomes limited or only after a heavy rainfall, They may resist drought with special anatomical and physiological mechanisms to take up, store, and retain water. Or they may "tolerate" drought with mechanisms to limit the destructiveness of internal water deficits. The complex interaction of factors involved with these responses has slowed the development of drought-resistant agricultural plants.

Animals exhibit a similar range of adaptations to limited water supplies. Some may never drink water, obtaining moisture instead from their diet and excreting little water. Since the total amount of water used by animals is small, there has been little effort to use or breed animals that use less water. Instead, efforts have been concentrated on ways to increase the efficiency with which animals convert plant biomass into their own.

IMPROVING PLANTS AND ANIMALS WITH BIOTECHNOLOGY

Biotechnologies include intensive new methods of introducing genetic variation into bacteria, plants, and animals and reproducing the results, Specific applications of biotechnology to the problems of water use in arid and semiarid lands are underway and are likely to increase substantially in the next 10 to 15 years.

Tissue culture of rangeland, dryland, and irrigated crops is in commercial use and analogous methods are used in animal breeding. Protoplasm fusion and recombinant DNA technologies are promising, but they face a potentially long period of basic research before being widely applicable.

Institutional constraints to biotechnology use exist in addition to the technical ones. There is concern that reliance on laboratory practices might narrow the genetic diversity of present crops to an undesirable degree. However, concerns regarding the release of novel, potentially dangerous, organisms have diminished. These technologies have already had important effects on agricultural research and have led to at least a short-term shortage of trained personnel. The fear exists that public sector agricultural research, handicapped by low funding and the inability to attract scientists, may not keep pace with private efforts and that there may be little progress in the application of new biological technology to problems of social importance with little foreseeable profit. While much former skepticism has been allayed regarding the potential of biotechnology, such capital-intensive enterprises use relatively sizable amounts of public research money at a time when research funds are increasingly limited. Some concern exists that less glamorous technologies that also have significant potential—e.g., new approaches to classical plant breeding—will be overlooked.

INNOVATIONS IN CLASSICAL PLANT AND ANIMAL BREEDING

Traditional methods of improving plants and animals will remain important. These techniques have accounted for yield increases of as much as 1 to 3 percent per acre per year for major annual crops. Range-plant breeding has been revitalized by the need for surface-mined land reclamation. Classical crop-plant breeding is likely to undergo an important shift in focus, however, as breeding for water stress becomes more important.

Identification of the character to be modified is the single most important step in plant breeding. It dictates both breeding and evaluation methodology. In many cases the fundamental mechanisms of adaptation to water stress are not known. Where critical features can be identified for breeding, they are often not based on more than a few genes, unlike the disease- and insect-resistant traits used successfully in past breeding programs. Thus, direct plant breeding for drought resistance awaits development of improved laboratory technology, Meanwhile, genetic markers can be used to correlate drought resistance with more readily measured features.

With adoption of the 1970 Plant Variety Protection Act and its 1980 amendments, institutional constraints to the development of new plant varieties decreased. Private investment increased, and larger numbers of new crop varieties were released, Concerns remain, however. First, the trend toward fewer, larger seed companies may have unanticipated effects on germplasm availability. Second, the ownership of seed companies by agricultural chemical firms may foster breeding programs that increasingly rely on agricultural chemicals.

Production of meat, fibers, and other products by ruminants is an important and appropriate use of unique Western resources. Breeding programs increase animal productivity, sometimes by as much as 2 to 3 percent per generation. Embryo storage and transfer, artificial insemination, and computerized herd recordkeeping promise to accelerate increases in animal productivity.

Some animal-breeding technology is available only to large ranches with high incomes. Other methods promise to make important new germplasm available to small ranchers for the first time. Major economic changes are occurring in the livestock industry, some of which are linked to the decreasing availability of inexpensive irrigated grains and forage. Shifts in the distribution of feedlots, the demand for red meat, and the relative importance of sheep and goats may have substantial implications for innovations in animal breeding.

CHOOSIN6 ADAPTED PLANTS AND ANIMALS

Many major crops and livestock species are not highly adapted to water stress, and their lack of genetic diversity may make Western agriculture overly susceptible to new pests or harsh conditions. The broader use of native organisms and the domestication of new crops have potential for alleviating some of the environmental problems caused by agriculture in the past and for tailoring it more specifically to arid and semiarid lands.

Promising crop candidates include amaranth, tepary bean, guar, cowpea, jojoba, guayule, saltbush, mesquite, buffalo gourd, and milkweed, These are food and fiber crops, biomass energy plants, or sources of industrial products. Their status varies widely. At least one, grain amaranth, may be poised for major entry into the agricultural market. Most others face major institutional hurdles: lack of an established market and infrastructure, disinterest from the established agricultural community, and incomplete research. Western agriculture may include "new" animals in the future, but the use of rabbits, elk, buffalo, and other species will probably not increase rapidly in the short term.

Salt-tolerant organisms may extend the agricultural life of areas that are naturally saline or that result from agricultural mismanagement. Adapting already salt-tolerant organisms for agriculture may be faster than adding salt tolerance to crops that now require freshwater. Salt-tolerant crops of the future may include algae, bacteria, and blue-green algae as well as higher plants. *

Technologies Affecting Ground Water

Ground water use in the Western United States almost tripled between 1950 and 1975, and the ground water percentage of the total water withdrawn in the region nearly doubled. Much of this increase in ground water use was made possible by technologies that permit the withdrawal of ever-deeper supplies at ever-faster rates, often in excess of recharge. This ground water "mining" has led to the noticeable depletion of ground water in many of the agricultural areas dependent on it. Technologies to recharge these supplies artificially depend on a water surplus during at least some portion of each year to use for recharge, Their effectiveness is also very site-specific, dependent on suitable geologic characteristics and availability of land where recharge ponds are to be used. In some situations, ground water overdraft may cause the collapse (commonly referred to as "subsidence") of underground, water-bearing formations. This process renders them incapable of fully reabsorbing or transmitting recharge waters and causes displacement of surface structures. In many of the areas most affected by ground water overdraft, the total available renewable water resources are being completely consumed each year.

Water quality among the major ground-water resource regions varies considerably with ground-water recharge rates, rock chemistry, and human waste-disposal practices. With the exception of portions of the Pacific Northwest and eastern Texas, the ground water of the Western States is moderate to very hard with high concentrations of calcium and magnesium salts. When water having high levels of these or other salts is brought to the surface and applied for irrigation, evaporation losses lead to increases of soil salinity. Irrigation return flows with high levels of dissolved materials and agricultural chemicals percolate back into the ground water, producing a further deterioration of the existing quality.

Once a ground water aquifer becomes contaminated, there is relatively little that can be done technologically and in a manner that is economically feasible to remove or contain the contaminant. A few technologies have been investigated for dealing with ground-water contamination problems, but in general these have been very expensive to implement and have produced uncertain results, Technologies effective against ground water pollution are those associated with surface and subsurface waste disposal designed to prevent contaminants from reaching the aquifer. Control of toxic and noxious substances in surface and subsurface waters will probably remain the only feasible ground water pollution-control technology in the foreseeable future.

*Higher plants are those such as conifers and flowering plants, which possess a well-developed conducting system. Plants such as mosses, fungi, and algae are not part of this group.

While irrigated agriculture has consumed the largest volume of ground water in recent decades in the Western United States, municipal and industrial uses have also become increasingly important. Many Western cities are now dependent on ground water and have a greater stake in its quantity and quality. While irrigated lands may be shifted to a lower value use as water levels decline, cities cannot make this transition so easily. The social costs of declining water tables and increasing contamination of ground water resources of the Western United States must be addressed as both an agricultural and a broader social and public health problem. Until more understanding has been gained, the most appropriate ground water technology may be prudent and conservative management. It is probable that, in the long term, ground water may become much more valuable in some Western areas than is indicated by its present value for irrigated agriculture.

Selected Technologies Affecting Land and Water Management

Much Western agricultural land suffers from erosion, soil compaction, or other adverse changes, and these lands require improved management to restore their inherent productivity. In irrigated areas, improved water management may compensate for decreasing availability of affordable water.

Modern management technologies are developing rapidly and have potential for sustaining agriculture in arid and semiarid lands. They represent a wide combination of individual practices involving animals, plants, cultivation equipment, irrigation systems, and computers. Few attributes are shared: some are capital-intensive; others substitute labor for capital. Some are highly specialized, while others are diversified. At least two features are common. The most promising technologies are based on an understanding of the operation and limitations of the natural hydrologic cycle, and they usually rely on significant amounts of information about the natural processes involved.

WATER-MANAGEMENT TECHNOLOGIES

Water management includes flexible cropping, irrigation scheduling, water reuse, conjunctive use of surface and ground water, and crop enclosures. Several of these rely on relatively sophisticated methods of assessing soil and plant water requirements, Additional research is needed to validate the accuracy of some techniques. More well-developed water-management technologies may not be available to managers because of high costs, a lack of trained personnel or suitable programs to transfer information to the producer, or the manager's inability to implement recommendations. Federal policies may, in some cases, impose an additional constraint on technology adoption.

Reuse of municipal wastewater may represent a source of additional irrigation water and a possible method to reduce water pollution. Before this technology is implemented, however, questions must be resolved regarding its long-term effects on renewable resources and health. Legal, economic, and policy questions about ownership of reused water, its market value, and its allocation to uses besides agriculture must be answered.

Conjunctive use of surface and ground water may be technically feasible, depending on local geology and the extent to which ground water is manageable over a wide range of depths. It requires careful planning and the thorough understanding of local water resources.

Enclosures for plants and fish, especially those using solar energy, have potential for using unique Western resources, particularly the high amount of incoming solar radiation characteristic of the region. At present, they are suitable only for high-value agricultural products.

LAND-USE MANAGEMENT TECHNOLOGIES

With uncertain economic and resource conditions, such as increasing energy costs and unknown water availability, production specialization may involve increased risks. Therefore, technologies that integrate different

types of land use and different types of agricultural and nonagricultural products are especially promising for stabilizing economic risk. Land-use management technologies are diverse and reflect a range of agricultural philosophies. They include alternative agriculture, multiple land use on rangelands and farmlands, and animal mixtures on rangelands.

Alternative types of agriculture have largely unexplored potentials in arid and semiarid regions. These new systems may include complex mixtures of crops in one field, perennial grains or tree crops instead of annuals, or the elimination of synthetic pesticides and fertilizers, Generally, they rely heavily on natural biological processes.

Diversified farming and ranching have important benefits in areas where climate is unpredictable or the economy is unstable. Most types of land are amenable to some type of diversified enterprise; however, markets for products, restrictions on the use of public land, and specialization of agricultural production hinder adoption of these management systems. Increasingly, rangelands are used for multiple purposes. Some of these uses are not compatible with agriculture, and their effects on production and natural resources need to be considered.

The more complex management methods have received little research attention. These methods have potential for improving use of arid- and semiarid-land resources and for increasing farm income. In the past, interested private experimenters have often been isolated from one another, and this has hindered wide dissemination of knowledge about these practices.

COMPUTERS AND INFORMATION MANAGEMENT

Computers are having a major impact on agricultural extension services and on individual farmers and ranchers. They assist in recordkeeping and help prevent costly management errors. Their role is likely to increase in the future, but questions remain regarding fair access to computerized information and the reluctance of many Western farmers and ranchers to adopt computer technology.

POLICY ISSUES AND OPTIONS FOR CONGRESS

Agriculture as it is known today in the arid/semiarid United States is being increasingly threatened by water-related problems. Federal agricultural and water-related institutions are poorly prepared for the long-term needs brought about by these problems. Change is inevitable and in some areas is likely to be severe if current trends continue. Whether change ultimately produces a sustainable Western agriculture that strengthens the agricultural producer, the region, and the Nation depends in part on the role Congress chooses or declines to play in the coming few years.

Theoretically, future congressional action might range from delegating all control over water resources to States and regions to preempting State laws completely and nationalizing the water resource. Israel's successful national water-management program is based on this latter action, providing a national focus and goal with respect to water. More likely, appropriate actions for Congress lay between these extremes. For example, this Nation has neither a comprehensive national water (surface and ground) policy nor a national agricultural policy. As limits are reached and long-term productivity is threatened in the West, Congress may be asked to decide whether it will, acting for the Nation, develop an effective national water policy or whether States and regions will be left to fill the vacuum in water-resources management and planning. The actions chosen will depend on the level of this Nation's commitment to protecting the long-term productivity of its renewable resources.

However, Congress alone cannot act effectively in this complex and diffuse area. Federal, State, and local governments are all involved in the regulation of Western water, for agricultural and other uses, and thus affect use and development of water-related technologies for arid/semiarid agriculture. The broad types of Federal tools available to influence use and development of these technologies involve institutional action to develop an improved statement of goals and priorities for Western water use and agriculture, provide incentives, penalize abuses, promote improved management, equitably resolve conflicting claims and demands, and provide more and improved information.

In recent years, awareness has increased that most of the West's water-resource problems transcend State boundaries and are extremely difficult in nature, involving a complex web of physical, chemical, biological, economic, legal, and sociopolitical issues. Often, they go well-beyond the ability of a single agency, State, university, or group of organizations to address effectively. Western States have begun to take impressive steps to increase their role in regional interaction and water-resources planning and management (see examples in app. C). However, they cannot handle all the problems alone. The need for an active Federal commitment to water-related matters of broad public concern and wide geographical jurisdiction has become increasingly evident for sustainable Western agriculture.

The following policy issues and options have been identified by OTA as those most critical for congressional action over the next few years. They are grouped in three major categories (treating renewable resources as systems, sustaining long-term productivity, and involving users in decisionmaking) to parallel the three fundamental findings of this assessment. They are not listed in any order of priority.

Treating Renewable Resources as Systems

This major action area is divided into three categories:

1. how Western scientists, water users, universities, and the public-at-large can play an expanded role in decisionmaking about water and Western agriculture;
2. how congressional decisionmaking can be strengthened; and
3. how other Federal and State Government agencies can improve specific programs.

Issue 1: The Need for an Interdisciplinary Program of Basic and Applied Research on Arid/Semiarid-Water Resources

The Nation's universities, water users, and private sector have a variety of research programs on water resources and water-resource management and could provide unique services in arid/semiarid-water resources research and decisionmaking. At present, however, links are often not made to broader national or regional problems and there is a lack of a national coherence and synthesis of university water-related research. Progress in Western water-resources research, both basic and applied, could benefit substantially by the creation of a broad coordinating mechanism to focus and interrelate the multidisciplinary talents of the academic community and water users with the resources of the private sector. The Nation's universities are especially important to tap at a time when Federal assistance to coordinate water planning and research has effectively disappeared.

Option: Congress could establish a National Center for Water Resources Research to provide a coherent and coordinated mechanism for the Nation's university research programs in water resources and water-resource management for problem-solving and policymaking.

The mission of this center could include:

1. Undertaking an interdisciplinary program of basic and applied research on water resources and water-resource management, including strong programs in the natural sciences, engineering, and social sciences, such as resource economics and law as they pertain to water-resources programs. The center could further assist in the conduct of site-specific research being carried out under State auspices.
2. Developing and providing advanced and sophisticated research facilities on a scale required to cope with the broad nature of water-resources problems, and often not affordable by single universities, to be used by resident staff, innovative producers, and university scientists.
3. Undertaking a program to develop and test conventional and emerging technologies for application to water-resources problems in United States arid / semiarid lands, including problems of agriculture and its sustainability in arid / semiarid lands, and coordinating such efforts with existing government research by USDA and State agricultural experiment stations.
4. Serving as an objective, nonpartisan, and continuing national source of information for Congress when formulating public policy dealing with water resources, and as a link to public agencies, water users, and the private sector for application of research findings.

This center could serve as a base for marshaling university and private industry talents and for augmenting, but not in any sense competing with, university work already underway. Using the successful experience of the National Center for Atmospheric Research (NCAR), an institution created some 20 years ago by an act of Congress, the center could be managed and operated by a consortium of universities with doctoral-level programs in water resources. An essential aspect for effective operation is that prime responsibility for program initiatives reside with this consortium. This requirement is in sharp contrast with "Government owned-contractor operated" laboratories where program initiatives commonly reside in the sponsoring, mission-oriented Federal agency. This contrasting approach for the center is important, since the university community is closest to the research and its potentials. In light of this knowledge, plans and priorities designed by the consortium would take into account national, regional, and State needs.

Issue z: The Need for Congress to Have Reliable Ongoing Information About the State of the Nation's Renewable Natural Resources

The assessment finds that existing data available for congressional decisionmaking is scattered throughout the Federal Government in a variety of forms. These data were not collected with the intention that each piece would be part of an integrated and self-consistent base for Congress to use in making decisions affecting resource sustainability, Moreover, existing data on components of the resource base on which agriculture depends are seldom synthesized because the data may be in noncompatible forms and no single agency has had the ongoing responsibility to seek compatibility or synthesis.

Congress needs improved information for setting near- and long-term goals for sustainable use of Western water and agricultural lands. This information should focus on congressional needs and emphasize systems analysis of the natural resources on which agriculture depends. Ongoing analysis and synthesis of existing data bases could provide improved information on the dynamics of the resource system and how interactions (natural and manipulated) among resource components affect the sustainability of Western agriculture,

Option 1: Congress could develop a bipartisan unit within the legislative branch with the principle purpose to provide Congress with ongoing quantitative evaluations of the state of the renewable natural resource system as a consequence of near- and long-term congressional policies. The unit's program should be interdisciplinary and multidisciplinary, with access to state-of-the-art computer facilities to conduct comprehensive data analysis and synthesis from existing data sources on specific topics requested by Congress. Such a unit could identify data gaps important to U.S. decisionmaking that affects the sustainability of the renewable resource base. It would require independence and flexibility to obtain and interpret data in a nonbiased fashion for the entire Congress. Specific organizational structure and legislative authority would have to be developed to meet the unit's defined purposes.

The first step in considering this option might be a workshop of interested and involved congressional, executive, State, and local participants to examine existing problems, the history of similar attempts and experiments in data synthesis, and possibilities for action. This workshop might be combined with the formation of a joint committee of members from relevant House and Senate committees to plan subsequent steps.

This option will require ongoing communication among the many branches of Government to achieve an acceptable arrangement for the new unit. Some individuals within Congress and the executive agencies may question the value of such a unit for a number of reasons. In recent years, public concern has increased over the growing size and cost of congressional staffs. Others may claim that existing agencies are competent and qualified to provide Congress with the resource systems analytical capacity.

Option 2: As an alternative to option **1,** Congress could develop an executive branch unit to provide ongoing quantitative evaluations for congressional decisionmaking affecting resource sustainability. On congressional request, this unit could coordinate, integrate, and interpret existing information similar to that noted for the legislative unit proposed in option 1, and report directly to Congress. Traditionally, Congress has turned to the executive branch for answers to fundamental questions involved with its policymaking, Existing executive agencies have personnel, equipment, and many separate data bases; some career staff have experience in aspects of water- or agricultural-data collection and analyses, partial funding might be available for this option through redirection of existing funds from lower priority executive activities, as determined by Congress.

Possible disadvantages of this option relate to the adequacy of existing agencies to incorporate this function and the nature of executive branch programs in general. The capacity of existing executive agencies for long-term and multidisciplinary resource systems planning is seriously lacking, The placement of this systems capacity in the executive branch poses concerns about continuity. Programs and priorities in the executive branch change with administrations. A small new executive unit is unlikely to be in a secure position to provide objectivity, coherence, and continuity, essential requirements for effective long-term data syntheses. In recent years Congress has found it necessary to develop inhouse expertise to supplement executive branch input in areas requiring focused analysis, integration of issues or activities, and verification or clarification of executive branch reports.

Issue 3: The Need to Integrate Water-Related Agricultural Activities in Government Agencies

Increased demands are being placed on the arid/semiarid-agricultural resource base as pressures grow from new and expanding water uses. The complexity of the natural processes in arid/semiarid agriculture requires an integrated approach to resource manipulation in order to cope effectively with these increasing demands and to ensure a sustainable agriculture, No longer can Western water-related agricultural problems be trusted to one-problem/one-solution procedures that have been relied on chiefly in the past by government institutions.

Federal agencies charged with implementing congressional policies and programs need a perspective that interrelates technological impacts as they affect various components and ultimately the agricultural system and long-term productivity of the region. The following options are specific areas conducive to immediate congressional action, All four are compatible.

Option 1: **Congress, through the hearing process, could initiate discussions with USDA for the purpose of designing and establishing a high-level office to integrate and provide coherence to water-related and agricultural activities within the Department.** This office of resource coordination should be placed at an appropriately high level—e,g., in the Office of the Secretary of Agriculture—to minimize confusion in organizational responsibilities and to ensure coordination and integration of activities among all specialized agencies of the Department. This office could have responsibilities for analyzing programs of the specialized agencies, for helping formulate a systems perspective that integrates the agencies' resource programs, for minimizing narrowness of focus and potentially conflicting activities, and for overseeing implementation of integrated programs in research, technology development, and production in long-range sustainable arid/semiarid agriculture. An office at the level of the Secretary could emphasize the importance of agriculture's natural resource base and make visible the role of the Department in protecting it. It could encourage the Department to take advantage of the most modern systems-analysis technology, technology that has not commonly been used in agriculture.

Option 2: Congress could instruct Federal land-management agencies responsible for Western areas to increase efforts in water resources and water-resources management pursuant to their existing multiple-use responsibilities for managing natural resources on public lands. Existing multiple-use statutory guidelines prohibit optimization of single measurable uses (e.g., timber and cows) at the expense of less quantifiable uses (e. g., watershed and recreation), and they forbid practices that impair long-term land productivity, This option will entail a reorganization of agency priorities such that more emphasis is placed on long-term benefits from water management and less emphasis is placed on short-term revenue-producing benefits from grazing and timber production. This is an area of considerable importance for long-term Western water-resources management and arid/semiarid agriculture because most Western surface water-producing areas are on public lands.

Option 3: Congress could assist States to develop and integrate computerized data bases for the wide range of hydrologic data now scattered among State and local agencies and private industry. Such information is not being entered into Federal data storage systems but is increasingly needed for effective water-resources planning and management at the regional, State, and local levels, Data bases could be designed to ensure integration of water quality and quantity data for systems planning. Federal funds to States for water-resources planning and coordination could be allocated for State participation in this data system. The private sector could share data and give advice on the best available technology for data storage, retrieval, and processing.

Option 4: Congress could expand mandates of Federal agencies responsible for water-project development and maintenance to take into account needs of instream flow, a subject that has had inadequate and, in recent years, reduced attention at the Federal level. Some minimum instream flow requirements are essential for rivers for dilution, hydroelectric generation, and fish and wildlife habitat protection. In many river systems of the West, however, virtually the entire flow of the river is committed already to various offstream uses. In view of the geographic nature of river systems, an increased Federal role is needed to help define and monitor instream flow requirements of Western rivers. The maintenance of instream flows may make it possible to maintain acceptable water-quality levels in some Western rivers without the need for greatly increased water-treatment facilities. An improved understanding of instream needs for the multiple purposes of Western river systems will also improve management information for planning long-term requirements of the various water users.

This option may raise additional burdens as well. Traditionally, the Federal Government has deferred to the States on matters involving local water rights. Virtually the entire flow of many Western river systems is committed already to various local offstream uses. If instream flow requirements are to be met on these rivers, some existing off stream uses might have to be curtailed or discontinued. Federal involvement will raise all the difficulties inherent in trying to coordinate and respect these two governmental systems, the longstanding States' interests in local water rights and the broader geographic and national interests of the Federal Government.

Sustaining Long-Term Productivity

Issue 1: The Need for a Strong Federal Role in Water Quality for Sustainable Western Agriculture

Congressional action to maintain strong water-quality standards, support pollution controls, and strengthen water-quality research is essential for protecting agriculture, the environment, and the public health of the arid/semiarid West. Because of the West's low or sporadic water-volume flows, the region cannot absorb the levels of industrial, municipal, and agricultural pollution possible for more water-abundant regions. Without the maintenance of a strong and committed Federal role, it is conceivable that agriculture in some areas may go out of production because of water-quality degradation rather than loss of supplies.

Three options are particularly important, and all are compatible for immediate congressional action.

Option I: Congress could maintain a firm commitment under the Clean Water Act to strong water-quality standards that are applicable across the Nation in order to ensure that economic burdens and benefits are evenly shared among States and to avoid industrial "shopping" for areas where water-quality standards might be low. National water-quality standards must be stringent in order to protect the range of present and future interests in water, some of which require the highest standards (e. g., for drinking-water purposes). Existing requirements could be retained, and any new or revised water-quality standards could be made to enhance the quality rather than allow degradation.

Option 2: Congress could refine national nonpoint source policy under the Clean Water Act and particularly under section *208* **of that act, and accelerate implementation of controls on water pollution from nonpoint agricultural sources.** Knowledge exists to reduce water pollution from agricultural nonpoint (diffused) sources through the adoption of improved management practices. Some of these practices may involve costs that are difficult for economically disadvantaged farmers and ranchers to absorb over the near term. However, such costs may be far outweighed by long-term benefits in reduced water-treatment costs and public health problems and thus justify Government assistance with implementation. As part of this action, Congress could strengthen Federal support to State and local efforts to achieve nonpoint source pollution reduction. Because the water-short Western States face more concentrated contamination possibilities with any pollutant, progress toward implementing control programs is essential, Increased Federal support could come in a number of forms, including providing incentives, assisting economically depressed farmers to adopt better practices, and offering technical and financial assistance for training farmers and ranchers to implement control measures.

Option 3: Congress could increase research and monitoring of short- and long-term agricultural and public health effects of Western surface and ground water-quality deterioration. Little water-quality research has been undertaken on a comprehensive areawide basis or on related health and environmental impacts of water-quality degradation, Existing standards may not adequately protect the public in some areas, while others may be too stringent. In view of the West's low or sporadic water-volume flows, the prudent approach is to maintain high or more stringent standards for both surface and ground waters and to support high levels of water-quality research to ensure long-term protection of the public health and of the environment on which agriculture depends. Particular focus could be given to synthesis of existing information, most of which is scattered and contaminant-specific, and to research on likely agricultural contaminants that are detrimental to other uses and on contaminants from other uses that are detrimental to agriculture. Such activities could provide valuable information for national and local policymaking to protect ground waters and surface waters from contamination.

Issue 2: Protecting and Maintaining the Long-Term Productivity of Rain-Fed Agricultural Resources

Protecting the renewable resource base for productive rain-fed agriculture in the arid/semiarid West is a growing national concern, especially since irrigated production in some areas is likely to decrease because of water problems. Two areas, in particular, have received inadequate Federal attention in the past. First, the problem of cultivating marginal or unsuited lands ("plow-out") has become particularly critical in the semiarid lands of the Great Plains and in other States in the West where the land is especially vulnerable to erosion. Some Federal agricultural programs encourage cultivation of fragile lands and thus contribute to resource degradation. Second, dryland and rangeland research and technology development have received scant Federal support. This area is particularly important for expanding the range and mix of opportunities for productive Western agriculture on rain-fed agricultural lands over the long term. The following two options are important and compatible.

Option 1: Congress could withdraw those Federal programs that induce conversion of rangeland to uses not suited to that land and thus cause resource degradation that ultimately limits long-term productivity. One method of achieving this could be to require that applicants for Federal agricultural assistance certify that their land is not new cropland or, if so, to demonstrate that a conservation system approved by the local conservation district is, or will be, in place for the land to be put into production. The land-capability classes could be used as a guide for determining what lands are unsuited for cultivation and thus ineligible for Federal assistance, except with an approved conservation plan.

Option 2: Congress could direct that USDA increase its R&D focus on rain-fed agricultural systems—both dryland and rangeland. Significant opportunities exist to develop and expand dryland and rangeland research into broader areas of focus than now exist. Increased support is needed if this Nation is to have the range of alternatives necessary to ensure flexibility in meeting anticipated and unanticipated future needs for agricultural production in the West. As one means of implementing this option, Congress could hold hearings with USDA to examine that Department's existing field research stations. The purpose would be to identify and convert appropriate stations to facilities for testing and developing technologies, based on an integrated resource approach, to sustain or improve rain-fed agricultural productivity of these arid/semiarid lands over the long term. The work could be made readily available to producers through special pilot projects and field-days and through the conventional extension programs,

Involving Users in Decisionmaking

Issue 1: Achieving Equity in Western Water Availability and Distribution

Lasting settlement of conflicts over Western water use must involve principles of equity and fairness for current users, for those whose rights have yet to be developed, for those whose communities and lifestyles might be affected by major water shifts, and for new users with economic power who seek to buy water supplies, Already, perceptions are growing among poorer farmers and American Indians that existing Western institutions responsible for water distribution and development have not treated them fairly. Without committed congressional action, conflict, distrust, and litigation will probably increase and will severely hinder effective water-resources planning and management for sustainable Western agriculture. Two kinds of congressional actions are important and compatible here.

Option 1: Congress, in its leadership role with reserved water rights, could increase its efforts to address the complex long-term task of resolving issues surrounding Indian reserved water rights under the Federal reserved rights doctrine by taking two initial actions: 1) increase opportunity for ongoing representation of Indian interests in both Houses of Congress, and 2) provide a mechanism through legislation to protect reserved rights and equity interests where the rights are already fully appropriated; that is, by compensating the reserved rightholder and by eventually reallocating the water to that rightholder. Because Congress has consistently left these issues unresolved, piecemeal court decisions have increased uncertainty for all parties, and important Federal interests and economic investments have been threatened. Resolving reserved water-rights issues is an essential step in the effective long-term planning and development of sustainable Western agriculture. Congress might consider a variety of approaches to increase its activity in negotiation and representation of Indian water interests including the appointment of a joint House and Senate committee, a special committee or task force to define more clearly appropriate future action, or creation of an ongoing subcommittee on Indian affairs.

Option 2: Congress could help to ensure that equity and fairness are elements of any water-resources distribution and reallocation decision for disadvantaged people, especially poorer farmers, by establishing a Select Committee on Disadvantaged People and Renewable Resources to investigate and recommend legislation to protect these interests. Among the topics the committee could address are mechanisms for: 1) educating Western disadvantaged people about their stake in water management, and 2) bargaining collectively for Western water rights that may be bought or sold in a market framework. Such mechanisms could be important in helping disadvantaged people increase participation in water-use and reallocation decisions in the arid/semiarid region. They could thus have a more effective voice in Western decisions involving major water-use shifts that are likely to have significant impacts on local lifestyles, economies, and community patterns.

Issue 2: Understanding the Impacts of Water Prices on Adoption of Technology

Federal reform of water-project repayment plans and policies is underway. Reduced Federal subsidies will make Western water more expensive for all users. Impacts on agriculture, a major water user, could be significant. Some agricultural users may become more efficient in water use by adopting water-"saving" technologies, while others may decide they cannot operate profitably and will attempt to transfer (sell or rent) their water rights. The outcome for agriculture is not well understood or studied. To help ensure that reforms produce desirable results, a careful study and documentation of existing markets and anticipated agricultural consequences is needed.

Option: Congress could seek the assistance of the Congressional Budget Office (CBO) to study the short- and long-term economic consequences of reduced Federal water subsidies and increased water-market activity on agricultural users and others affected by agriculture. A CBO analysis could help Congress: 1) understand the possible near- and long-term economic consequences of reforming water-project repayment plans and programs for Western agriculture and nonfarm economies; and 2) provide guidance, monitoring, and assistance with the transition to greater use of water markets to the extent that is likely to result from reduced development subsidies. While scattered studies are beginning to appear on the economics of water in the West, CBO could provide an objective, comprehensive synthesis of available socioeconomic information and a focused analysis of the Federal connection with the economics of Western water and agricultural practices.

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Issue 3: Improving the Effectiveness of Water-Related Technologies for Sustainable Agriculture

Development and successful application of water-related technologies depend, in part, on the ability of the researcher and user to adapt them to local conditions. This is a result of the complexity and spatial and temporal variability of the natural resource system on which agriculture depends. In addition, the researcher's perspective about effectiveness may vary from that of the user. The former r-nay be concerned with technical efficiency, while the latter is interested in economic efficiency for farm or ranch use. A gap appears to be growing between the researcher and user of water-related technologies in Western agriculture in some areas. Research for both onsite and offsite technologies commonly suffers from questions of relevance and practicality for a particular agricultural site and user.

Option: Congress could direct the establishment of two user oversight groups specifically focused on Western water and agriculture. One user group could address onsite water-conserving technology potentials and needs and provide advice principally to USDA. The other user group could focus on offsite water augmentation technologies for downstream agriculture. This second group could advise Federal agencies responsible for those water-related technologies (e. g., weather modification, watershed management, snowmelt forecasting) applied upstream or in highland areas offsite from arid / semiarid agriculture but having potential water-related impacts for downstream or low-land agriculture. Each user group could advise appropriate congressional committees as well.

By making use of innovative producers and by bringing the research to the farm or ranch, this option could improve research / user interaction, an essential aspect of effective technology development and adoption now seriously lacking in many areas. User groups could assist Congress to determine whether existing programs are doing the job needed for sustainable agriculture from the Western users' perspective.

Concerns about this option relate to the possible effectiveness of the user groups. At present, a National Agricultural Research and Extension Users Advisory Board (UAB) exists pursuant to legislation in the Food and Agriculture Act of *1977,* A recent OTA report* on the food and agricultural research system found this board's effect on USDA research priorities to be unclear. Other concerns are that researchers who interact with user groups would be taking time that might be spent otherwise with laboratory or field work. Moreover, the focus of particular users might be on short-term economic solutions rather than long-range issues involved with the development of technologies for sustainable agriculture.

Precautions in establishing these groups will be required to ensure that they effectively represent the range of users' views, include long-range interests, and have the capacity to evaluate and scrutinize Federal agency research work. Congress could require that users be nominated by representative agricultural organizations and have access, when necessary, to scientific expertise independent of the Federal agencies. Membership rotation could ensure a flow of new ideas to minimize loss of research time on new potentials.

**An Assessment of the United States Food and Agricultural Research System,* OTA-F-1 55, December 1981.