Reports

Utah Water Research Laboratory

January 1981

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Recommended Citation

Frickel, Theodore R. and Narayanan, Rangesan, "Economic Impacts of Irrigation Technologies in the Sevier River Basin" (1981). *Reports.* Paper 470.
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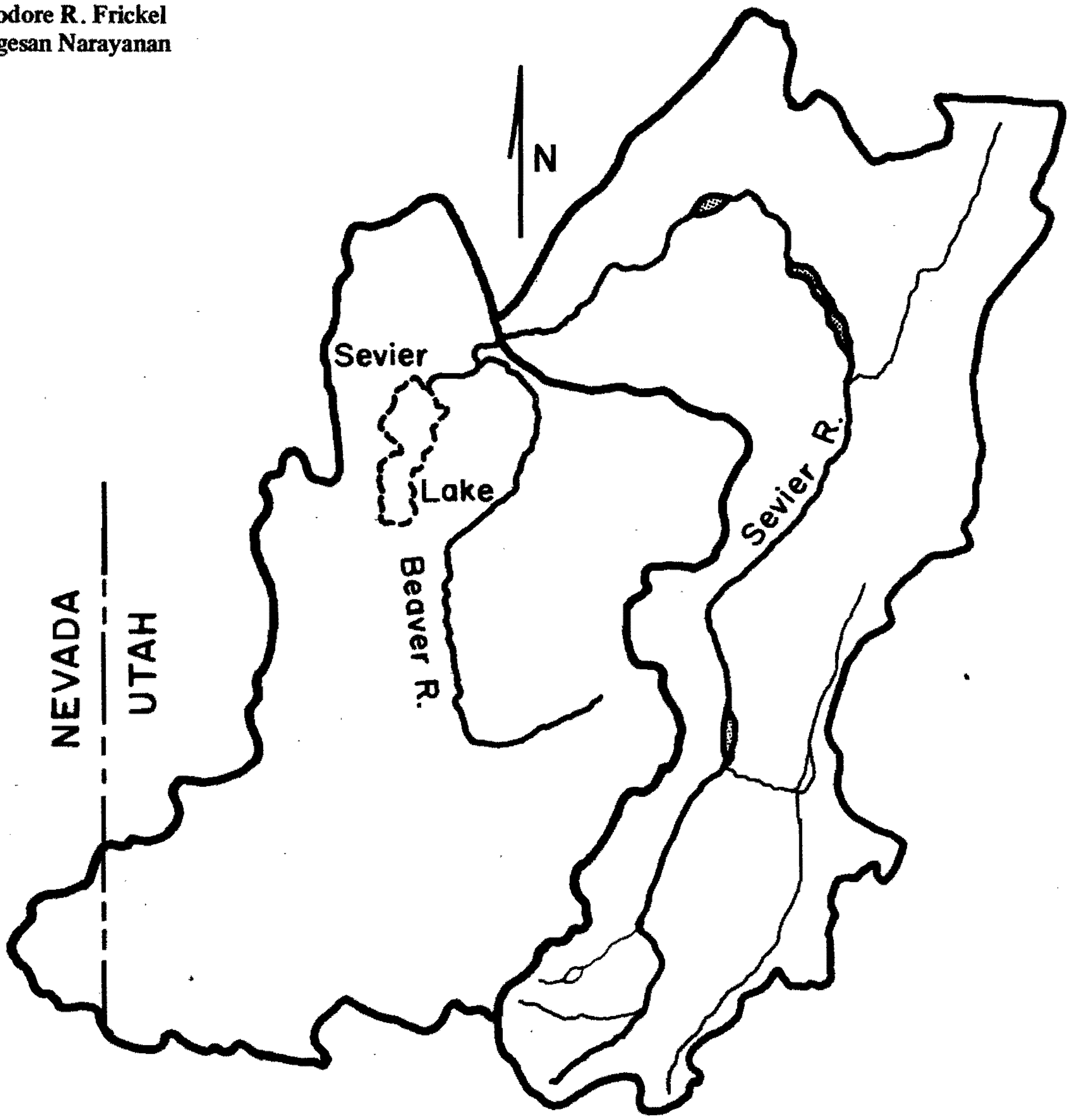

Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

March 1981

WATER RESOURCES PLANNING SERIES
UWRL/P-81/02

ECONOMIC IMPACTS OF IRRIGATION TECHNOLOGIES IN THE SEVIER RIVER BASIN

by

Theodore R. Frickel
and
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WATER RESOURCES PLANNING SERIES
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ABSTRACT

The economic well-being of the semiarid intermountain area requires efficient use of available water supplies. Agriculture, the major water-consuming industry, depends on irrigation water. The adoption of sprinkler systems that increase on-farm irrigation "efficiencies" and the area which can be irrigated from upstream diversions may interfere with the "tenure" of downstream water rights. These downstream effects need to be evaluated before allowing farmers to use the water "saved" to irrigate additional acreages or crops to obtain greater profits.

The problem in letting farmers expand their irrigated acreage is that the individual farmer increases his profits through increased consumptive use. The consequent reduction in return flows reduces the water available to the downstream irrigators and violates the downstream user's proper rights. Water rights administrators have a responsibility to both users. They need to protect downstream water rights. In doing so, the policies should not deny those who install new sprinkler systems the right to any water they really save from wasteful consumptive use (e.g., by weeds or evaporation).

A linear programming model was developed to evaluate the effect of changes in irrigation technology on basinwide cropping patterns and hence consumptive use and return flows for downstream users within the Sevier River Basin. Cropping choices were made from information on field slopes and soil types as represented by land classifications, consumptive use for nine crops, and the characteristics of four on-farm irrigation systems (flood and sprinkler irrigation systems with lined and unlined ditches). In addition, water diversions and available irrigated acreages were constrained to the limits imposed by the State Engineer's Office as a means of protecting property rights.

Modern irrigation systems were estimated to be profitable and hence would be adopted with the present acreage and diversion restrictions. Basin output would increase; however, downstream water rights would not be met. With relaxation of these restrictions, the farm economy would gain even more from the adoption of new irrigation systems. Again, present water rights would not be met. Federal and state cost sharing programs could also aggravate the water rights problem and possibly cause environmental problems by reducing instream flows.

The empirical linear programming model developed to represent the agricultural economy of the Sevier River Basin was able to provide reasonable replication of cropping patterns, water use, and instream flows in the basin. This success generates some confidence in the model's ability to estimate the effects of adaptations of new irrigation technology and various basin water management policies on the cropping decisions made by basin farmers. The estimates made by the model provide a valuable tool for equitable water rights administration, but the results would be much improved if refined to incorporate hydrologic routing, hydrosalinity effects, optimal irrigation levels, and year-to-year variation in water availability.

ACKNOWLEDGMENT

This study was supported by the Utah Water Research Laboratory under State Appropriated Funds. We would like to thank Dr. Douglas James for the financial support as well as for his technical review and comments on an earlier draft. The Division of Water Resources and the Office of the State Engineer cooperated extensively throughout the study period. In particular, we would like to thank Barry Saunders, Eugene Bigler, Lyle Summers and Dee Hansen. In addition, we were benefited by the discussion with Jay Bagley, Alvin Bishop, Jay Andersen, and Basudeb Biswas during the course of the study. The authors assume responsibility for any errors in the manuscript.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Water Management Issues in a Closed Basin

From a Practical Perspective

State water rights laws are well structured to resolve conflicts between directly competing uses, but their application becomes clouded when an upstream user changes downstream water availability by altering flow paths in a complex system of diversions, flows through the soil, return flows, and stream flows to the next diversion. For example, farmers can change irrigation technology in ways that will produce the same crop yield even though reducing water applications to their irrigated land and use the water saved to irrigate additional acreage. The problem in letting upstream farmers expand their irrigated acreage is that the individual farmer increases his profits through increased consumptive use. The consequent reduction in return flows reduces the water available to downstream irrigators and violates their property rights. Water rights administrators have a responsibility to both upstream and downstream groups. They need to protect downstream water rights, but to do so in a way that does not deny those who install new irrigation systems the right to any water they really save by reducing wasteful consumptive use (e.g. by weeds or phreatophytes). The practical administrative problem is one of determining how much real savings, if any, results from an irrigator upgrading his application technology. The hydrologic details differ, but the principle is the same when the water use change is from irrigation to industry, etc.

Upstream use changes can alter the supply available to downstream water users in one of three ways. They can change the volume of water available. In a closed basin, volume changes are largely associated with differences in water consumption by nonproductive vegetation or stream evaporation. They can change the timing of flow to downstream users. A change which slows water movement downward through the basin causes flows to remain higher later into the summer and hence gives downstream users more water when they most need it. Finally, upstream water use changes can change downstream water quality. Added downstream salinity reduces the value of the water to users even though not affecting the amount.

Water laws are generally administered from the viewpoint of protecting the interests of water right holders. This principle only allows upstream use changes that do not affect downstream water availability. From a broader perspective, however, water rights administration should be cognizant of the relative productivities of upstream and downstream water uses. When additional upstream uses are denied to protect downstream water uses, how do the values received from the water in the two uses compare? This study presents a model for making this comparison, not only for its value in assessing presently proposed use changes but also in order to gain understanding of how long run economic trends will change water values in various geographical areas.

As Analyzed by Economic Theory

The economic welfare of a water-short basin is enhanced by increasing the productivity of available water supplies. The available water supply needs to be allocated among competing users (agricultural, commercial, industrial, residential, etc.) so as to maximize the output produced.

Economic theory shows that maximum output is reached when the value of the marginal product (the incremental value of output produced per incremental unit of water used) is the same in all uses. Under this concept, the first water available to a use (e.g. agriculture) goes to the most valuable application (e.g. a high-valued crop in the best soil), and additional increments of available water go to progressively less valuable applications. If water is going to one use (e.g. agriculture) in an application much less valuable than potential applications in another use (e.g. industry) which are doing without, the economy would be advanced by a shift from the first use to the second (agriculture to industry in this example).

The potential uses, amounts of water needed for each use, the value of water in each application, and the supply available all change with time. Changes in the economy or in water availability require shifts in water use to maintain economic productivity.

The Utah water rights system provides for these changes through a water rights market. Someone needing more water can purchase what he needs from someone else willing to sell. A competitive market will optimize water allocation (maximize economic productivity) if 1) exchanges producing adverse impacts (third party effects) are limited so that the adverse impact does not exceed the gain achieved through the use shift, 2) the water right is precisely defined by amount, timing, quality, and other properties affecting its value to the user so that the buyer has no uncertainty as to what he is purchasing, 3) the sale process can be consummated without undue delay either because of lack of information on market opportunities (rectifiable through a water banking program (Bagley et al. 1980)) or prolongation of the administrative approval process, and 4) the supply and demand conditions are not fluctuating too rapidly for the market to have time to adjust.

For a regulatory body to promote the first of these four conditions, it needs a modeling capability for estimating downstream hydrologic and economic effects. Hydrologic impact estimation determines how much downstream water supplies are altered and which downstream users will have their supply changed. The economic assessment uses this information to estimate the change in total with output in the changed uses. The modeling described in this report provides a tool for this economic assessment. The model approximates basinwide optimality as a frame of reference for evaluating regulatory needs. The results answer questions on how much actual allocations depart from optimal both as to where the water is used and the economic value obtained from total water use.

Generally speaking, from the viewpoint of the individual water user, the economic motivation to change water uses or application methods favors changes in which a larger portion of the diverted water is consumed. Improving on-farm irrigation efficiency and increasing irrigated acreage with the water saved (from private point of view) is an example. Even when consumptive use is held constant, alterations in the timing and spatial distribution of return flows and water quality deterioration can degrade the water rights of third parties. Since the individual water user does not have economic motivation to watch out for adverse downstream effects from his action, upstream water use changes generally reduce basinwide output unless water rights administration protects downstream interests.

Appropriation doctrine, the principal rule for water allocation in the western states, defines water rights. The administering agencies frequently face needs to protect downstream users from the adverse effects of upstream use changes. The general goal of downstream protection of property rights in water is to prevent hydrologic change that would be harmful. Regulation based on this principle, however, prevents water use changes in which the upstream economic gain exceeds the downstream economic loss. Stringent regulatory measures that protect hydrologically defined water rights prevent water transfers that would increase basinwide economic productivity and lead to a decline in the basinwide output through resource misallocation. The fault is neither with the Appropriation Doctrine nor with the enforcement agencies. The costs of defining and measuring all the attributes relevant to determining the economic value of a water right and monitoring these attributes for enforcement are prohibitive. If these costs are taken into account, a system of protecting water rights hydrologically may in fact prove economically efficient with low values of water. Nevertheless, western states facing substantial increases in the social value of water due to anticipated energy development and urban growth may need to begin weighing economic trade offs in resolving water rights conflicts. Rumblings toward moving in this direction can already be heard in Utah. This study is an initial attempt toward developing needed practical tools.

General Problem Framework

Irrigation is the process of supplying water for plant growth. The crop consumptive use requirement is defined as the water transpired in plant growth and equals the amount of water entering plant roots and used to build plant tissue. The weight of vegetative matter produced is proportional to plant transpiration (Hanks et al. 1978). Plant transpiration is reduced by soil moisture deficiencies during the various stages of plant growth. If irrigation water applications exceed amounts required to prevent these soil moisture deficiencies, the extra water cannot be used productively and will either be used by other vegetation or returned to the stream. If applications are not sufficient to prevent soil moisture deficiencies, the plant suffers moisture stress and growth is reduced. Irrigation practices that permit some stress are economically efficient because the cost of the last increment of water normally exceeds the economic value of the extra growth it would induce.

Opportunities to upgrade irrigation technology by adopting more capital-intensive methods for on-farm water application and for conveying water to the farms are becoming economically attractive to irrigators. The older technology utilizing unlined distribution canals and field flooding generally results in large water losses to the individual irrigator because of overland runoff and seepage and is also very labor intensive. The newer water conveyance technologies reduce these losses by lining open canals with impermeable material (clay, asphalt, concrete, etc.) or enclosing the distribution system in pipes. The newer water application technologies spread the water over the field more uniformly to reduce irrecoverable deep percolation at the upstream end while the water is flowing to the downstream end of the field or deliver the water to precise locations of need as does drip irrigation. The economic incentives that have attracted recent widespread adoption of modern capital-intensive irrigation technology include the rising cost of labor, federal and state subsidies, lower prices (due to increased supply) of irrigation systems, and the higher productivity of water obtainable with higher value water-intensive crops.

All water diverted to arable land is not consumptively used by crops. Some of the water is lost to evaporation, transpiration by phreatophytes, and seepage which does not reappear downstream. The rest returns to the river through surface and underground return flows (see Figure 1). Return flows may then be rediverted downstream. Rediverted return flow accounts for a substantial part of the annual water supply being used for irrigation.

Numerous studies claim that more capital-intensive irrigation systems save water (Mizue 1968; Austin 1970), which can be used to irrigate additional acreage (USDA 1969a; Hiskey 1972). In closed basins, however, the net increase is small. For example, in the Sevier River Basin, one study (USDA 1969a) concluded that the adoption of lined ditches, sprinklers, land leveling, and reservoir construction would increase overall or basinwide irrigation "efficiency" by only 4 percent. Hydrologically, only this amount of water saved could then be used to increase irrigated acreage basinwide. Upstream farmers could hydrologically increase their irrigated acreage by much more, but only at the cost of reduced downstream water availability.

An upstream irrigator can spread a fixed supply of water for crop consumptive use further by investing in more efficient irrigation systems. This additional water might be used by growing more profitable water-intensive crops, by expanding irrigated acreages, or by more frequent utilization of idle and fallow land. In addition, the productivity of water increases due to greater control of the water supply over time as well as uniformity in application throughout the farm, thus reducing surface runoff. Thus, a profit-maximizing farmer has private incentives to invest in irrigation systems up to the point where the additional value of the output received is equal to the additional cost of increasing the irrigation capital. If the percentage increase in the productivity of water associated with adding irrigation capital is greater than percentage increase in cost of supplying water, the consumptive use of water will increase, leading to a decrease in return flows. The water rights of downstream users partly draw from these return flows, and consequently any diminution of these flows, alteration of their timing, or increase in their salinity will affect downstream water rights.

Hydrologically, equitable water rights administration requires estimation of these effects. Economic evaluation requires the added comparison of the benefits of alternative irrigation technology to the upstream user with losses caused by these effects downstream. The comparison might be done empirically on the basis of current uses, but this method provides no power for forecasting future effects over the life of the irrigation facility. A model that can determine optimal irrigated areas, crops, and technologies provides the capability needed for this purpose. This study uses linear programming for optimizing and projecting the implications of alternate policies that are currently being pursued for resolving water rights conflicts and improving water supply and productivity. The model is applied to the Sevier River Basin in Utah where major concerns have been expressed on water rights issues as increasing investments are being made on new irrigation systems.

Sevier River Study Area

The Sevier River Basin was chosen for this study because it is essentially a closed system in which the river water is fully utilized within the basin. Present water users have rights to specific amounts of water. Any changes in irrigation technology, areas irrigated, or water use affect downstream water rights.

Past studies of basin hydrology, land use, and crop productivity provide the necessary data base to construct a model to estimate the impact of the adoption of modern irrigation systems. These data include: irrigated acreage by location and application methods, water diversions, consumptive uses, irrigation efficiencies, land classes, crop acreages, farming practices, types of farms, etc.

Sevier Lake collects runoff from the Sevier River (Figure 2) and Beaver River Basins (Figure 3). The landlocked Sevier Lake Basin contains over 17.7 million acres in a nine-county area. The Sevier River Basin covers about 12.5 million acres (USDA 1969a), and the Beaver River Basin covers about 5.2 million acres (USDA 1973a). Economic modeling uses data available on a county basis; and for this study, the modeling covers the six counties of Garfield, Piute, Sevier, Sanpete, Juab, and Millard. These counties make up the Sevier River Basin and part of the Beaver River Basin.

The Sevier River Basin is characterized by high plateaus, narrow mountain valleys, and broad desert areas. Topographic features include table-topped mountains, lofty peaks, fertile valleys, steep cliffs and terraces, and dry desert lands. Altitudes vary from 4,500 at Sevier Lake on the desert floor to over 12,000 feet at the Tusher Mountains. Fifty percent of the Sevier River Basin is mountainous, and these higher elevations yield most of the water for irrigation. All perennial streams and rivers and most intermittent streams originate in the high mountains in the southern portion of the basin.

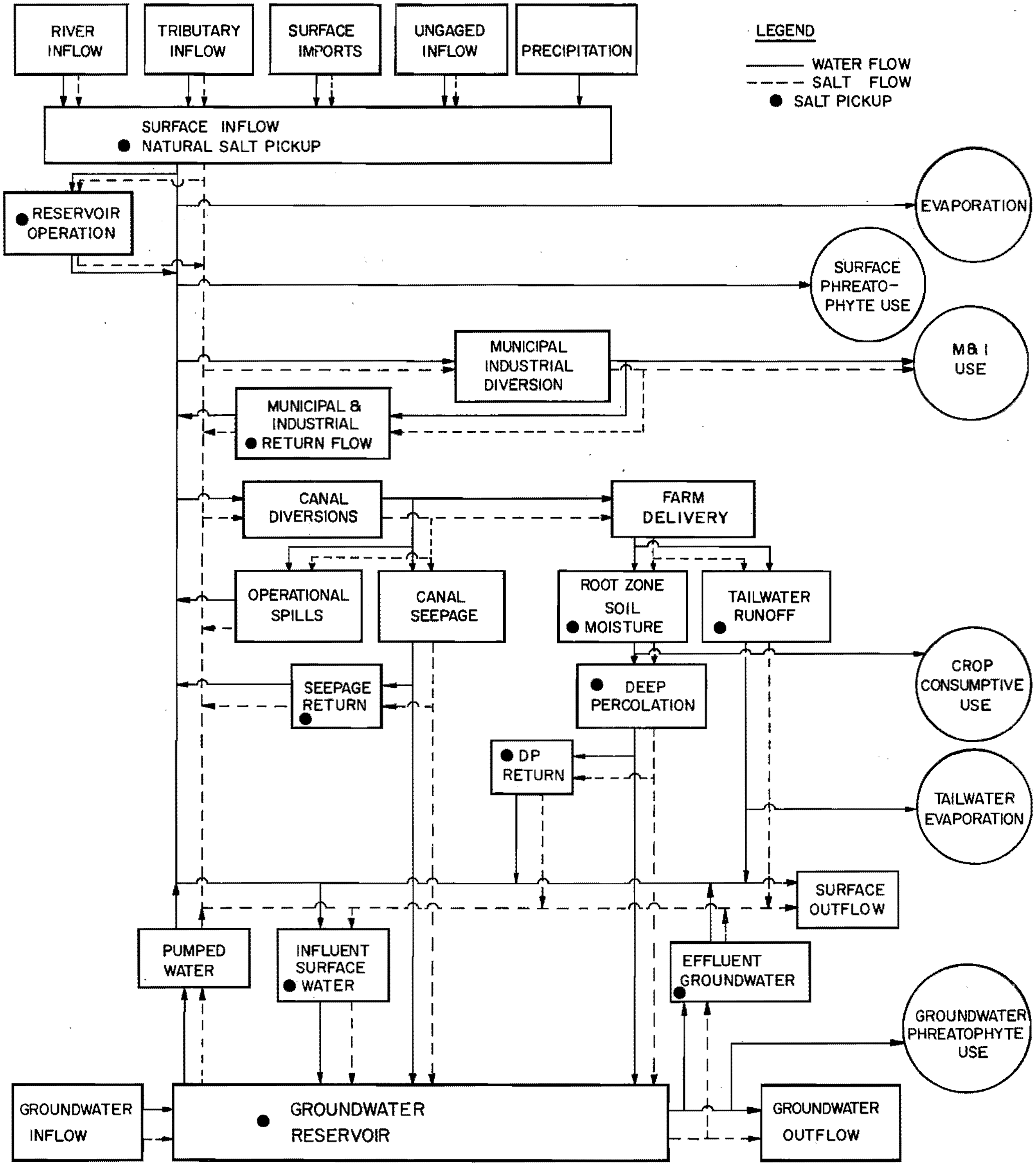

Figure 1. Schematic of the flow paths in the hydrosalinity model, BSAM-SALT. (From Narasimhan et al. 1980.)

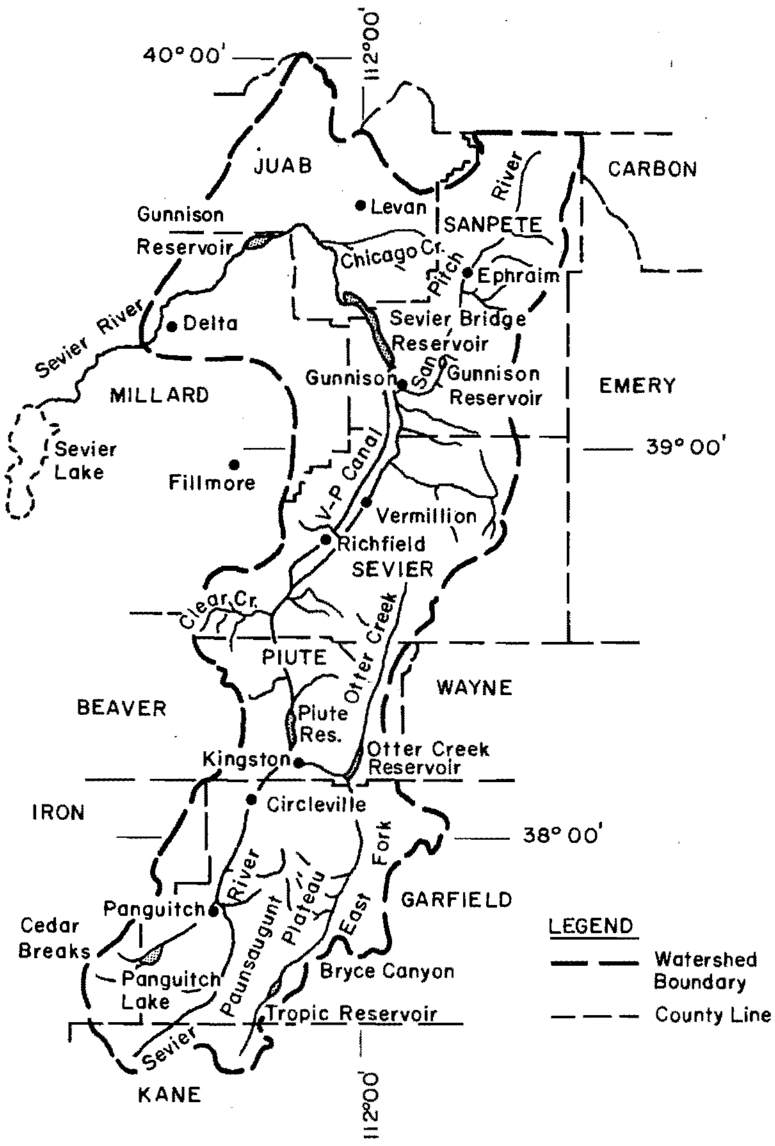

Figure 2. Sevier River Basin study area.

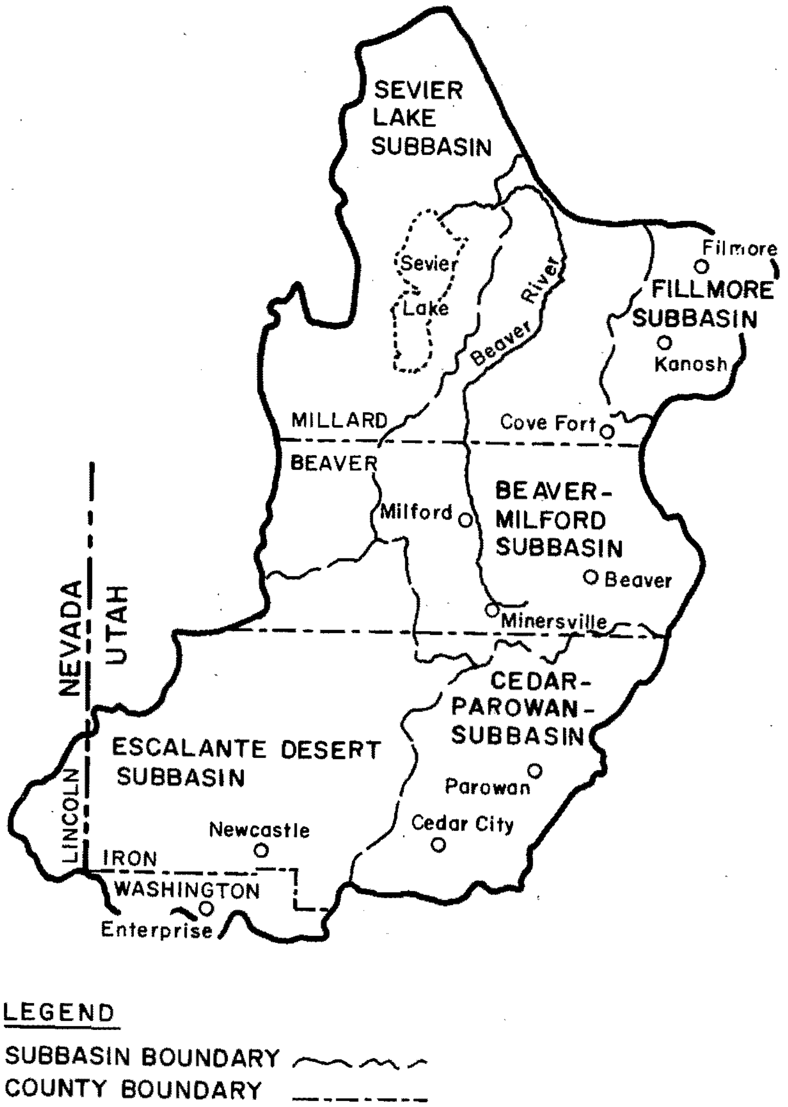

Figure 3. Beaver River Basin, Utah.

Agricultural Sector

The irrigated agricultural lands are located in the relatively long and narrow valleys and in the desert area near Delta. Irrigated cropland and wet lands are about 8 percent of the total: 1,036,000 acres in the Sevier River Basin (USDA 1969a), 196,000 acres in the Beaver River Basin (USDA 1973a). Agricultural production in the Sevier River Basin is about 25 percent of the Utah total. Approximately 28.5 percent of the labor force in the basin is engaged in farming, compared to about 6 percent for Utah. Alfalfa has been the leading crop, accounting for 62 percent of all production (Census of Agriculture 1974). Since 1955, crop production has been relatively stable, while livestock oriented enterprises have increased.

Agriculture in the Sevier River Basin in essence is based on two types of farm enterprises: 1) The livestock-oriented farm with cropping to meet livestock needs--alfalfa, grass hay, pasture, corn for silage, and feed grains. These enterprises are made up of dairy, range beef, and general livestock farms. 2) The cash-crop-oriented farm whose crop is primarily sold for cash. Alfalfa, alfalfa seed, wheat, feed grains, potatoes, and corn for grain are the principal crops. These enterprises are made up of the cash crop-feeder farm and cash crop farm.

Cash crop oriented farms account for 33.4 percent of the total farm enterprises within the basin. They account for 24 percent of the total acreage and 43 percent of all irrigated crops. Despite making up only one third of the farms, cash crop oriented farms account for 55.5 percent of the net incomes for all agricultural enterprises in the Sevier River Basin.

River System

The main stream of the Sevier River arises on the slopes of the Markagunt Plateau east of Cedar Breaks National Monument. From this point the river flows about 320 miles, first, northward through agricultural areas alongside Utah Highway 80 and then in a westerly direction into Sevier Lake.

About 60 miles downstream from head waters, the Sevier River is joined by the East Fork near Kingston. This fork combines drainage from Otter Creek with the main branch of the East Fork, which drains the western slope of the Paunsaugunt Plateau (the eastern slope is greatly eroded and forms the beautiful Bryce Canyon National Park). Downstream from its confluence with the East Fork, the Sevier River flows through intensive agricultural areas containing many feedlots and dairies. Several tributaries join the main stream, and many diversions of water for irrigation usage occur.

About 34 miles downstream of Kingston near the town of Sevier, Clear Creek joins the river, and about 25 miles further downstream Vermillion Canal waters are diverted. The Vermillion Canal terminates adjacent to or into the Piute Canal. Richfield (5,500 people) is the largest city on the Sevier River, and it is located near the Vermillion Canal diversion.

The San Pitch River drains Sanpete Valley to the northeast of Gunnison, and most of its flow is used for irrigated agriculture in the area. The San Pitch River has intermittent flow and is mostly stored in Gunnison Reservoir.

About 6 miles downstream from Gunnison, the backwaters of the Sevier Bridge Reservoir begin. Yuba Dam, which creates the reservoir, marks a change from the verdant river valley south of Gunnison to the arid, sagebrush dominated area to the west. The Sevier River then loops out to the west and the agricultural area around Delta.

It is about 67 miles from Yuba Dam to the backwaters of Gunnison Bend Reservoir just west of Delta. Most of the Sevier River flow is held in water rights by the farmers and ranchers in the Delta area, and flows are controlled for their uses. Although high flows occasionally continue out to the Sevier Lake, the river essentially ceases to exist just west of Deseret, a small town 3 miles west of Delta.

Under natural conditions, waters of the river ultimately spill into Sevier Lake, which provide a large evaporative surface to dispose of the flows. Over a long period of water development manmade depletions steadily reduced the water quantities entering Sevier Lake. Today, only about 10 percent or 13,690 acre-feet of the runoff is discharged into Sevier Lake (USDA 1969a), most of it in subsurface flows.

Within the Beaver River Basin, there are five hydrologically independent irrigated agricultural areas (Figure 3). Surface waters seldom leave any of these subbasins. They are either diverted for irrigation or recharge the groundwater aquifer. The economic modeling of this study covers Millard County, and the primary agricultural area in the Beaver River Basin in Millard County is in the Fillmore subbasin. The other subbasins within Millard County have negligible area being irrigated. Thus, only agriculture in the Fillmore subbasin of the Beaver River Basin is considered in detail in this report.

CHAPTER II

REVIEW OF LITERATURE

Estimation of third party effects requires capabilities in hydrologic modeling, determining crop productivity, and economic modeling. Several alternative techniques were reviewed to select approaches to be used in this study.

Basinwide Economic Modeling

Mathematical programming has become an increasingly useful tool for quantifying economic relationships for regional and river basin planning, design, and management. Area wide studies are normally done by either simulation models or linear programming models.

In the simulation approach, the physical and economic systems are approximated on the computer with a mathematical model, then various scenarios are considered. While the simulation approach does not optimize, it can be used to compare alternatives. Studies that have used simulation modeling in analyzing river basins include: Nelson (1959), USDA (1970 VIII), Mizue (1968), Austin (1970), and Keith et al. (1978a).

Since the Second World War, linear programming has become one of the most widely used tools for identifying economically optimal decisions. It is used extensively by resource and agricultural economists to optimize resource use, organization, and product specialization. Many applications have been made in agricultural and water resources. These include: Tolley and Hastings (1960), Moore and Hedges (1963), Hartman and Whittlesy (1961), Gisser (1970), Cummings and Gisser (1977), Condra et al. (1975). Utah studies include: Anderson (1971), King et al. (1972), Keith et al. (1973), and within the Sevier River Basin, Davis (1965, 1966), Davis and Johnson (1966), Milligan (1970), and Hiskey (1972).

Representation of Irrigation Technology

In the earlier basin studies, modern irrigation practices were not considered. The choice of irrigation methods was usually between irrigated and nonirrigated systems without respect to specific technology.

One of the first studies to incorporate modern technologies was done by Moore and Hedges (1963). However, they did not go beyond estimating demand for water to report the impact of the adoptions. Gisser (1970) considered three different irrigation systems in estimating the demand function for water with a model that selected efficient systems to maintain acreages as low salinity water declined. To evaluate the effect that the adoption of modern technologies had in maintaining irrigated agriculture in Estancia Valley in New Mexico, Cummings and Gisser (1977) modeled a choice among four irrigation technologies: unlined ditches, pipelines, sprinklers, and trickle systems. They reported that with the adoption of modern technology, greater "efficiencies" could be achieved and land retirements could be moderated when faced with reduced water allocations.

Mizue (1968) and Austin (1970) investigated the impacts of irrigation efficiencies in the Utah Lake drainage and Bear River Delta, respectively. Their parametric model, however, did not examine the methods by which the increased efficiencies would be achieved.

USDA (1970 VIII), through an analog model, simulated hydrological flows, irrigation efficiencies, and farming practices in the Sevier River Basin to evaluate the effects of specific projects such as land leveling, canal and ditch lining, adoption of sprinklers, and improved irrigation practices. From this model, the Department of Agriculture (USDA 1969a) concluded that a 4 percent increase in efficiency could be achieved and that it would "save" enough water to irrigate an additional 70,000 acres.

In many of the basin studies, like the one above, the increased "efficiencies" or water savings not only included reductions in evaporation, deep percolation losses, and phreatophyte consumption, but also classified reductions in seepage and runoff losses as savings, while not considering them as part of the return flows. Although some have argued that (Committee on Research 1974) any seepage reduction is a savings because water lost by seepage must be "redeveloped" and seepage degrades water quality, the practical implication of this approach is to consider only the individual irrigator's savings and not possible third party effects.

The adoption of modern irrigation technologies was analyzed by Strong (1962). His study identified the least costly method of irrigation from among unlined, graded pipe, lined ditches, and sprinklers for various combinations of slope and soil types which cause variations in costs and returns. His method minimized the total cost of irrigation in the context of the decrease in output caused by the various factors. Strong only considered the adoption of modern technologies from the cost side and did not consider third party effects.

Return Flows

The Committee on Research of the Irrigation and Drainage Division (American Society of Civil Engineers) recognized the increased importance of socioeconomic analysis to equitable basinwide water rights management when the waters of the basin are fully developed with the statement:

> The day is rapidly approaching when some irrigated regions will operate as an essentially closed system. Thus, all (or nearly all) return flows would be collected and recycled or treated. The social problems and institutional constraints associated with water planning and management, are complex and cannot be solved by only one discipline alone. It needs a multi-disciplinary approach, and a very close cooperation between physical and social scientists.... It should be noted that in several recent system studies to facilitate water planning and management operations have completely neglected the whole complex role of institutions in policy planning and decision making.... (Committee on Research 1974, p. 153.)

The reason for this greater need for socioeconomic evaluation lies in the greater dependency of downstream water users on upstream user return flows. Since, as Bagley (1963) has stated, upstream seepage is a loss to the farm but not to the system, the incentives that induce upstream farmers to reduce their losses also reduce downstream water availability. In this context, the Committee on Research further states that little has been done to identify the social, economic, and institutional factors that have an important, if not overriding, influence on water management and policy particularly on a regional basis; that not only should the physical sciences adapt but that social and institutional changes are necessary to accommodate technological advances.

Specific detailed studies are also needed on the effect of methods of application on the quantity and quality of return flows. Of those studies which have considered the effect of the method of irrigation on return flows [Nelson (1959), Mizue (1968), Austin (1970), Hiskey (1972), Hurley (1968), Hall (1968), Sylvester (1963), Willardson (1972)], only Hiskey noted that return flows would be rediverted downstream and that upstream irrigation methods that reduce them affect downstream property rights. Despite some additional progress (Narasimhan et al. 1980, Israelsen 1981), no one has developed a reliable hydrologic model for quantitatively covering the effects of upstream irrigation practices on the volume, timing, and salinity of downstream flows.

Water Application--Yield Relationships

Studies on the impact of water application methods on crop yields have been reported by numerous authors, and they do not all agree that the adoption of modern irrigation systems increases yields. Studies on how field crops respond to different irrigation methods fall into two types: controlled plot or actual field observations.

Some of the controlled plot studies include: Lewis (1949), Jacobson (1952), Somerholder (1958), Finkel (1959), Frost (1961), Kruse et al. (1962), Pair (1962). The controlled plots eliminate many factors other than irrigation method that might affect yields, such as climate, slope, water holding capacity of soils, and other farm management practices. The controlled studies are usually made on simultaneously irrigated paired plots which utilize sufficient management, labor, and hardware that the operational efficiency differences between the methods become negligible. In general, irrigation method was not found to be a significant determinant of crop yield.

Field studies gave somewhat different results. Under field conditions, where total yields were unaffected by conversion to more capital-intensive irrigation systems, crops were grown with 7 to 40 percent less water [Israelsen (1944), Hamilton and Schrank (1953), Proceedings (1962), Strong (1962), and Swarner and Hargood (1963)]. Although total yields for many crops did not change, Strong (1962) and Swarner and Hargood (1963) found about 10 percent increases in alfalfa yields. Other authors who found or used increased yields with the adoption of sprinklers include: Price (1938), Ewing and Zerfoss (1942), Davis et al. (1961), USDA (1969 XII), and Cummings and Gisser (1977). The increased yields with the adoption of sprinklers in these studies was credited to better spatial and temporal uniformity in water delivery and to better complementary management techniques which occur when sprinkler irrigations are adopted. This second factor, of course, did not occur on the controlled plots.

For purposes of estimating the parameters required by this model, the results of studies measuring actual field conditions seemed more appropriate; and those studies suggest that, depending on the water management approach, sprinkler irrigation can both save water and increase yields. Increased yields are indicated to be the primary effect by USDA (1969 XII) and Cummings and

Gisser (1977). The USDA study on the Sevier River Basin reports a significant increase in alfalfa yield and alfalfa consumptive use. Thus, more efficient irrigation is associated with both higher alfalfa yields and increased consumptive use. Cummings and Gisser based their conclusion that sprinkling increases yield in part on the belief that with the adoption of the newer system, the farmer usually receives additional training and better uniformity in water application (Franklin 1979).

CHAPTER III

THEORETICAL APPROACH

Demand

In short run, the demand for irrigation water depends on the relative prices of the crops, the relative prices of other inputs used in the production of the crops, and the amount of land.

Given the relationships of crop yield to these inputs and the prices, the demand for water can be derived. A modern irrigation system is one of the inputs and one that increases the marginal productivity of water through better uniformity of application (both spatially and temporally). The more productive the resource becomes, the greater the demand for it. As the demand for irrigation water increases, more widespread use of modern irrigation systems will be observed.

In deciding whether or not to adopt a new irrigation system, the farmer weighs the increased private benefits he expects to receive against the costs. With the same allocated water diversions, the farmer can increase the total amount of water available for use by the crops. The irrigator views this additional water as a savings, which should be available for his private use. However, part of this water would normally return to the system via surface and subsurface flows and become part of the downstream water rights. As a result, the incentive to the irrigator is to use more water after adoption of a sprinkler irrigation system than he should after considering the water rights of his neighbor.

Under the present water rights system, a specified quantity of water is allotted for diversion to irrigate a specified parcel of land. Changed irrigation systems increase the water the irrigator has available for on-farm consumptive use without changing diversions. Irrigated acreages can be increased as a farmer irrigates previously idle or fallow acreages more frequently. (These are included in the definition of irrigated land as long as it is irrigated at least once during any 7-year period.) Secondly, the farmer can increase water use by growing more profitable and more water consuming crops. These can result in the upstream user, by virtue of his location, taking away part of the downstream water user's rights.

Initial Condition

The economic impact of any water rights reallocation associated with the adoption of new irrigation technology by upstream irrigators depends on the initial conditions, particularly in the comparative values of the marginal products of water in its various uses. Under initial water rights, one of three situations exists when marginal products are compared between use units (whether farms, counties, sectors, etc.). Specifically, if one use unit is called A and the other B, 1) the value of the marginal product of water use in Unit A (VMPa) may be equal to the value of the marginal product of Unit B (VMPb), 2) the VMPa may be greater than the VMPb, or 3) the VMPa may be less than the VMPb. These three states are shown in Figure 4a,b,c.

When the value of the marginal products are equal (Figure 4a), the economic value of water in the two uses is maximized and equals the sum of the areas under the two marginal physical product curves up to the amount of use. If the division of water is not such as to equate VMPa with VMPb (CUe on Figure 4a), the sum of the values in the two uses is reduced and the loss to society represented by the shaded area in Figure 4b or 4c occurs. The shaded area in Figure 4b shows the loss (externality) when VMPa > VMPb. In Figure 4c the area shows the loss when VMPa < VMPb.

Adoption of Modern Techniques

When the new technologies are adopted causing the marginal physical products of Units A and B to shift, one of several situations will result: 1) an externality will be created, 2) the initial distortion will be reduced or eliminated, 3) the welfare loss will be increased, or 4) the externalities will be imposed on the other unit.

Figure 5 shows the first situation, the one where an externality is created. Here, the values of the marginal physical product are initially equal between the two users. The adoption of sprinklers causes the marginal products to increase. This is shown as a shift of the demand curves from Da to Da' and Db to Db'. If water use in Unit A (by the upstream user) expands to CUa (the point where the marginal value now equals price) and from CUe assuming total supply of water is fixed, the water available for consumptive use by B falls to CUb. At this new quantity the value of the marginal product increases to VMPb' (greater than VMPa). As a result, an externality is imposed on B. A net loss to society occurs equal to the area BCD. A increases his value received by area ABDE but

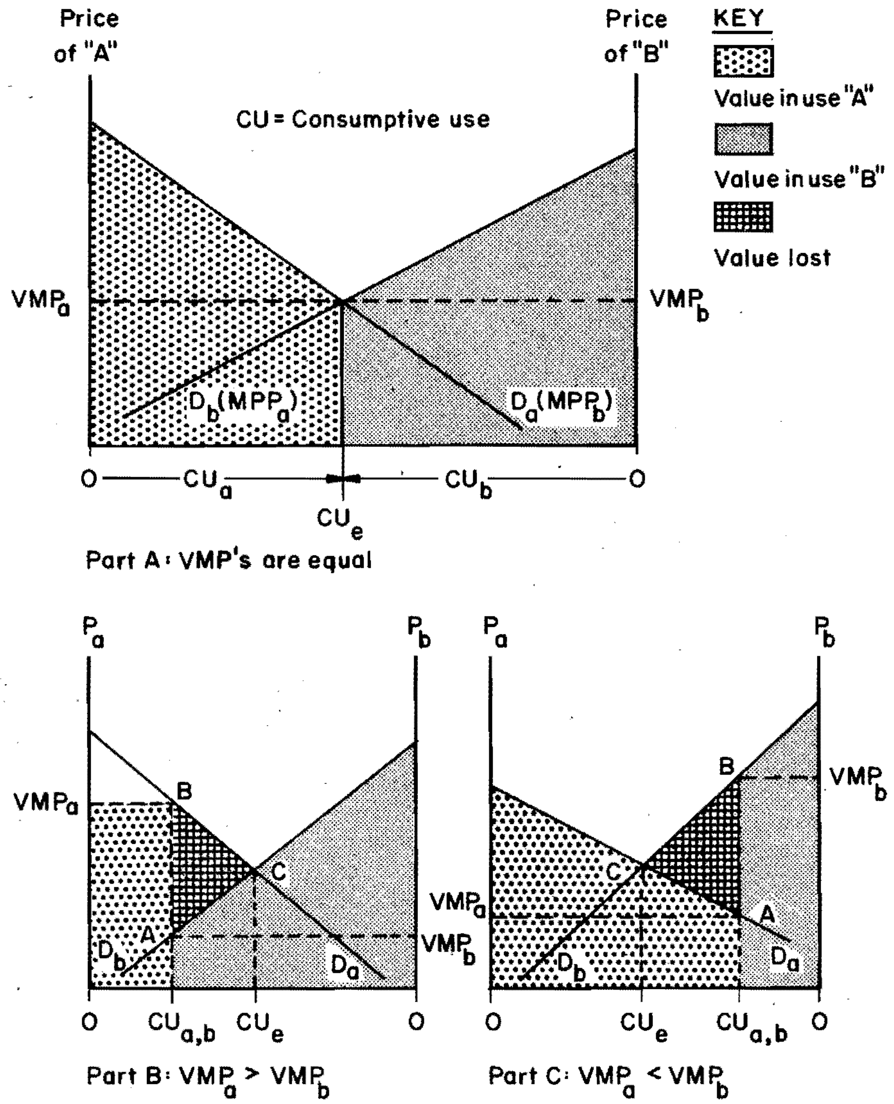

Figure 4. Externality states prior to technology adoption.

does so by depriving B of the greater value ABCE.

If an initial externality exists, i.e. the VMPa ≠ VMPb, one of several impacts can occur. The externality can be reduced or eliminated, aggravated, or switched to the other party. If the externality is reduced or eliminated, society will gain. For example, if prior to the adoption the burden of the externality, because of junior water rights, is on Unit A (VMPa > VMPb), as shown in Figure 6, society's loss is equal to area ABC when Unit A consumes CUa. With the adoption of the newer technologies in Unit A, the demand curve shifts to Da'. If through locational advantage Unit A is able to increase its consumptive use from CUa to CUa', where CUa' is still less than CUe', the loss to society is reduced to area XYZ (XYZ < ABC). Had one or both of the demand curves shifted in a manner where CUe was attained (VMPa = VMPb), then the externality would no longer exist. This occurs in this example when the demand for Unit A shifts to the Da^2 curve and the demand for Unit B shifts to the Db' curve. A shift to a still higher demand curve for water by A would reverse the direction of the externality, and a large enough shift could produce an externality favoring Unit B larger than the original one favoring Unit A.

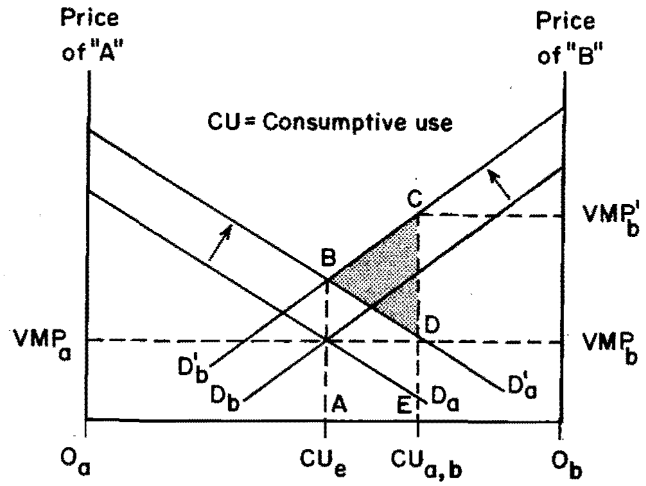

Figure 5. Externality created with the adoption of technology.

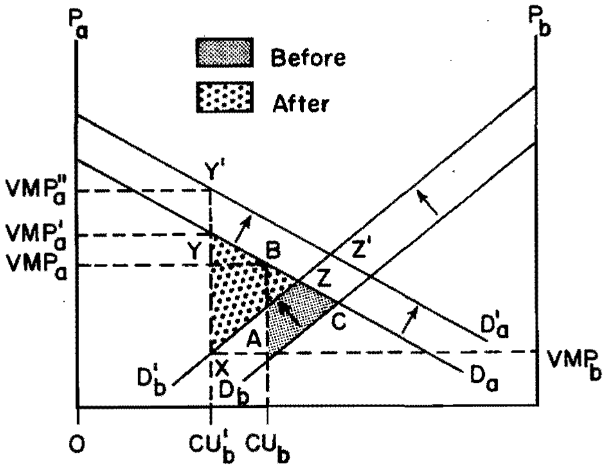

Figure 7. Technology adoption aggravating an externality.

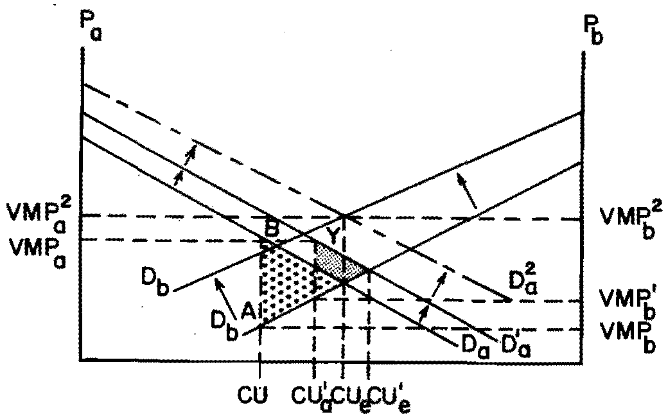

Figure 6. Externality existing prior to technology adoption.

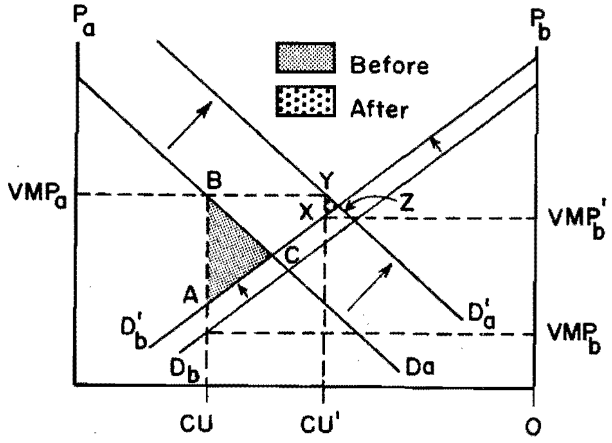

Figure 8. Externality reversal with technological adoption.

If the burden of the externality is on Unit A and the new irrigation technologies are being adopted in Unit B, the demand curve shifts to Db'. If Unit B is able to increase its consumptive use to CUb', as in Figure 7, then society's loss would have increased (area ABC < XYZ) as indicated by VMPa' > VMPa > VMPb. If Unit A also adopted the newer technologies, then the loss to society would increase to area XY'Z' where the VMPa" > VMPa' > VMPa > VMPb.

As another example for an initial burden on A (VMPa > VMPb), adoptions of the newer technologies in Unit B and not in Unit A increases the demand in Unit B and not in Unit A and ends with a social loss represented by area ABC (Figure 8) if the consumptive use is maintained at CUa. If Unit A increases the technology and CU to CUa' and reduces the consumptive use in Unit B accordingly, the VMP increases in Unit B to VMPb'. This reduces the externality in A and reduces the loss to society (area XYZ). If the VMPb increases even greater than VMPb' in Unit B, the externality will be reversed, i.e., VMPa < VMPb from Unit A to Unit B. If the social loss after the adoption is less, although reversed, society gains. If the social loss is greater then society loses.

Adoption of Technology Without Violation of Water Rights

In the above hypothetical examples, the water available for consumptive use was assumed to remain constant. However, when the new systems are adopted the total water available for productive consumptive use could be increased by reducing nonproductive evaporation, deep percolation, or unused flood runoff. If saved water can be used for irrigation, it would be possible to increase consumptive use without causing externalities or violating water rights.

Figure 9 illustrates this condition where a previous externality exists. Prior to the adoption of the new system the following conditions hold: VMPa > VMPb; water rights are CUa for Unit A, and CUb for Unit B; the total water available is CUt (CUa + CUb). If the water can be made available, Unit A and Unit B can increase their consumption by δCUa and δCUb respectively. In this instance total consumption by each unit increases and all units can maintain their water rights.

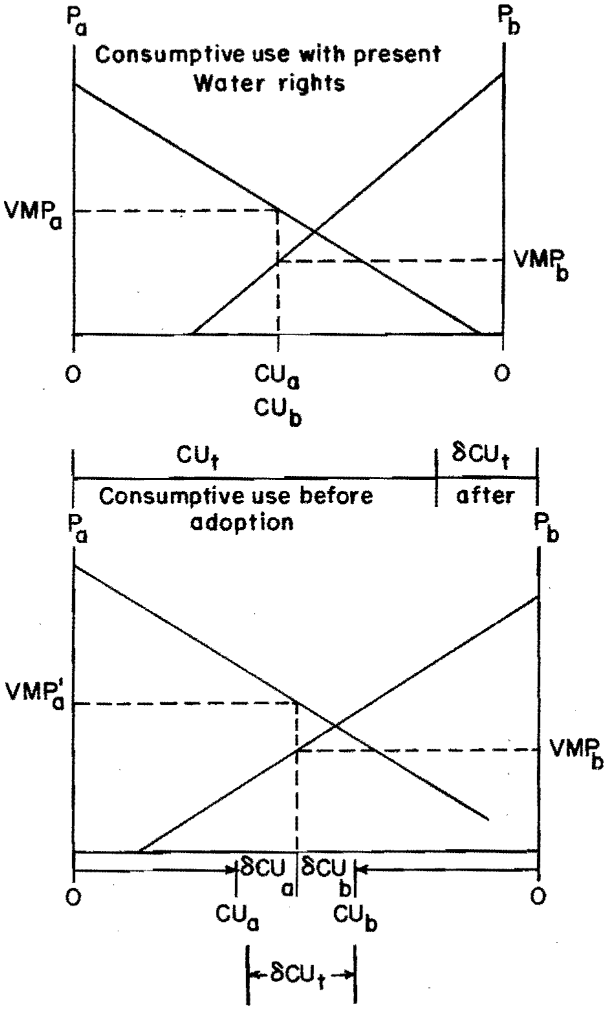

Figure 9. Technological adoption without violation of water rights.

If this additional water cannot be found, there will be losers and gainers. Even though there are losers, the shift is still desirable if losses exceed gains, and society would be served by facilitating appropriate water transfers.

When the adoption of sprinklers and other systems increased net basin output, government intervention to protect losers through enforcement of diversion and acreage limitation or the use of taxes or subsidies may reduce basin output (social output). For example, acreage limitations could prevent irrigation of more productive land to protect the water rights of less productive land. The economic modeling developed below provides a tool for determining whether this would happen.

Supply

In the discussion so far, the cost of a new irrigation technology has been neglected. In addition to the irrigator being a demander of water for consumptive use, the irrigator is also the supplier of water to be consumptively used by the crops. The extent of adoption of modern systems depends on their cost. Associated with the new irrigation system, the supply curve of water changes. The introduction of a capital intensive system (lined ditch, pipe, drainage systems, and/or sprinklers) generally causes the supply curve to shift to the left. The amount of shift depends on the increased costs for supplying water and the balance reached between the new supply curve and the shift in the demand curve caused by the increased productivity of water, determine whether or not in fact, the consumptive use increases. Both the cost and increased productivity associated with the new system depend on the class of land to be irrigated.

The classifications of land, with respect to yield and ability to grow crops, range from a high of Class I to a low of Class VII. Agricultural lands range from Class I to Class IV. Lands are classified as less productive on the basis of wetland, climate, erosion, and soil quality problems. When drainage is the primary problem, the soil is classified as "w." If climate is the primary problem in growing crops, the soil has a "c" subclassification. Erosion or slope problems are given a subclassification of "e." For shallow soil or salt-alkali problems, a subclass of "s" is used. For the higher quality lands in the Sevier Basin (Classes IIw, IIc, IIe, and IIIe), the annual costs are higher for sprinkler and/or lined ditches than for a surface flood irrigation system. While there is an increase in output (revenues) associated with the adoption of more "efficient" systems, it may not be sufficient to close the cost differential between the systems.

However, investment and annual cost of surface irrigation systems are inversely related to the lengths of irrigation runs (the amount of water that can be beneficially applied in a given irrigation); i.e. as irrigation runs are shortened, costs per acre increase. Lands with steeper slopes and coarse soil require shorter runs and more frequent irrigations and, consequently, more irrigation structures and equipment to convey and distribute water. Thus, the cost gap between sprinklers and surface irrigation methods is decreased for the poorer quality lands, IIIe, IVw, IVs, IVc. However, total crop production for the poor quality lands is significantly less where shorter runs are required. In this instance the gain in yield may not be sufficient to warrant the more costly system.

For the medium quality land (IIe, IIIw, IIIe, IIs), the investment and annual costs of surface irrigation systems are rising while sprinkler systems costs remain relatively constant. This, combined with increasing yields, could result in the medium quality land being relatively more profitable for sprinkler adoption.

These considerations are important to evaluating the private incentives for the adoption of sprinklers and improved conveyance systems. The private actions affect third parties. If there is a welfare loss as a result of private decisions, preventive government policies need to be considered. To examine the implications of policy alternatives and manage water resources basinwide, a framework is needed through which optimal irrigation systems can be determined.

CHAPTER IV

EMPIRICAL MODEL

The Programming Model

Water rights are generally assigned in terms of the quantity of water that an individual farmer is allowed to divert to irrigate a specified parcel of land. Changes in economic, technological, or physical factors affecting water consumptive use may create externalities. Therefore, the enforcement of water laws to protect property rights should entail monitoring actual quantities of water consumptively used. But the measurement costs would be prohibitively high and as a consequence, alternate procedures are needed to estimate use and use change effects.

Specifically, to examine the impact of the adoption of modern irrigation systems on third-parties and to determine whether efforts to facilitate water transfers would be consistent with basinwide output maximization, a mathematical programming model of the irrigation economy was developed. The model formulated in this study uses data that have been observed for the Sevier River Basin, and the policy conclusions based on this model are directly applicable to that area.

One of the key factors of the model was the inclusion of the various soil types and slope features as they affect the various methods of irrigation, associated "efficiencies," and crop yields. Soil types and slope data have been appropriately weighted by percentage of land types so that these characteristics are reflected in the various land classifications.

The model was designed to maximize the Sevier River Basin's agricultural net returns subject to various constraints. Important model features are shown in Figure 10 which includes the agricultural and the hydrologic submodels. The basin was divided into six counties, with the following factors being considered: slope, soil types and yields as reflected by land class; consumptive use for nine crops (alfalfa, alfalfa seed, barley, barley as a nurse crop, wheat, pasture, potatoes, corn for silage, and corn for grain); crop rotation patterns; various on and off-farm irrigation systems and efficiencies; water diversions and acreages limitations which took into account the legal constraints administered by the state engineer. Table 1 lists the data sources used.

The linear programming model used the objective function:

$$\text{Max } Z = \underbrace{\sum_{i=1}^{L}\sum_{j=1}^{M}\sum_{r=1}^{N} b_i^r X_{ij}^r}_{\text{(net crop revenue)}} \quad \underbrace{- \sum_{r=1}^{N} \theta GW^r}_{\text{(groundwater costs)}}$$

$$\underbrace{- \sum_{q=1}^{S}\sum_{r=1}^{N} \phi_q^r\, Wd^r}_{\text{(cost of off-farm conveyance system)}} \quad \underbrace{+ \sum_{h=1}^{t}\sum_{r=1}^{N} \delta\Gamma_h^r Td_h^r}_{\text{(cost sharing)}}$$

$$\underbrace{- \sum_{h=1}^{t}\sum_{r=1}^{N} \eta\Gamma_h^r Td_h^r}_{\text{(tax on system)}} \quad . \; . \; . \; . \; . \; . \; . \qquad (1)$$

Subject to the following constraints:

Land:

$$\sum_{j=1}^{M} X_{ij}^r \leq PIL_i^r \qquad i=1,\ldots,L$$

(presently irrigated land) $r=I,\ldots,N$

$$. \; . \; . \; . \; . \; . \; . \qquad (2)$$

$$\sum_{j=1}^{M} X_{ij}^r \leq PDL_i^r \qquad i=1,\ldots,L$$

(potentially irrigable land) $r=1,\ldots,N$

$$. \; . \; . \; . \; . \; . \; . \qquad (3)$$

Crop Rotations:

$$\sum_{h=1}^{t}\sum_{i=1}^{L} \Big(\varepsilon_j X_{ijh}^r \pm \sum_{\substack{J_1=1 \\ J_1\neq j}}^{M} \sigma_{J_1} X_{iJ_1}^r h\Big) \gtrless 0$$

$$r=1,\ldots N$$

$$. \; . \; . \; . \; . \; . \; . \qquad (4)$$

Surface water for agricultural diversion:

$$\sum_{r=1}^{N} IF_r + A_r^* \geq TD_r \quad . \; . \; . \; . \; . \; . \qquad (5)$$

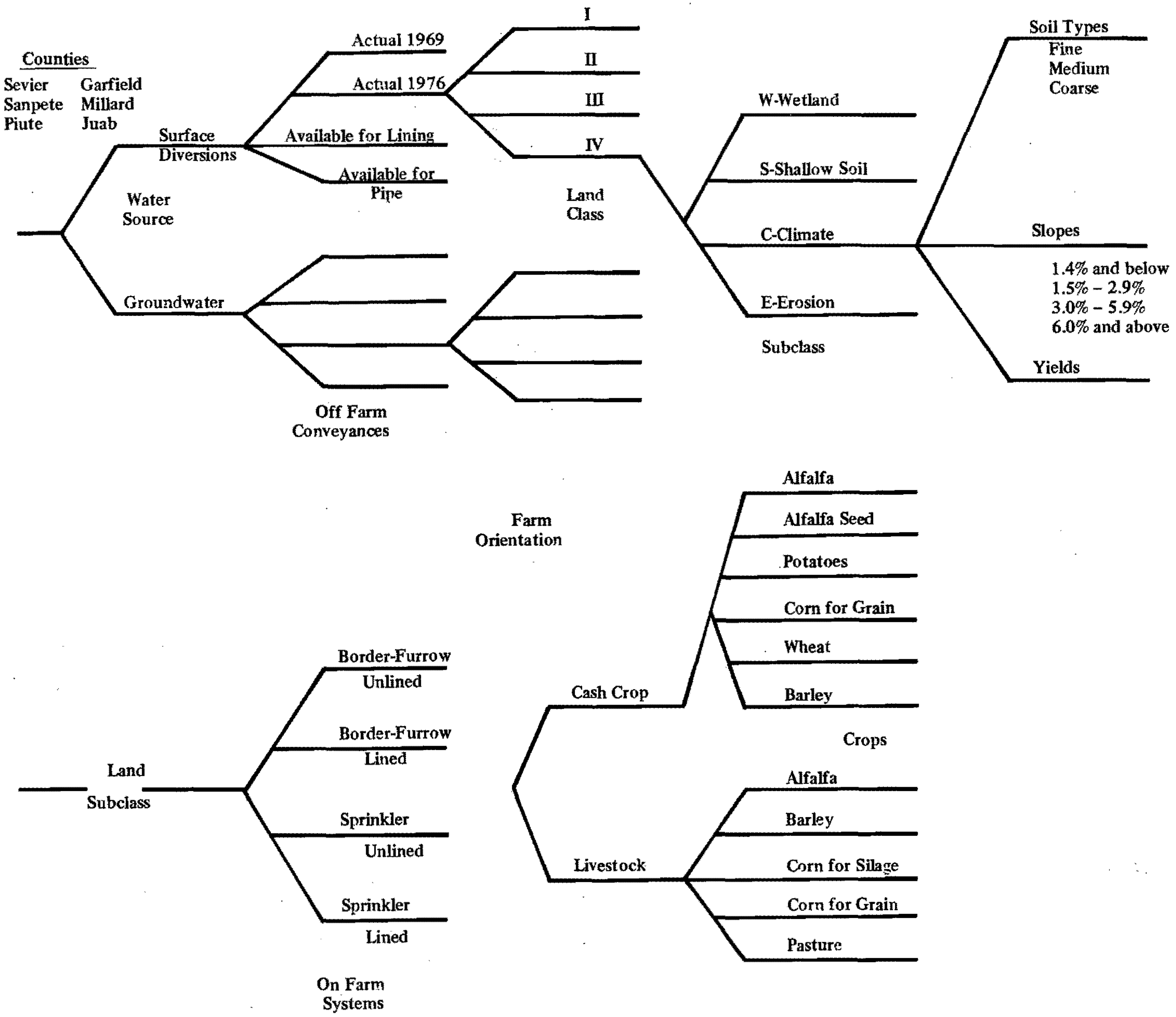

Figure 10. Flow diagram of the Sevier River Basin.

Table 1. Sources of data.

Data	Source
Agricultural prices	Utah Agricultural Statistics (1970-1977)
Pasture prices	Nebraska Formula Davis (1979)
Crop productivities by land class	Utah and Idaho Soil Surveys (1968-1979) SCS
for nurse crop	Richards (1979)
Basic farm budget	
general	Utah Agricultural Statistics (1975-1977) and Christensen et al. (1973)
Sevier Lake Basin	USDA (1969 X)
Cropping practices	
Sevier River Basin	USDA (1969 X)
Alfalfa seed production	Ogden (1979)
Costs	
Labor	Utah Agricultural Statistics (1976)
Machinery, depreciations and insurance rates	Franklin (1979) and Cummings and Gisser (1977)
Land evaluations	Christensen et al. (1973)
Sprinkler	Franklin (1979)
Groundwater mining	Oklahoma (1978), USDA (1973a)
Off-farm systems	Tuttle (1979), UWRL (1975)
Power and fuel costs	UWRL (1975), Inter-agency Task Force (1978), Franklin (1979)
Potato cost by farm size	Davis et al. (1974)
Land clearing costs	Snyder (1979)
Drainage costs	Hancey (1978)
Leaching costs	USDA (1969a)
Land classification	
Soil and slope relationships	Utah Soil Surveys (1968-1979) Soil Conservation Service
Irrigation efficiencies	
For slope and soil type	Strong (1972)
For off-farm systems--unlined	USDA (1969a), Mizue (1968)
County total system	USDA (1969)
Length of raw requirements	Utah Soil Surveys (1968-1979) Soil Conservation Service, Strong (1972)
Rotation practices and acreage limitations	
Maximum acreages--wheat, potatoes and alfalfa seed	Agricultural Census data (1959-1979), Davis (1974)
General constraints	Stewart (1979), McAllister (1979), Hiskey (1972), Ogden (1979), Andersen (1979)
Corn irrigation by sprinkler	Finkel (1960), Ogden (1979), McAllister (1979)
Consumptive use requirements	USDA (1969 IV), Irrigation Operator's Workshop (1966), and Criddle (1962)
Acreages by land class	USDA (1970), USDA (1969 IV)
Water losses	
Deep percolation	Mizue (1968), Keith (1978)
Evaporation	Snyder (1979)
Phreatophyte consumption	Blaney (1961)
Farm classifications	USDA (1969a)

Inflows:

$$\sum_{\substack{r=1\\ r_1 \neq r_2}}^{N} OFr_1r_2 = IF_{r_2} \qquad r_2=1,\ldots,N \qquad \ldots\ldots\ldots \quad (6)$$

Groundwater availability:

$$\sum_{r=1}^{N} GW^{r} \leq \sum_{r=1}^{N} GW^{r*} \qquad \ldots\ldots\ldots \quad (7)$$

Total water available for diversions:

$$TD_{r1} + OF_{r1} - RF_{r1} - \sum_{r2=1}^{N} IF_{r_1r_2} = Ar_1^{*} \qquad r_1=1,\ldots,N \qquad \ldots\ldots\ldots \quad (8)$$

Diversions:

$$\sum_{h=1}^{t} \frac{1}{\gamma_h} \left(\sum_{i=1}^{L} \sum_{j=1}^{M} CU_{ij}^{r} \right) = WA^{r} \qquad \ldots \quad (9)$$

On-farm water availability:

$$GW^{r} + \sum_{q=1}^{S} \lambda_q^{r} \, Wd_q^{r} = WA^{r} \qquad r=1,\ldots,N$$

(total water conveyed to the farm)

$$\ldots\ldots\ldots \quad (10)$$

Total stream diversions:

$$\sum_{q=1}^{S} Wd_q^{r} = TD^{r} \qquad r=1,\ldots,N \qquad \ldots\ldots\ldots \quad (11)$$

Return flow constraint:

$$WA^r - \sum_{i=1}^{L} \sum_{j=1}^{M} CU_{ij}^r - \sum_{q=1}^{S} \beta_q^r (1-\lambda) Wd_q^r$$

$$+ \sum_{q=1}^{S} \left| (1-\beta)(1-\lambda) \right| \cdot Wd_q^r - w \sum_{h=1}^{t} Wd_h^r = RF^r$$

$$r=1,\ldots,N \qquad \ldots\ldots \quad (12)$$

Total conveyance losses:

$$\sum_{q=1}^{S} \beta_q^r (1-\lambda) Wd_q^r \qquad \ldots\ldots \quad (13)$$

In which equations the terms are defined as follows:

i	Class of land (IIw, IIIw, etc.)
j	Type of crop grown
r,k	County
h	On-farm irrigation system
q	Off-farm conveyance system
b_{ij}^r	Net revenue associated with 1 acre of the jth crop grown in the ith class of land in the rth county
X_{ij}^r	jth crop acreage grown in ith land class in county r
θ	The cost of pumping 1 acre-inch of groundwater
θ_q^r	The cost of diverting water by qth off-farm method for the rth county
Wd^r	The amount of water diverted from surface flows to the rth county
PIL_i^r	Potential land for irrigation of the ith class in the rth county
δ	Percent of the irrigation system costs paid by cost sharing
η	Percentage tax rate based on system cost
Γ_h^r	Per acre cost of the hth on-farm irrigation system in the rth county
Td_h^r	Total water diverted by the hth on-farm irrigation system in the rth county
β_q^r	Percentage of waters lost to deep percolation, evaporation, and phreatophyte consumptive use for the qth off-farm conveyance system in the rth county
w	Percentage of water percolated beyond groundwater recovery
γ_h	Efficiency of the hth on-farm system
CU_{ij}	Consumptive use of the jth crop on the ith land class
TLC	Total conveyance losses to the system due to evaporation, deep percolation, and phreatophyte losses in the rth county
X_k^r	The amount kth crop acreage allowed in the rth county
k	Crops, potatoes, alfalfa seed, and wheat
$\varepsilon_j, \sigma_{j_2}$	The rotational coefficient of the jth and j_1st crop on the ith land class using the hth type of on-farm irrigation system in the rth county
WA^r	Water conveyed to the farm available for delivery to the crops by an on-farm system
IF_r	Water flows into the rth county
A_r^*	Surface water flows available from within the rth county
TD_r	Total surface water diverted from the stream in the rth counties
OF_r	Water flows out of the rth county
GW^r	Groundwater diversions in the rth county
GW^{r*}	Total groundwater diversions allowed in the county
λ_h	Off-farm efficiency for the hth irrigation system in the rth county
RF_r	Water not consumed and returned as stream and groundwater
CU_{ij}^r	Beneficial consumptive use requirement by the jth crop on the ith class of land in the rth county

Objective Function Coefficients

Total Revenue

In order to maximize net agricultural revenue for the basin, both total revenue and total cost had to be determined for each crop for the 11 land classes. In estimating revenues, averages were used to eliminate the year to year variability of agricultural productivities and prices. An 8-year price average was determined for each crop, except for pasture lands and an establishment (nurse) crop as prices for these crops are not reported (Utah Agricultural Statistics 1970-1977). The price of pasture land was determined using the Nebraska formula which linked the price of pasture land to the price of alfalfa (Davis 1979). The nurse crop price was estimated from a weighted price determined by taking the price of alfalfa times the expected yield for one alfalfa cutting (USDA 1969 IX) plus the expected yield of barley as a nurse crop (Richards 1979) times its price.

Crop yields for the 11 land classifications found in the basin were determined by averaging estimated yields for each land class per acre as found in the various soil surveys of Utah, published by the Department of Agriculture Soil Conservation Service. For corn and potatoes, data for several Idaho counties were used. Total revenue by land class was then determined by multiplying the yield by the average prices (Table 2). Ten percent higher yields were used for sprinkler irrigations based primarily on Cummings (1977) and USDA (1969 XII) indicating that yields increased as water application efficiency increased.

Farm Budgets and Costs

Separate farm budgets were developed for each of the 11 land classes, four on-farm irrigation systems, three off-farm delivery systems, nine crops, and six counties shown in Table 3. Table 4 shows a sample budget for alfalfa. The basic farm budget for each crop was developed from the Utah Agricultural Statistics (1975, 1976, 1977), USDA (1969 X), and Christensen (1973). USDA (1969 X) was used to determine general cropping practices within the basin, e.g., whether alfalfa was grown strictly for seed or as alfalfa for hay and seed. Table 5 shows how the basic budget was varied by land class.

At the time the model was developed, the most comprehensive data available were for the year 1976; and those data were used to calculate farm budgets. Wage rates and labor costs were taken from Utah Agricultural Statistics (1976). Machine costs, depreciation and insurance rates were determined from Franklin (1979) and Cummings (1977), with machine time from Christensen (1973). Land evaluations by class were updated from Christensen (1973) for incorporating tax costs.

The initial step in estimating irrigation costs was to develop a land class profile which reflected soil textures and slopes. USDA-SCS soil surveys were used to determine percentages for the soil textures which are classified as fine, medium, and coarse. Slopes classified are: less than 1.4 percent, 1.5 to 2.9 percent, 3.0 to 5.9 percent, and 6.0 percent and over, for each of the 11 land classifications.

Data from Strong (1962) were used to determine irrigation efficiencies for the 11 land classes for each irrigation system, as well as to identify machine time and labor requirements based on soil types and slopes. The soil surveys were used to determine recommended irrigation timings and lengths of run for the land classifications and irrigation systems. The irrigation timings and lengths of run were then used to weight the labor and machine times to reflect the differences. Power and fuel costs, depreciation, insurance, and interest on irrigation capital were calculated using information from UWRL (1975), Inter-Agency Task Force (1978), Franklin (1979), and Oklahoma State University (1978), and then adjusted for

Table 2. Total revenue for agricultural production by land classes for flood irrigation.

Crops / Land Classes / Price		Alfalfa (August) $41.75 (ton)	Alfalfa Seed $74.84 (CWT)	Establishment Crop[b,c]	Potatoes $3.07 (CWT)	Corn for Grain $2.45 (bu)	Corn for Silage $14.18 (ton)	Wheat $2.67 (bu)	Barley $1.84 (ton)	Pasture[c] $8.35 (AUM)
		TR[d]	TR	TR	TR	TR	TR	TR	TR	TR
Class	IIw	221	304	129	875	256	341	193	172	96
	IIs	221	304	122	893	284	231	187	160	84
	IIc	234	308	129	936	a	330	222	170	92
	IIe	255	316	124	921	229	281	199	153	88
Class	IIIw	205	300	110	801	212	279	180	143	84
	IIIs	196	296	106	783	180	220	160	138	71
	IIIc	167	246	97	a	a	a	134	131	63
	IIIe	209	300	105	866	189	271	160	135	75
Class	IVw	180	250	89	642	135	260	153	112	67
	IVs	171	246	97	660	116	242	134	129	63
	IVe	200	296	105	672	162	212	a	134	75

[a] Not enough acreages of the crop grown on this class to determine an average.

[b] Calculated on the basis on a 1 ton alfalfa yield and 50 percent of the barley yield for that class of land.

[c] Estimated price.

[d] Total revenue in dollars.

Table 3. Farm characteristics used in the Sevier River Basin model.

Land Classes:

Class II: High yielding land
Subclass
- w = water problem
- s = soil salts and alkaline problem
- c = climate problem
- e = erosion and slope problems

Class III: Medium yielding land
Subclass
- w = water problem
- s = soil salts and alkaline problem
- c = climate problem
- e = erosion and slope problems

Class IV: Low yielding land
Subclass
- w = water problem
- s = soil salts and alkaline problem
- e = erosion and slope problems

Crops:
- Alfalfa
- Alfalfa seed
- Nurse crop
- Corn for grain
- Corn for silage
- Potatoes
- Wheat
- Barley
- Pasture

Counties:
- Garfield
- Piute
- Sevier
- Sanpete
- Juab
- Millard

Irrigation Systems:
- On-farm
  - Surface flooding unlined ditch
  - Surface flooding lined ditch
  - Sprinkler with unlined ditch
  - Sprinkler with lined ditch
- Off-farm
  - Unlined channel
  - Lined channel
  - Covered pipe

each land type and system using the above weights.

The farm budgets for alfalfa seed production were based on the cropping practices in Millard County as over 85 percent of the total seed output was grown in this county. The budget reflected that 66 percent of the seed grown included at least one hay cutting, while 33 percent was straight seed production.

Potato production costs were adjusted to reflect farm size. A cost index by farm size was used and acreages were determined using Census of Agricultural data (Davis 1974, Census 1974, 1979).

Land development costs were calculated and added to the basic farm budgets. It was assumed that all land required clearing prior to use. The costs reported by Snyder (1979) were used. Due to high water tables and salinity problems, all wetlands class IIw, IIIw, and IVw would require draining in order to maintain yields over time (Irrigation Operators Workshop 1970). Drainage costs were estimated from Hancey (1979).

Other Costs

For sprinkler irrigation in Millard County, an additional cost was added to the farm budgets to reflect the labor and ditch maintenance necessary to provide for a flood irrigation leaching (Irrigation Operators Workshop 1970 and USDA 1969a). The cost of mining groundwater at $1.27 per acre inch was determined from USDA (1973a) and Oklahoma State University (1978) for up to a 300 foot deep well.

The cost of converting to the various off-farm irrigation systems was determined from UWRL (1975) and Tuttle (1979). The costs were weighted by irrigation conveyance system condition percentages from USDA (1969a), in which it was assumed that the poor quality system would require the highest costs.

$$C_i^r = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}\gamma_{ij}\alpha_j^r}{\beta} \qquad r=1,\ldots,N \qquad \ldots\ldots\ (14)$$

in which

i	type of off-farm system, lined ditch or covered pipe
C_i^r	cost per acre of the ith system in the rth county
γ_{ij}	cost of the ith system for the jths conveyance condition per mile
α_j	percentage for the jth conveyance condition in the rth county per mile
β	acres per mile

Constraint Coefficients

Agriculture

Rotational constraints were used to reflect cropping practices used to maximize yields (alfalfa) to limit decreases (potatoes) or weed and insect problems (seed and wheat). Rotational constraints for all crops were developed from Stewart (1979), McAllister (1979), Hiskey (1972), and Ogden (1979). The rotational constraints are listed in Table 6.

Alfalfa and alfalfa seed constraints were established from Hiskey (1972) at levels to maximize yields. Ogden (1979) indicated that the average farmer in Millard County

Table 4. Farm budget for alfalfa, basic budget.

Basic Variable Costs	Number of Times[e]	Man Hours[e]	Labor Costs at 2.38/hr	Machine Time[e]	Power and Fuel[b]	Depreciation & Insurance	Materials[a]	Total Flood Unlined	Total Flood Lined	Total Sprinkler Unlined	Total Sprinkler Lined
Fertilizing 45 lbs/acre	1	0.4	0.95	0.3	1.38	1.09	6.90	$ 10.32			
Spraying	1	0.4	0.95	0.1	0.31	0.28	4.20	5.74			
Swathing	3[a]	1.3[a]	3.09		4.32	5.22		12.63			
Bailing	3[a]	1.7[a]	4.05		6.06	4.13	3.75[b]	17.99			
Loading & hauling	3[a]	7.4[a]	17.61		6.66	2.94		27.21			
Taxes $88 assessment at 60 miles								5.25[a,e]			
Subtotals								$ 79.14	$ 79.14	$ 79.14	$ 79.14
<u>Irrigation Costs</u>											
Land planning[c]								5.20	5.20		
Ditching-corregating	1.8[a]	0.3[c]	0.71	0.25[c]	1.51	0.47		2.69	2.69		
Renovating system	1[d]	1.5[d]	3.57	1.4[d]	3.92	3.46		10.95	4.94	10.95	4.94
Preirrigation setup[d]	1	0.3	0.76	0.1	0.14	0.13				1.03	1.03
Irrigating											
Flood 2A/hr	4.5	2.25	5.22					5.22	5.22		
Sprinkler	6x.94	5.64	13.42	5.7	5.77	15.61				34.80	34.80
Down Time 10%								3.62	3.62	2.62	2.62
Subtotals								27.68	21.67	49.40	43.39
Interest variable cost 6%								6.09	6.45	7.40	7.40
Interest other								7.17	7.17	7.17	7.17
Interest ditches									9.77		9.77
sprinklers										7.17	7.17
Depreciation ditches									7.98		7.98
sprinklers										9.77	9.77
Subtotals								13.26	31.37	31.51	49.26
								$120.08	$132.18	$160.15	$171.79

[a] Utah Agricultural Statistics

[b] Franklin (1976)

[c] USDA (1969 X)

[d] Strong (1962)

[e] Christensen et al. (1973)

Table 5. Farm budget by land class for alfalfa.

Land Classes	Cost Index									
	IIw/IIc	IIs	IIe	IIIw	IIIs	IIIc	IIIe	IVw	IVs	IVe
Ditching & renovation	100	117	129	100	127	151	156	112	173	168[a]
Irrigating costs, downtime and interest	100	100	111	100	111	135	136	107	148	151[b]

Budgets for Alfalfa - Flood Unlined

	IIw/IIc	IIs	IIe	IIIw	IIIs	IIIc	IIIe	IVw	IVs	IVe
Basic (flood-unlined) cost	79.14									
Plus other interest	7.17									
	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31
Ditching & renovation	13.64	15.96	17.60	13.64	17.32	20.60	21.28	15.28	23.60	22.92
Irrigation & downtime	8.84	8.84	9.81	8.84	9.81	11.93	12.02	9.46	13.08	13.35
Subtotals	108.79	111.11	113.72	108.79	113.44	118.84	119.61	111.05	122.99	122.58
Interest v.c. 6%	6.09	6.67	6.82	6.53	6.81	7.13	7.18	6.66	7.38	7.35
Land planning	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
Total costs	120.08	122.98	125.74	120.52	125.45	131.17	131.99	123.91	135.47	135.03

Alfalfa - Flood-lined

Base \ Land Class	IIw/IIc	IIs	IIe	IIIw	IIIs	IIIc	IIIe	IVw	IVs	IVe
Basic costs	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31
Ditching & renovation	7.63	7.63	8.64	7.63	8.64	10.30	10.38	8.16	11.29	11.52
Irrigation & dep....etc.	16.82	18.50	20.52	16.82	20.52	26.74	24.22	18.84	26.74	26.74
Interest system	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77
Interest v.c. 6%	6.45	6.63	6.81	6.53	6.81	7.28	7.14	6.78	7.28	7.63
Land planning	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
Subtotals	45.87	47.73	50.94	45.95	50.94	59.29	55.71	48.75	60.28	60.86
Totals	132.18	134.04	137.25	132.26	137.25	145.60	143.02	135.06	146.59	147.17

Alfalfa - Sprinkler-unlined

	IIw/IIc	IIs	IIe	IIIw	IIIs	IIIc	IIIe	IVw	IVs	IVe
Basic cost	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31
Renovation	10.95	12.81	14.13	10.95	13.90	16.53	17.08	12.26	18.94	18.40
Irrigation, preirrigation, interest, depreciation, downtime	62.89	62.89	69.81	62.89	69.81	84.90	85.53	67.29	89.93	94.96
Total Cost	160.15	162.01	170.25	160.15	170.02	187.74	188.92	165.86	195.18	199.67

Alfalfa - Sprinkler-lined

	IIw/IIc	IIs	IIe	IIIw	IIIs	IIIc	IIIe	IVw	IVs	IVe
Basic cost	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31	86.31
Renovation	4.94	5.78	6.37	4.94	6.27	7.45	7.71	5.53	8.55	8.30
Irrigation; preirrigation; interest; system, v.c.; downtime	80.54	80.54	89.40	80.54	89.40	108.73	109.53	86.18	119.20	121.62
Total Cost	171.79	172.53	182.08	171.79	181.98	202.49	203.55	178.03	214.06	216.23

[a] Adjusted for length of runs.

[b] Irrigation time, soil and slope adjustment.

Table 6. Rotational constraints for selected crops in the Sevier River Basin.

1) Alfalfa = 4 alfalfa establishment [except in Millard County]
2) Alfalfa seed $\leq$ 8 alfalfa establishment [except in Millard County]
3) 0.33 alfalfa $\geq$ alfalfa seed [Millard County only]
4) 0.25 alfalfa + 1.67 alfalfa seed $\leq$ alfalfa establishment [Millard County only]
5) Alfalfa + alfalfa seed $\leq$ 8 corn for silage [except in Piute County]
7) Potatoes $\leq$ 4 alfalfa
8) Potatoes $\leq$ 4 wheat + 4 corn for grain
9) Wheat $\leq$ 4 barley
10) Wheat $\leq$ 5 alfalfa establishment

harvested a seed crop every third year of alfalfa growth, as this generally produced the best yields. The alternative according to Ogden (1979) and McAllister (1979) would be to have the farmer concentrate on seed production, something not generally done in the basin. The potato and grain constraints were established in order to minimize the problems of weeds and diseases (Richards 1979, Ogden 1979, Andersen 1979).

Corn is not grown in Garfield County because of short growing seasons. Corn was not generally considered as being a crop irrigated with sprinklers as stated by Finkel (1960):

> Those crops which grow fairly tall such as corn cannot be easily irrigated by sprinklers because the crop interferes with uniformity of distributions unless the sprinkler heads are mounted in very high standards. Portable pipe is also seriously hindered by tall plants. Furrow irrigation in general is the advantage for all plants (p. 93).

In all counties except Millard, sprinkler irrigation was accomplished by portable pipe or big wheel methods. However, in Millard, the center pivot is used and often mounted in high stands for potato irrigation. There, corn for grain irrigated by sprinkler was considered feasible.

Crop Water Requirements

The data for consumptive use of water by crops were obtained from USDA (1969 III), and verified for reasonableness using Irrigation Operator's Workshop (1966) and Criddle (1962). The crop irrigation water requirement per acre (CU_j) for the jth crop was defined as total consumptive use (TCU_j) of the jth crop per acre, less total precipitation (P) on irrigated lands, total direct use from groundwater (G), and total root zone capacity (RZ) per acre to hold winter moisture into the growing season from May 1 to October 30.

$$CU_J = TCuj - \left(\frac{P + G + RZ}{\text{Total Acres}}\right) \qquad J=1,\ldots,M \qquad \ldots\ldots\ (15)$$

Diversion Requirement

The diversion requirement was defined as the amount of water which has to be taken out of the system and diverted via the on-farm irrigation system to meet crop consumptive use need.

$$DR_h = \frac{1}{n_h^r} CU_j^r \qquad \begin{array}{l} h=1,\ldots,E \\ j=1,\ldots,M \\ r=1,\ldots,N \end{array} \qquad \ldots\ldots\ (16)$$

DR	on-farm diversion requirement for the hth on-farm system
n_h^r	the efficiency of the hth on-farm delivery system in rth county
CU_j^r	consumptive use requirement for the jth crop in the rth county

Conveyance and Delivery System Efficiencies

Total system efficiencies were taken from watershed values reported in USDA (1969 IV) and interpolated by county. Total miles and type of off-farm conveyances in pipe and lined ditch were given in USDA (1970). The mileage and condition of unlined canals by subbasin were available from USDA (1969a). Mizue (1968) estimated ranges of efficiencies for the various conveyances (Table 7). Inter-Agency Task Force (1979) gave similar efficiency ranges. For unlined ditches, the range used for this model was between 20 and 60 percent. It was assumed that an unlined

Table 7. Estimated range of losses and efficiencies of conveyance.

Conveyance	Loss, Percent of Diversion		Efficiency, Percent
	Seepage	Operational Waste	
Closed pipeline	0	0-5	95-100
Exposed hard surface ditch	5-15	3-8	77-92
Unlined ditch	15-45	5-15	40-80

Source: Mizue (1968).

canal in poor condition would be 20 percent efficient and a canal in good condition would be 60 percent efficient. The efficiency for a canal listed as in fair condition was taken as midway between the high and low.

The average efficiency of an unlined canal in each county was calculated as follows:

$$\Omega^r = \sum_{s=1}^{\gamma} \eta_s^r \theta_s^r \qquad r=1,\ldots,N \qquad \ldots\ldots\ (17)$$

where Ω^r is the weighted unlined canal efficiency for the rth county estimated as the sum of the efficiencies (η_s^r) of the Sth condition of unlined ditch times the percentages (θ_s^r) of that condition for the total unlined conveyance system in the rth county. Then, the total off-farm system (ditch and pipeline) efficiency for each county was similarly calculated.

On-farm unlined ditch efficiencies (γ) for the rth county were then calculated as:

$$\gamma^r = \frac{X^r C}{\varepsilon^r} \qquad r=1,\ldots,N \qquad \ldots\ldots\ (18)$$

where C is the consumptive use requirement and assumed to be 1. X^r was the total system efficiency for the rth county and ε^r was the off-farm efficiency for the rth county.

The attainable field application efficiencies for the four alternative irrigation systems for various physical land situations were estimated from the land class profiles. Acreages and percentage of land by each class were determined from the Conservation Needs Inventory for Utah (USDA 1970). An overall county wide on-farm efficiency was calculated (a weighted average based on land acreages) using the above acreages and efficiencies for each land class. A ratio of the tabulated on-farm efficiency developed from Strong (1962) and the calculated efficiencies from the Sevier Basin budgets (USDA 1969 IV) was used as an adjustment factor. Thereby, expected efficiencies (γ_s^r) for each on-farm system(s) were calculated. Then, the diversion requirement for each system was developed using Equation 15.

Water Diversions

Total surface water diversions could not exceed the stream flow entering a county from upstream counties plus the stream flow originating locally within the county. Locally originating water was assumed to consist of small streams, springs, and snowmelt runoff from basins totally within the boundaries of the county.

Total water originating within the county was calculated by summing the total diversions from all sources for each crop, land class, and on-farm irrigation system, adding the outflow from the county, and subtracting the return flows from the diverted irrigation water and the sum of the inflows into the county. On-farm water availability was made up of mined groundwater and the sum of the water diverted by the various off-farm conveyance systems (Equation 9). The water requirement for the jth crop on the ith class of land in the rth county utilizing the hth on-farm system was determined to be:

$$\sum_{h=1}^{t} k\left(\sum_{i=1}^{L} \sum_{j=1}^{M} CU_{ij}^r\right) \qquad r=1,\ldots,N$$

where $k = 1/\gamma_h$,

where γ_h is the efficiency of the hth on-farm delivery system.

The return flow constraint, made up of several sections, completed the model. Return flow was equal to the water available on the farm (WA^r) less that water which was consumed

$$\left(\sum_{i=1}^{L} \sum_{j=1}^{M} CU_{ij}^r\right)$$

and was lost to the system through deep percolation

$$\left(w \sum_{h=1}^{t} Wd_h^r\right)$$

plus the seepages which were not lost to the system from the off-farm conveyance systems

$$\left[\sum_{q=1}^{S} (1-\beta)(1-\tau)_q Wd_q^r\right]$$

(See page 20 for definition of symbols.)

Water losses that did not appear downstream as usable return flow were assumed to consist of deep percolation, evaporation, and consumptive use by phreatophytes. Total basinwide deep percolation was estimated as 5 percent of the water diverted in unlined conveyance systems plus 5 percent of the return flow from the field (Mizue 1968, Keith 1973), overall from 7 1/2 to 10 percent of the total water available. Evaporation was considered to be equal to 10 percent of the water diverted (Wd) (Snyder 1979). The phreatophyte consumption was estimated as 15 acre-feet/mile for poor-condition unlined canals, 10 acre-feet/mile for fair-condition canals and 5 acre-feet/mile for good-condition canals (Blaney 1961). Summing, the percentage of the basinwide water supply lost through off-farm conveyance losses was equal to:

$$\frac{D_p + E_v + P_c}{\tau_q Wd_q^r} = \beta_q^r \qquad \begin{array}{l} r=1,\ldots,N \\ q=1,\ldots,S \end{array} \qquad \ldots\ldots\ldots (19)$$

where D_p is deep percolation, E_v is evaporation, and P_c is phreatophyte consumptive use divided by total losses of the qth irrigation system.

Right Hand Side (RHS) Constant Values

Water Resources

Since data on the total diversions allowed in each county are not available in the State Engineer's Office (Ryan 1979), water budget data (USDA 1969 IV) were used to estimate the water rights and available surface allocations. Groundwater availability and rights were determined by interpolating the 5 year average withdrawal of water from wells reported in UWRL (1974). These availabilities were calculated for a 6 month growing season, May 1 through October 30. Groundwater is generally pumped only during the growing season (USDA 1969 IV).

Agricultural Resources

The amount of land available for agriculture in the 11 land classes and subclasses (Table 8) was obtained from USDA (1970) and USDA (1969 IV). Land was categorized as presently irrigated or potentially irrigated. Potentially irrigated land excluded forest acreages found in the 11 land classes. The definitions of the various land classes are in Table 9. Acres of present and potentially irrigated land are shown by county and land class in Table 8.

In an unconstrained model, three cash crops (potatoes, alfalfa seed, and wheat) would be the only crops produced. Other crops are introduced through rotational constraints. The dominance of these three crops is a result of two factors. First, the grain crops are less water intensive. Two irrigated acres of a grain crop (wheat) use about as much water as 1 acre of alfalfa and the net returns from 2 acres of grain equal or exceed the net return to alfalfa. Second, for potatoes and alfalfa for seed the net returns are generally greater than those of the other crops.

Such a cash crop domination, however, is not realistic for the basin as cropping patterns over the past century have been livestock oriented. There are 155,000 acres of alfalfa, 24,200 acres of irrigated wetlands, and 106,090 of wetlands supporting livestock, and these total over half of the 540,360 acres in the Sevier River water budget area (USDA 1969a). The cash crop farms were generally concentrated in the Millard County area. Agriculture in all other counties has been livestock oriented (Table 10).

To force the model into a better match with historical cropping patterns, acreage limitations were placed on potatoes, wheat, and alfalfa seed production. Potatoes were restricted to the highest acreage for the 24-year period from 1950 to 1974 or the maximum recommended acreages proposed by Davis (1974). Alfalfa seed in Millard County was restricted by rotational constraint in addition to an upper bound by the highest acreage reported in the Census of Agriculture (1954, 1964, 1969, 1974). Irrigated wheat was also limited to its maximum acreages reported by the Census for the same period. However, in addition to

Table 8. Land available for agriculture and irrigation by land class.

	Garfield		Piute		Sevier		Sanpete		Juab		Millard	
Land Class	Presently Irrigated (I)	Potentially Irrigated (P)	I	P	I	P	I	P	I	P	I	P
Total Acreage	32,272	18,863	23,905	4,448	65,303	28,696	72,930	24,706	28,306	35,214	136,600	59,524
IIw	-0-	-0-	837	210	916	1,449	-0-	-0-	1,814	-0-	26,432	26,920
IIs	567	-0-	572	-0-	3,163	2,131	-0-	-0-	102	-0-	36,153	2,061
IIc	178	-0-	4,641	-0-	15,542	2,834	2,559	1,456	5,419	1,205	29,677	885
IIe	4,005	-0-	1,861	-0-	16,390	5,587	37,456	3,433	2,992	573	6,919	1,073
IIIw	3,440	697	7,757	2,045	11,349	2,766	10,702	892	1,261	1,929	8,472	8,846
IIIs	4,579	-0-	1,774	769	2,462	1,924	1,485	-0-	8,285	3,634	3,965	4,470
IIIc	2,548	290	1,425	-0-	-0-	-0-	3,316	3,628	3,476	17,525	20,653	-0-
IIIe	13,733	-0-	3,095	633	6,950	1,831	11,463	3,525	4,070	1,784	2,842	-0-
IVw	2,683	2,117	-0-	-0-	-0-	-0-	381	-0-	-0-	-0-	-0-	-0-
IVs	539	8,282	1,590	791	521	188	3,754	4,558	463	8,664	732	6,528
IVe	-0-	7,377	353	-0-	7,510	7,259	1,521	7,214	424	-0-	695	8,741

Table 9. Land class descriptions, irrigated acreages, Utah.

Irrigated Land Class	Description
Class II	
Subclass:	
w Drainage:	Excessively to poorly drained. No standing water table within 40 inches of surface after drainage. Overflow or flooding: May occur 1 year in 10.
s Soil:	More than 30 inches deep, surface light, sandy loam to light silty clay. Up to 50 percent gravel. Moderately slow to rapid permeability. Crops affected some by salt or alkali.
c Climate:	Suitable for wide choice of field, small grain, and forage crops. Growing season--100 to 149 days.
e Slope:	6 percent or less for low erodible soils and 2 percent or less for highly erodible soils. Erosion hazard none to moderate.
Class III	
w Drainage:	Excessively to poorly drained. No standing water table within 30 inches of surface. Overflow or flooding: May occur 1 year in 5.
s Soil:	More than 20 inches deep, surface heavy, loamy sand to clays and may be peaty. May be gravelly or stony. Stones are 30 feet or more apart. Moderately low water-holding capacity. Permeability slow to rapid. Moderate amount of salt or alkali.
c Climate:	Limited to production of small grains and frost tolerant forage. Growing season--70 to 99 days.
e Slope:	10 percent or less for low erodible soils and 5 percent or less for highly erodible soils. Erosion hazard may be severe.
Class IV	
w Drainage:	Excessively to poorly drained. No standing water table within 40 inches of surface. Overflow or flooding: May occur 1 year in 5.
s Soil:	Shallow to 10 inches (20 inches if over saline shales). Surface sandy to heavy clay and may be peaty. May be gravelly, cobbly, or stony. Stones are 5 feet to 30 feet or more apart and are less than 3 percent of surface. Low water-holding capacity. Permeability slow to rapid. Crops affected some by salt or alkali.
e Slope:	25 percent or less for low erodible soils and 10 percent or less for highly erodible soils. Erosion hazard may be severe.

potential lands for development, dry land acreages were also considered for possible irrigation.

For the Northern Juab subbasin located in Utah County and for the Fillmore subbasin located in Beaver County, the diversions and outflows were fixed, as the stream flows and return flows do not enter into the Sevier River. They are included in the model in order to approximate the total counties agricultural output.

Table 10. Farm types within the Sevier Lake Basin excluding the Fillmore subbasin.

Type	Dairy	Range Beef	General Livestock	Cash Crop Feeder	Large Cash Crop	Small Cash Crop	Total
Number of farms	554	972	210	461	300	150	2,647
Percent total	20.9%	36.7%	7.9%	17.4%	11.3%	5.7%	100%
Total acreages	37,874	702,468	67,500	109,049	120,000	11,250	1,048,141
Percent of total acreages	3.6%	67.0%	6.4%	10.4%	11.4%	1.1%	100%
Income (000)	3,984	7,091	3,209	13,797	3,678	335	32,127
Percent of income	12.4%	22.0%	10.0%	42.9%	11.5%	1.0%	
Irrigated acres	26,326	129,992	32,025	79,862	59,100	5,550	332,855
Percent of total irrigated acres	10.9%	39.0%	9.6%	24.0%	17.8%	1.7%	31.8%
Percent irrigated within farm type	69.5%	18.6%	47.4%	73.2%	49.2%	49.3%	

CHAPTER V

RESULTS OF MODEL APPLICATIONS

Application Scenarios

A series of model applications were used to verify model cropping choices and associated stream flows against historical conditions and, once the model results were found reasonable, to estimate how crop choices would vary and the consequent flow changes one could expect with alternative future changes in water management policy or irrigation technology. The nine policy or technology items considered are shown as rows on Table 11. The ten scenarios used to examine the consequences of various combinations of these nine items are defined by the ten columns. In the table, a "Δ" is used to indicate a policy or technology item introduced or changed in advancing to a higher number scenario.

The first scenario represents the 1969 situation and thus provides a base condition against which all the other scenarios can be compared. At that time, the use of sprinklers and on-farm lined ditches was minimal. Accordingly, the efficiency coefficients used represent a technology of flood or furrow irrigation from unlined ditches (USDA 1969a, USDA-SCS 1970). The model optimization should approximate 1969 crop choices, and model flows should compare with those being measured at that time.

Scenario 2 allowed adoption of both new off-farm and new on-farm technologies. However, water diversions, irrigated acreages, and the Sevier Bridge Reservoir releases were fixed at 1969 levels as estimated with scenario 1. Scenario 2 thus measured the impact of modern irrigation technologies if cropping patterns remain unchanged.

Scenario 3 also allowed irrigators to take advantage of the new technology by shifting to cash crops that maximize basin output. Thereby, total gains that would occur with the adoption of new technologies and cash cropping pattern shifts were measured. The results may be considered the long-run condition in that they reflect the cropping shifts one would expect to occur over time as irrigation technology is upgraded.

The fourth scenario was the same as the third scenario except as it handled the release of water from Yuba Dam for use in Juab and Millard Counties. The release of water was made to depend on the inflow into the Sevier Bridge Reservoir (outflows from Sanpete County). Thus, if inflows decreased due to the adoption of new technologies upstream, releases would also be decreased. Previous scenarios fixed the releases at Yuba Dam at 1969 levels (USDA 1969 IV) under the assumption that this level was necessary to maintain downstream diversion. In 1969, the releases at the dam were approximately 1.15 times the inflows into the reservoir and adjoining wetlands. In this scenario, the releases were held to the above multiple of the inflows.

Scenario 5 looked at the impact of the off-farm water projects undertaken by the Board of Water Resources in Utah, between 1966 and 1979. The off-farm efficiencies in the model were increased to reflect the improvements implemented by the Board. These improvements included the lining of canals and installation of pipelines.

Scenarios 6 to 8 were used to determine the impact on the "long-run" solution (scenario 3) of relaxation of various institutional constraints (acreage and diversion limitations). Scenario 6 held water diversions to the 1969 level but allowed the irrigation of new potentially irrigable land to enter the solution. In scenario 7, in addition to relaxing the acreage limitations, the Yuba Dam releases were held to the 1.15 multiple of the inflows into Sevier Bridge Reservoir. Scenario 8 did not hold to the above reservoir operating ratio but rather dropped the water diversion requirements (water rights) and thus allowed both land and water to be developed in a manner that would maximize basin output and would approximate a "free" market solution.

The ninth scenario examined the effects of two programs to regulate modernization of irrigation technology. The first part attempted to estimate the impact of the federal cost sharing programs to encourage modernization by reducing the price of sprinklers to the irrigator by providing a 0 to 80 percent subsidy. Diversions were restricted to 1969 levels, but acreages were allowed to expand. The second part of the scenario dealt with the use of taxes to discourage modernization and reduce the adverse impacts of sprinkler adoptions. In this scenario the cost of sprinklers to the farmer was increased from equal to twice their market cost.

The last scenario was designed to determine the impact of maintaining various levels

Table 11. Alternative scenarios for application of the Sevier Lake Basin model.

	1969 Conditions	New Irrigation Technology	"Long-run" Solution	Long-run Solution, Sevier Bridge--Yuba Dam Water Control	1979 Off-farm Improvement Projects	"Open Land," Irrigation of New Lands Possible	Open Land with Sevier Bridge--Yuba Dam Water Control	Open Land and Water	Cost Sharing programs	Ecology-Outflow Analysis
Item / Scenario	1	2	3	4	5	6	7	8	9	10
Irrigation Technology										
a) Base (no sprinklers)	X									
b) New technology		Δ	X	X	X	X	X	X	X	X
Cropping Patterns										
a) Base	X	X								
b) Maximums			Δ	X	X	X	X	X	X	X
Water Diversions										
a) Fixed	X	X	X	X	X	X	X		X	X
b) Open								Δ		
Acreage for Irrigation										
a) Fixed	X	X	X	X	X					
b) Open						Δ	X	X	X	X
Sevier Bridge Reservoir										
a) Fixed flow releases	X	X	X		X	X		X	X	X
b) Fixed release ratio				Δ			Δ			
Off-Farm Improvement										
a) Base	X	X	X	X		X	X	X	X	X
b) 1976 status					Δ					
Basin Analysis										
a) Total basin	X	X	X	X	X	X	X	X		
b) Upper section									Δ	X
Out Flow Analysis										
a) Free	X	X	X	X	X	X	X	X	X	
b) Minimum levels										Δ
Cost Sharing Programs										
a) With program									Δ	
b) Without	X	X	X	X	X	X	X	X		X

X = Status
Δ = Major Parameter Changed

of flow in the streams to meet possible ecological and environmental goals, particularly in the upper basin (Garfield, Piute, Sevier, and Sanpete Counties). This scenario parametrically increased outflows (stream flows at the border of each county) as a means of maintaining stream flows, using the long-run open acreage solution as a base. Outflows were increased by 10 percent increments until a 50 percent increase was achieved.

Discussion of Results

The results of modeling the first scenario are shown in Table 12 and Figure 11. The irrigated acreages estimated by the model were somewhat smaller than actually existed within the basin. There are two reasons for this. One is that since the model includes additional water requirements for leaching purposes in Millard County, less water is available for irrigation in other areas, thus reducing the total irrigated land. Another reason is that the model assumed that the full water needs would be supplied to all irrigated crops and thus did not take into account partial irrigations through lesser water applications. The model estimate of beneficial consumptive use for the basin was somewhat larger than that reported due to model assignment of a larger percentage of land to alfalfa, which has a high consumptive use requirement (particularly if no allowance is made for partial irrigations). Even though consumptive use was higher, total diversions were the same. In the solution, outflow (flows from county to county) compared well to those reported in USDA (1969 IV). Table 13 shows the acreage distribution

Table 12. Comparison of scenario 1 (base) solution to 1969 actual conditions.

	Actual Conditions	Scenario 1 1969 Conditions
Profits		
Basin	NA[a]	$21,667,000
Garfield	NA	1,774,000
Piute	NA	1,732,000
Sevier	NA	5,206,000
Sanpete	NA	5,435,000
Juab	NA	1,422,000
Millard	NA	6,108,000
Irrigated Acreages		
Basin	335,794	294,709
Garfield	32,272	26,655
Piute	23,905	22,315
Sevier	65,303	61,401
Sanpete	72,903	64,832
Juab	28,306	27,780
Millard	113,105	91,726
Diversions (acre-feet)		
Surface water basin	697,268	697,268
Garfield	36,860	36,860
Piute	63,150	63,150
Sevier	194,030	194,030
Sanpete	225,890	225,890
Juab	30,350	30,350
Millard	146,988	146,988
Groundwater (acre-feet)		
Basin[c]	270,165	261,514
Garfield	5,527	5,527
Piute	11,580	2,929
Sevier	5,650	5,650
Sanpete	23,593	23,593
Juab	40,125	40,125
Millard	183,690	183,690
Consumptive use (acre-feet)		
Basin	360,394[b]	397,592
Garfield	17,350	16,613
Piute	31,685	29,644
Sevier	81,150	78,723
Sanpete	98,170	92,993
Juab	28,983	42,778
Millard	103,056	136,841
Return flows (acre-feet)		
Basin	NA	
Garfield	NA	17,186
Piute	NA	25,796
Sevier	NA	111,623
Sanpete	NA	120,557
Juab	NA	20,994
Millard	NA	---
Outflows (acre-feet)		
Garfield to Piute	78,380	78,712
Piute to Sevier	123,590	117,745
Sevier to Sanpete	123,890	133,785
Sanpete to Sevier Bridge	122,730	124,754
Sevier Bridge to Juab	135,798	135,798
Juab to Millard	134,680	142,764
Millard to Sevier Lake and wetlands	172,258	147,472

[a] Data not available—crops grown but not sold are not figured into basin total for reporting.

[b] Estimated.

[c] Source: UWRL (1974).

by crop and county for the 1969 solution. Rounding differences cause a small deviation from the Table 12 totals.

Most crops were grown in the basin. However, barley as a cash crop (not as an establishment crop) was grown in only Garfield and Millard Counties. Corn for grain did not appear in this solution. Irrigated pasture and meadows did not appear in any of the counties or scenarios throughout the study (perhaps because no provision was made for partial irrigation).

The results for scenarios 2 and 3, are shown in Tables 14 and 15. Scenario 2 permitted new irrigation technologies while holding cropping patterns at the 1969 levels. The adoption of sprinkler systems increased net output of the basin by $855,000 (off-farm technologies did not enter into the solution in any of the first eight scenarios). When cropping patterns were allowed to adjust to achieve maximum productivity (scenario 3), an additional net basinwide output of $1,180,000 resulted. Garfield County gained the most with a 24 percent increase in output from the base year solution. Sanpete and Millard Counties also gained significantly.

In scenario 2, the three irrigation technologies examined were flooding, lined, and unlined ditch with sprinklers; only sprinklers with lined and unlined ditches were adopted. Lined ditch for flood irrigation did not enter the solution in any of the first eight scenarios.

With the adoption of sprinkler irrigation in over 125,000 acres (of which 80,000 acres were above Sevier Bridge-Yuba Dam) return flow to Sevier Bridge-Yuba Dam complex decreased by over 40,000 acre-feet compared to the 1969 levels, with Sanpete County diversions not being met. One cause was that the adoption of on-farm technologies resulted in an increase of 24,000 irrigated acres over the 1969 solution (scenario 2). In scenario 3, the irrigators accommodated the technological shift by changing to less water intensive crops and adding 3,000 acres to the land being irrigated. Of the 32,205 acre-foot reduction from 1969 levels in surface and groundwater diversions (scenario 3) 86 percent (mostly in reduced groundwater pumping) was due to the more "efficient" system being adopted. The remaining 14 percent was a result of shifts to crops using less water.

Even though diversions decreased, the combined impacts of crop adjustments and technology adoptions caused total crop consumptive use of water to increase by almost 31,000 acre-feet. It was as a consequence of the increased acreages and aggregate consumptive use with adoption of the modern systems that surface diversion rights could no longer be met in Millard and Sanpete Counties.

Scenario 1, scenario 2, and scenario 3 outflow at Yuba Dam into Juab County was

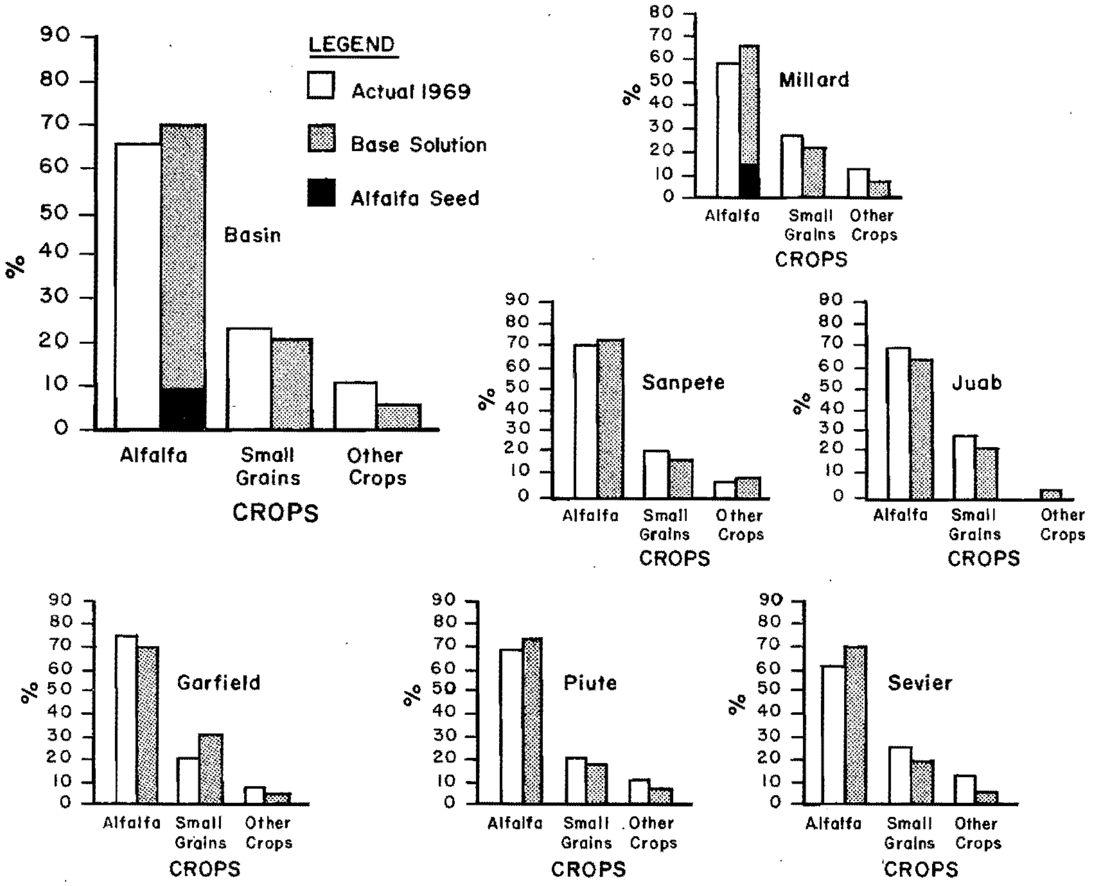

Figure 11. Crop distribution percentages, basic solution vs. actual.

Table 13. Base solutions acreages and crops.

Crop	County						
	Garfield	Piute	Sevier	Sanpete	Juab	Millard	Total
Alfalfa	18,571	16,629	44,411	47,124	18,393	47,437	192,565
Alfalfa seed	--	--	135	95	1,071	14,453	15,754
Alfalfa establishment crop	4,665	4,158	11,035	11,799	4,776	14,274	50,707
Barley	3,034	--	--	--	--	1,494	4,528
Wheat	306	91	1,453	--	2,348	5,975	10,171
Corn silage	--	1,259	4,304	5,705	1,213	7,736	20,218
Corn grain	--	--	--	--	--	--	--
Potatoes	100	176	63	108	10	358	815
County Totals	26,676	22,313	61,401	64,831	27,811	91,727	294,758

Table 14. Model solutions by scenario.

Item \ Scenario	Actual 1969	1969 Conditions	New Irrigation Technology	"Long-run" Solution	Long-run Solution, Sevier Bridge-Yuba Dam Water Control	1979 Off-farm Improvement Projects	"Open Land," Irrigation of New Lands Possible	Open Land with Sevier Bridge--Yuba Dam Water Control	Open Land and Water
		1	2	3	4	5	6	7	8
Profits (thousands)	NA	21,667	22,522	23,702	22,596	24,451	26,761	24,639	27,387
Acreages									
Available for Irrigation	335,794	294,710	318,709	321,734	305,635	310,862	277,659	275,805	281,001
Potentially Irrigable	186,724	--	--	--	--	--	93,114	55,305	104,133
Total Acreage	522,518	294,710	318,709	321,734	305,635	310,862	370,773	331,110	385,134
Technological Adoption (acres)									
Lined Ditch	--	--	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Sprinkler with Unlined Ditch	--	--	91,668	94,614	92,468	91,076	98,265	102,932	79,836
Sprinkler with Lined Ditch	--	--	34,030	33,684	17,956	35,883	58,990	35,883	62,445
Diversions (acre feet)									
Surface Flows	697,268	697,268	694,905	690,709	628,252	669,500	687,633	668,723	705,951
Groundwater	270,165	261,514	236,238	235,868	264,061	220,071	243,394	269,865	246,272
Consumptive Use (acre feet)	360,394	397,592	428,706	428,310	404,719	435,875	473,048	423,718	483,048
Outflows (acre feet)									
Sevier Bridge-Yuba Dam	122,730	124,754	82,640	82,274	110,485	61,265	47,139	126,894	36,725
Wetland and Sevier Lake	172,258	147,472	167,967	176,722	142,606	125,193	166,412	134,468	157,381

fixed at the 1969 levels. Scenario 4 was constructed so that the release of water for irrigation in Juab and Millard Counties would be determined by the outflow in Sanpete County (a part of the inflow to the Sevier Bridge Reservoir).

When the water released at Yuba Dam was tied to the inflows (outflow was restricted to be equal to inflow), net basin output fell by over $1,106,000. Except for Garfield and Juab Counties, all output in the basin declined. Millard's output dropped by $848,000. This can be in part explained by the high diversion requirement and costs for leaching. The results are shown in Figure 12.

The management of releases at Yuba Dam would cause a net decrease of about 16,000 irrigated acres. In addition, the basin would require numerous cropping pattern adjustments as well as shifts in the use of sprinkler-irrigation system between counties. Total irrigated acreages (all methods) dropped by 17,600 acres in Millard County but increased in Piute County. Unlined sprinkler acreages declined in all counties except Sanpete. Millard and Piute Counties had the highest sprinkler acreage losses with about 6,000 and 4,000 acres respectively. The total basin area irrigated with sprinklers from unlined ditches declined by 2,100 acres (2.3 percent). Sprinkler systems using lined ditches within the basin declined by over 15,700 acres (47 percent) with the major impact in Sanpete County (14,000 acres). Over 11,300 acres of alfalfa previously irrigated with sprinklers from lined ditches would instead be irrigated with sprinklers from unlined ditches. The output of corn for grain grown in Millard County would be reduced by over 3,500 acres.

Furthermore, when the variable release management for Yuba Dam was used, Juab and Millard Counties received less water for diversions than the 1969 level of 134,630 acre-feet. As a consequence 91.3 percent (21,536 acre-feet) of the decline in consumptive use within the basin would occur in Millard County. Over 10,000 less acres were in sprinklers with lined ditches and about 2,000 less acres were with unlined ditches.

In scenario 5, the impact of the program to upgrade off-farm water conveyance facilities administered by the Board of Water Resources in Utah between 1966 and 1979 was

Table 15. Scenario solutions by county.

Item / Scenario's	Actual 1969	1969 Conditions	New Irrigation Technology	"Long-run" Solution	Long-run Solution, Sevier Bridge--Yuba Dam Water Control	1979 Off-farm Improvement Projects	"Open Land," Irrigation of New Lands Possible	Open Land with Sevier Bridge--Yuba Dam Water Control	Open Land and Water
		1	2	3	4	5	6	7	8
Garfield Profits (000)		1,774	1,858	2,208	2,208	2,167	2,262	2,244	2,811
Acreages	32,272	26,655	27,731	29,325	29,325	29,185	31,793	29,799	42,752
Potential	18,863								
Sprinkler with unlined ditch		--	2,178	4,075	4,075	9,736	17,733	4,635	4,635
Diversions--surface flow	36,860	36,860	36,860	36,860	36,860	36,860	36,860	36,860	62,196
groundwater	5,527	5,527	5,527	5,527	5,527	5,527	5,527	5,527	5,527
Consumptive Use	17,350	16,613	19,010	19,513	19,513	19,421	20,926	19,535	28,624
Piute Profits (000)		1,732	1,755	1,908	1,886	1,912	2,017	1,963	1,933
Acreage Irrigated	23,905	22,315	22,781	22,406	23,905	22,406	26,060	26,362	24,544
Potential	4,448								
Sprinkler with unlined ditch	--	--	5,047	5,047	696	5,047	5,680	547	486
Diversions--surface	63,150	63,150	63,150	63,150	63,150	63,150	63,150	63,150	56,983
groundwater	11,580	2,929	1,636	1,176	6,429	860	8,702	11,580	11,580
Consumptive Use	31,685	29,644	29,973	29,667	31,506	29,667	34,570	34,767	32,237
Sevier Profits (000)	--	5,206	5,339	5,339	5,334	5,420	6,047	5,944	6,259
Acreage	65,303	61,401	64,765	64,782	64,782	64,782	69,729	74,782	73,716
Potential	20,382								
Sprinkler with unlined ditch	--	--	27,758	27,758	25,883	18,079	37,117	34,702	37,117
Diversions--surface	194,030	194,030	194,030	194,030	194,030	194,030	194,030	194,030	205,325
groundwater	5,650	5,650	5,650	5,650	5,650	4,202	5,650	5,650	5,650
Consumptive Use	81,150	78,723	84,164	84,164	83,243	84,164	86,205	85,788	90,664
Sanpete Profits (000)	--	5,435	5,874	5,999	5,769	5,966	7,018	6,488	6,968
Acreage	72,930	64,832	72,930	72,930	72,930	72,930	97,635	84,101	97,635
Potential	24,706								
Sprinkler with unlined ditch	--	--	26,636	26,562	40,728	23,805	10,903	35,037	10,903
Sprinkler with lined ditch	--	--	14,092	14,116	0	16,923	43,979	11,915	47,434
Diversions--surface	225,890	225,890	220,791	220,057	224,130	223,848	218,880	223,196	206,752
groundwater	23,593	23,593	-0-	-0-	-0-	22,940	-0-	-0-	-0-
Consumptive Use	98,170	92,993	104,098	103,927	103,927	103,927	137,905	100,955	138,041
Juab Profits (000)	--	1,422	1,459	1,459	1,459	1,565	1,802	1,663	1,802
Acreages	28,306	27,780	28,213	28,213	28,213	24,830	33,955	31,330	24,830
Potential	35,314								
Sprinkler with unlined ditch	--	--	3,131	3,131	3,131	15,449	11,683	9,630	11,683

Table 15. Continued.

Item \ Scenario's	Actual 1969	1969 Conditions 1	New Irrigation Technology 2	"Long-run" Solution 3	Long-run Solution, Sevier Bridge--Yuba Dam Water Control 4	1979 Off-farm Improvement Projects 5	"Open Land," Irrigation of New Lands Possible 6	Open Land with Sevier Bridge--Yuba Dam Water Control 7	Open Land and Water 8
Juab (Continued)									
Diversions--surface	30,350	30,350	30,350	30,350	30,350	30,350	28,678	24,171	28,678
groundwater	40,125	40,125	40,125	40,125	40,125	27,084	40,125	40,125	40,125
Consumptive Use	28,983	42,778	43,539	43,539	43,539	38,067	43,990	41,770	43,990
Millard Profits (000)	--	6,108	5,237	6,788	5,940	7,469	7,614	6,336	7,638
Acreages	113,105	91,726	102,779	104,076	86,480	96,729	112,532	90,425	112,806
Potential	83,029								
Sprinkler with unlined ditch	--	--	26,918	26,497	17,955	18,960	15,012	18,381	15,012
Sprinkler with lined ditch	--	--	19,938	19,518	17,956	18,960	10,012	18,381	15,012
Diversions--surface	146,988	146,988	146,988	146,262	79,723	146,262	146,066	70,486	146,066
groundwater	183,690	183,690							
Consumptive Use	103,056	136,841	147,923	147,500	125,963	160,638	149,316	127,316	149,316

explored. Table 16 shows the amounts of off-farm improvements installed during the period. This scenario used fixed acreages and water diversions, maximum crop adjustments, and modern technology. In addition, it was assumed that the cost of these improvements was not placed on the irrigator. If the irrigator were required to pay for off-farm improvements, a separate analysis with the model showed that no off-farm improvements entered into any of the solutions. However, in reality the farmers have absorbed most of the costs of canal improvements. This could be explained by considering only private benefits and costs to the locations where improvements were made and not considering the opportunity cost of water use downstream.

With the installation of the various projects, basin agricultural output increased by three quarters of a million dollars annually (as compared to scenario 3). The largest gain would be in Millard County ($600,000) while Sevier and Juab Counties would also gain ($80,000 and $106,000 respectively). Sanpete and Garfield lost about $60,000 each while Piute County showed no change. Consumptive use of surface water increased by about 7,500 acre-feet while about a 5 percent reduction occurred in groundwater use. This reduction could be attributed to the estimated $1.27 per acre inch pumping cost for groundwater. A further outcome of the installation of the off-farm improvement was the decline of outflows into Sevier Bridge Reservoir and Sevier Lake drainages and wetlands by about 21,000 and 51,000 acre-feet respectively, making it more difficult to maintain the Yuba Dam release at 1969 levels.

Table 16. Irrigation projects installed.

County	Ditch Lining and Pipeline (Miles) 1966-1979
Piute	4.3
Sanpete	75.6
Garfield	8.3
Juab	6.9
Millard	23.6
Sevier	39.2
TOTAL	157.9

Source: Division of Water Resources, State of Utah, 1979.

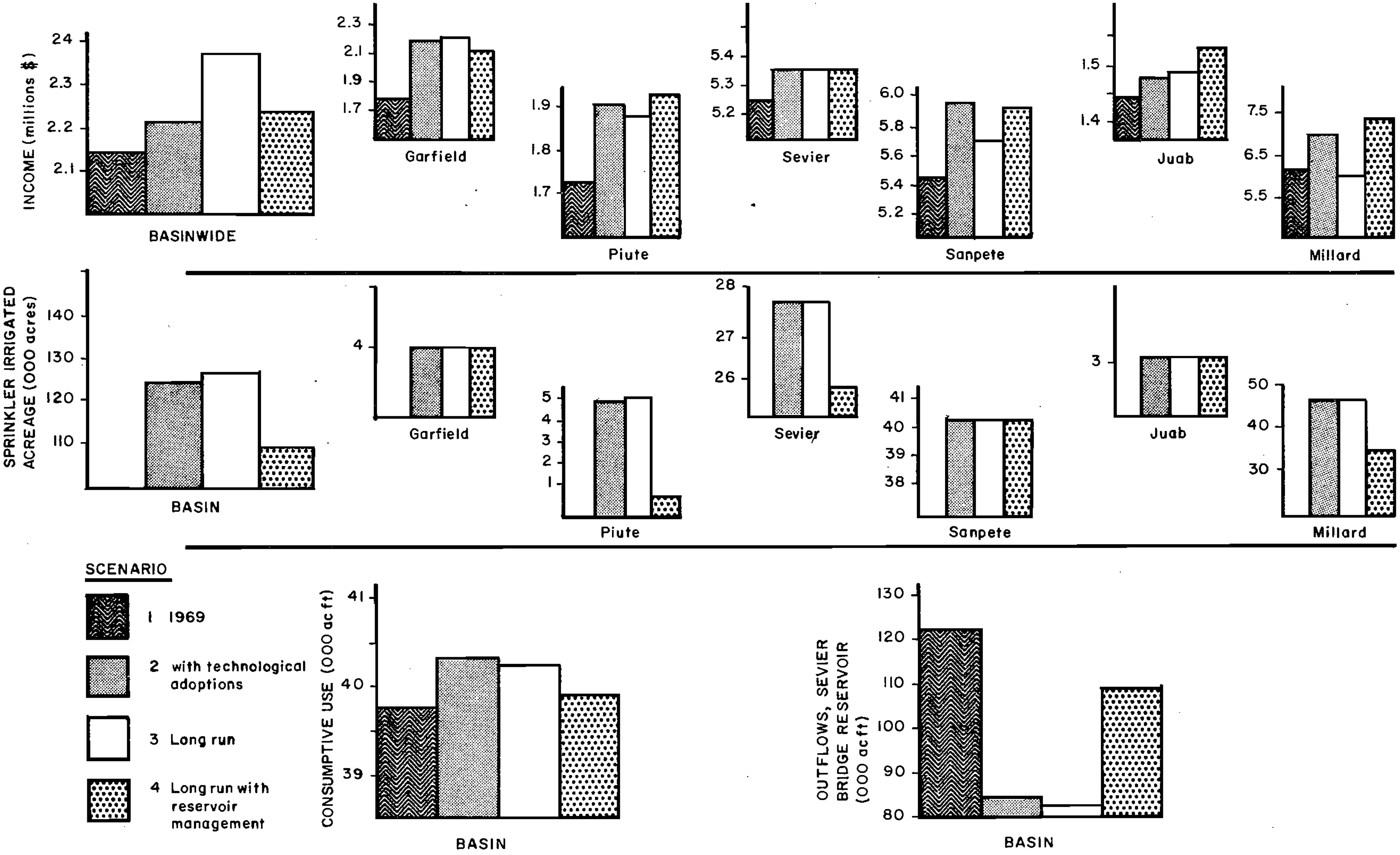

Figure 12. Long run solutions.

The improved off-farm conveyance systems have very little impact on overall adoptions of on-farm systems but a large impact on the geographical distribution of adoptions. In the basinwide total, the use of sprinklers declined by about 1340 acres (about 1 percent) but about 2200 sprinkler irrigated acres shifted from unlined to lined ditches.

Although the total impact was small, considerable changes occurred in the lower basin (Juab and Millard Counties). Juab would adopt over 12,000 additional acres in sprinklers while reducing its groundwater diversions by over 14,000 acre-feet and consumptive use by 5,500 acre-feet. In Millard, the major impact was a 7 percent reduction in acreage and a reduction in sprinkler alone and sprinkler with lined ditch improvements on about 8,000 acres. The reduction in sprinkler acreages occurred due to a shift out of corn for silage (14,000 acres to less than 1,000 acres). There was also an increase in wheat-barley production from straight sprinkler to sprinkler-lined ditch irrigation of about 6,000 acres.

The next three scenarios were used to determine the impact of relaxing various institutional constraints (acreage and diversion limitations). Table 8 shows how much land is presently irrigated and potentially suitable for irrigation. Presently irrigated lands are defined as lands that are being irrigated at least once over a 7-year period. This category includes irrigated cropland, fallow land, idle land, and land in conservation.

Even without allowing irrigation outside these presently irrigated areas, average annual irrigated acreages within the basin increased from 294,710 acres to 321,734 acres with the introduction of modern technology. This increase would be brought about by the use of water "saved" for more regular irrigation of the fallow and idle lands counted in the lands considered irrigated (USDA-SCS 1970).

The model application in scenarios 6 and 7 opened all land in the basin to development, while holding the diversion rights constant. It was assumed that the irrigation of lands not counted as presently irrigated would not require any major conveyance system development. Development costs did include drainage of wetlands (subclass w), land clearing, and the cost of purchasing and installing irrigation systems. The results of this analysis are shown in Table 14 and Figure 13.

With the development of higher yielding lands, basin output increased from $23,702,000 (scenario 3) to $26,761,000 (scenario 6). However, the increase was only to $24,639,000 (scenario 7) if the inflows and releases at Yuba Dam were taken into account.

In scenario 6, all counties would gain. Sanpete's gain would be about $1,000,000 with Millard and Sevier gaining about $800,000 and $700,000 respectively. However, if the releases of water at Yuba Dam were to be regulated based on inflows at the Sevier Bridge Reservoir, Millard County would bear the brunt of an output decline losing $1,200,000. This is because water released at Yuba Dam is not sufficient to meet Millard County's diversions requirements without further reductions in Sanpete and Sevier County diversions.

Sanpete would be required to forego an output of $500,000 in order to increase outflows to the reservoir. Although in scenario 7 all counties would forego output, the other upstream counties would suffer less reduction.

In both scenarios, the irrigated acreages increased. Total irrigated acreages increased by about 59,000 acres, a net gain from developing 93,000 acres of potentially irrigable land and retiring 34,000 acres of presently irrigated land. When Yuba Dam management was considered, only 55,000 acres of potentially irrigated land would be developed, with the majority of the 38,000-acre reduction from the scenario 6 solution being in Millard and Sanpete Counties. The newly developed lands were generally of classes IIw, IIIw, IIe, IIIe, while reductions occurred in presently irrigated land in classes IVe, IIIc, IIIs, and IIc and classes IVw and IVs in scenario 7.

In scenario 6, only slight increases in groundwater use and decreases in diversion occurred when acreage limitations were dropped. However, consumptive use increased by 44,000 acre-feet. These increases in acreages and consumptive use resulted in full diversions (implied water rights) not being met in Sanpete, Juab, and Millard Counties. Furthermore, the inflow to Sevier Bridge Reservoir would be 38 percent of the 1969 levels. The outflow to wetland and Sevier Lake would be 32 percent below the 1969 level.

Numerous adjustments were necessary when the Sevier Bridge-Yuba Dam was taken into account. Over 18,000 less acres would be in sprinklers. All counties but Sanpete and Garfield (13,000 acres) would reduce acreages. While Sanpete County would have 31,000 less acres in sprinklers from lined ditches, it would have an additional 25,000 acres in unlined sprinkler systems. Even though no groundwater diversions were used in Sanpete, surface diversions were not met in Sanpete, Juab, and Millard Counties. In this solution, inflow into Sevier Bridge Reservoir increased to 126,894 acre-feet or 80 percent of the 1969 level.

Analysis of scenario 8, the market solution permitting both land use and water

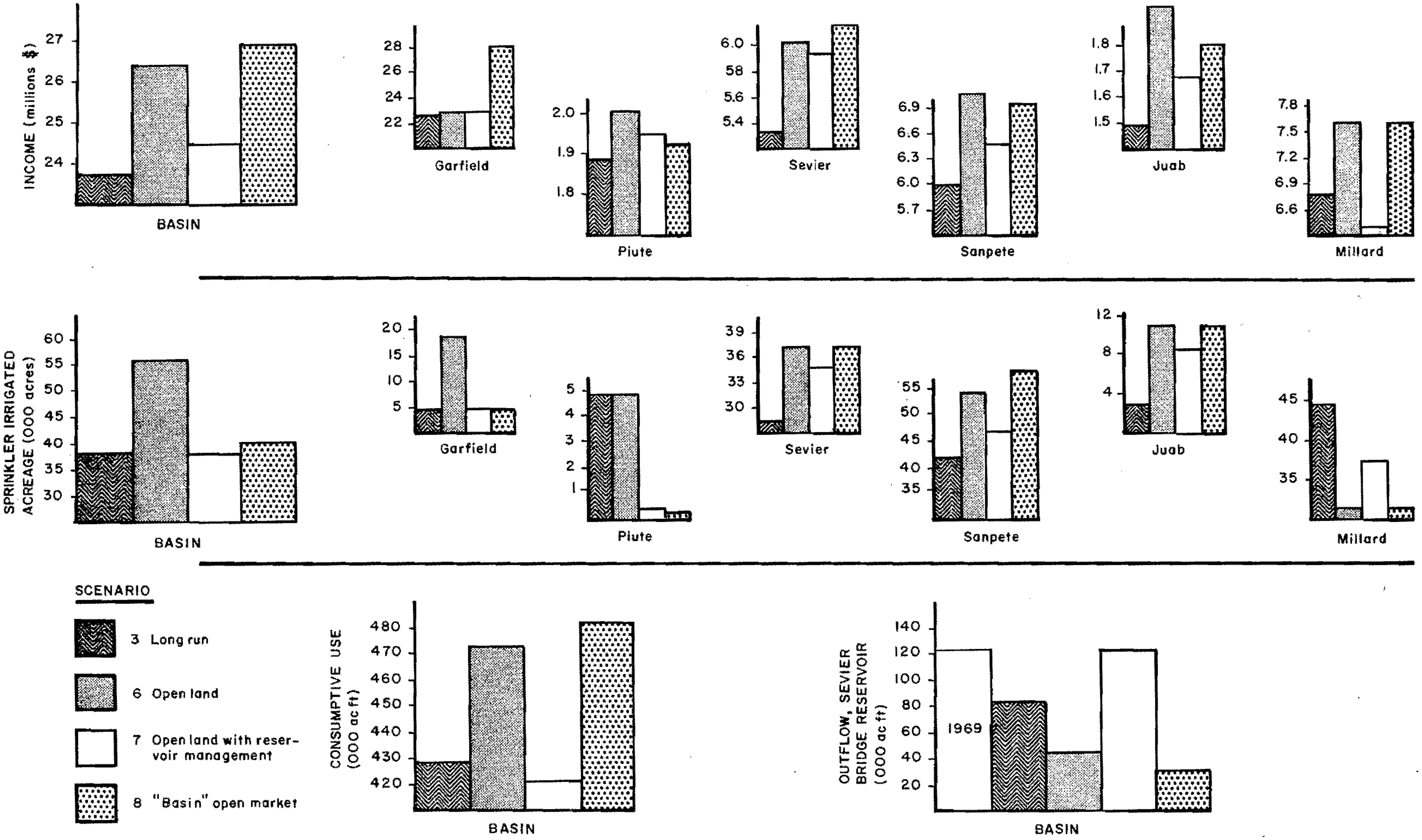

Figure 13. Management options.

rights shifts produced the greatest net value of agricultural output, $27,387,000 from 385,134 irrigated acres. Total diversions amounted to 952,223 acre-feet and consumptive use of 483,048 acre-feet. One result was the lowest inflow level to Sevier Bridge-Yuba Dam of 36,726 acre-feet which is only 29.4 percent of 1969 levels. A maximum of 80,000 acres with unlined canals and sprinklers and 62,500 acres of lined canals and sprinklers were adopted. All the additional acres irrigating with sprinklers from lined canals were in Sanpete County on class IIe and IIIe land.

The flexibility of permitting both land and water use shifts produced the largest percentage output gain in Garfield and Juab, 27 percent and 24 percent respectively ($600,000 and $350,000). The largest total dollar gains occurred in Sevier, Sanpete, and Millard Counties with about $900,000 in additional outputs produced (17, 16, and 12 percent gains). The solution for Piute County was basically unchanged from the long-run solution.

Cost Sharing and Tax Policy

In 1978-79, federal (SCS) cost sharing programs would pay a percentage of the capital costs of installing various on-farm irrigation improvements, principally the installation of sprinklers and lined ditches. The first part of scenario 9 examined the impact of these federal cost sharing programs. To do this, the price of sprinklers was varied parametrically from a zero to an 80 percent subsidy at 20 percent increments. Since the use of on-farm improvements in the lower basin depends on the Yuba Dam management policy and on the outflows from upstream users, only the upper basin was analyzed. Diversions were restricted but the acreages were not.

The impact of the government's subsidy policy is shown in Tables 17 and 18. The general results of the federal subsidy policy would be to cause an increase in basin output (private gains shown on Table 18) but with an associated social welfare loss (federal cost exceeding private gain) for all subsidy levels.

The largest social loss, $100,000 annually, occurred with the 80 percent subsidy. This was a $60,000 increase in the social losses over a 60 percent policy. The 80 percent subsidy would cost the government over 3.5 million dollars or $389,000 on an annual basis. The model indicates that

Table 17. Impact of federal cost sharing programs on the Upper Sevier River Basin (area south of the Sevier Bridge-Yuba Dam complex).

	Subsidy				
	Long Run	20% Subsidy	40% Subsidy	60% Subsidy	80% Subsidy
Net Upper Basin Profits	17,344,000	17,331,000	17,330,000	17,304,000	17,244,000
Garfield	2,262,347	2,257,763	2,257,763	2,257,196	2,229,532
Piute	2,016,846	2,016,846	2,016,894	2,016,894	2,016,894
Sevier	6,047,356	6,047,356	6,046,601	6,040,638	6,040,638
Sanpete	7,017,967	7,009,535	7,009,084	6,988,878	6,957,342
Annual Subsidy (1000 dollars)	0	152	184	302	389
Total Subsidy Paid (1000 dollars)	0	1,388	1,680	2,757	3,551
Acreage Irrigated					
Garfield	29,185	29,185	29,185	29,185	29,185
Piute	22,406	22,406	22,406	22,406	22,406
Sevier	55,033	55,033	55,033	55,033	55,033
Sanpete	72,930	72,930	72,930	72,930	72,930
Sprinkler Acreages with					
Unlined Ditch					
Garfield	17,733	24,730	24,730	24,877	30,166
Piute	5,680	6,033	6,033	6,033	6,033
Sevier	37,117	37,117	37,630	39,498	39,498
Sanpete	10,904	20,500	20,462	27,601	33,993
Lined Ditch					
Sanpete	43,979	42,848	42,885	41,628	40,498
Total Both	115,413	131,258	131,740	139,637	150,182
Consumptive Use	279,741	280,926	281,039	281,399	281,901
Garfield	20,926	21,679	21,679	21,679	22,181
Piute	34,569	34,570	34,570	34,570	34,570
Sevier	86,205	86,205	86,318	86,678	86,678
Sanpete	138,041	138,472	138,472	138,472	138,472
Outflow to Sevier Bridge	47,139	45,955	45,860	45,549	45,130

Table 18. Social costs and gains from subsidy policy.

Subsidy			
Rate of Tax or Subsidy	Fiscal (cost) or Revenue	Private Gain or Loss	Social (cost)
80% (Basin)	(389)	289	100,000
Garfield	(139.1)	106.3	(32,815)
Piute	(3.9)	3.9	48
Sevier	(26.6)	19.9	(6,718)
Sanpete	(219.4)	158.8	(60,625)
60% (Basin)	(302)	262	40,000
Garfield	(89.1)	84.0	(5,151)
Piute	(4.4)	4.4	48
Sevier	(29.7)	23.0	(6,718)
Sanpete	(778.8)	149.7	(29,089)
40% (Basin)	(184)	170	14,000
Garfield	(78.8)	74.3	(4,584)
Piute	(4.0)	4.0	48
Sevier	(5.8)	5.0	(755)
Sanpete	(95.4)	86.5	(8,883)
20% (Basin)	(152)	139	13,000
Garfield	(67.3)	62.7	(4,584)
Piute	(3.4)	3.4	48
Sevier	(0)	0	0
Sanpete	(81.3)	7.29	(8,432)

without any subsidy the irrigators would install over 115,000 acres in sprinklers. The full 80-percent subsidy would result in a total of 150,000 acres being irrigated by sprinklers (83.3 percent of the total irrigated acreage), an increase of 35,000 acres.

In addition, the third party flow impacts would be severe as the additional acreage decrease the inflows into the Sevier Bridge-Yuba Dam Reservoir to 37 percent of the 1969 inflow. Therefore, with federal subsidies the management of the lower basins releases and water rights will become critical as releases of water at the dam may not be maintainable. Third party impacts associated with water quality changes were not studied.

In terms of the net social losses, Garfield and Sanpete were the counties impacted the most. With an 80 percent subsidy, $93,000 of the $100,000 social loss occurred in these two counties. The only county to gain was Piute. A 20 percent subsidy increased irrigated acreages by 353 acres and increased output (with subsidy) by $48. Sevier County was only moderately impacted. The impact in Garfield County occurred because of its location at the headwaters where what happens has a significant impact on the downstream counties. In Sanpete County, the high social loss occurred in attempting to maintain high yield as inflows decreased and as upstream county adoptions increased. The adoptions enabled Sanpete County to reduce outflows into the Sevier Bridge Reservoir-Yuba Dam complex in order to maintain output.

With reduced inflow to the Sevier Bridge Reservoir as modern irrigation techniques are being adopted, some water rights problems will result. One policy option for alleviating the problem would be to place a tax on sprinklers, thereby increasing the costs to the irrigator. Scenario 9b examined this possibility by varying parametrically the tax on sprinklers from 0 to 100 percent of their capital cost in 20 percent increments. Tables 19 and 20 show the impact of taxes on sprinkler adoptions, agricultural output, and outflows from the basin. Figure 14 shows how upper basin profits vary with rates of tax or subsidy.

Net basin output declined with higher tax just as it did with higher subsidy. The following impacts were observed: 1) a shift from sprinklers with lined ditch to an unlined ditch sprinkler system in Sanpete County (systems with unlined ditches dropped from the solution); 2) in Garfield County and with high tax rates in Sanpete County lined ditch was adopted for flood irrigation; and 3) the switching of large acreages of low consumptive cash-crops to smaller acreages of a more water intensive crop, alfalfa. The third shift was to be expected as the net return for water intensive crops is higher when flood irrigation is used. At the higher tax rates, the consumptive use declined and outflows increased more rapidly.

The impact of taxes varied in each county. Sevier County had the largest social losses of about $183,000 with a 100 percent tax rate. At this rate, Sevier would lose about 32,000 acres from sprinkler systems. Sanpete would retire the lowest percentage of acres and would pay 85 percent of the total tax revenue at a 100 percent tax rate. This low impact can be attributed to the high productivity of the land available under sprinklers in this county.

The major impact in Garfield occurs at a 20 percent tax rate with a 72 percent reduction in sprinkler irrigated acreages. The primary result is to reduce consumptive use and increase outflows; thereby, increasing water available downstream particularly in Sanpete where more productive land is located.

Outflows to the Sevier Bridge-Yuba Dam complex increased by 33.8 percent to 63,081 acre-feet. This was approximately 51 percent of the 1969 levels. The bottom row on Table 19 indicates that a large tax may be necessary to increase outflows. Some other policy measure may be more appropriate if it is desired to increase flow into the Sevier Bridge Reservoir to the 1969 levels.

Ecological Considerations

Scenario 10 was designed to determine the impact of maintaining minimum stream

Table 19. Impact of a tax on sprinklers for the Upper Sevier River Basin.

	Tax					
	Open Land	20%	40%	60%	80%	100%
Upper Basin Profits (000)	17,344	17,332	17,313	17,279	17,177	17,094
Garfield	2,262,347	2,249,698	2,248,897	2,248,897	2,234,762	2,231,150
Piute	2,016,846	2,009,431	2,004,208	2,004,208	2,004,208	2,003,721
Sevier	6,047,356	6,047,356	6,029,347	6,016,478	5,920,397	5,864,529
Sanpete	7,017,967	7,025,462	7,029,939	7,009,137	7,017,389	6,994,620
Annual Tax Revenues (000)		151	244	328	496	588
Total Tax Revenues (000)		1,378	2,227	2,994	4,528	5,368
Acreages						
Garfield	29,185	29,185	29,130	29,130	28,990	29,954
Piute	22,406	22,406	22,406	22,406	22,406	22,315
Sevier	55,033	55,033	52,260	52,014	50,400	50,480
Sanpete	72,930	72,930	72,930	72,930	72,930	72,930
Acreage Lined Ditch						
Garfield		2,798	2,798	2,798	2,798	3,209
Sanpete						3,316
Sprinkler Acreages						
Unlined						
Garfield	17,733	4,955	4,635	4,635	1,975	1,426
Piute	5,680	1,952	486	486	486	395
Sevier	37,117	37,117	30,657	27,423	13,460	5,446
Sanpete	10,904	8,423	8,423	8,423	8,423	8,423
Sanpete Lined	43,979	43,629	43,323	37,456	36,026	33,126
Total Both	115,413	96,076	87,524	78,772	60,370	48,816
Consumptive Use	279,741	278,083	277,408	269,909	266,132	264,031
Garfield	20,926	19,593	19,555	19,555	19,457	19,432
Piute	34,569	34,389	34,318	34,318	34,318	34,197
Sevier	86,205	86,205	85,654	85,324	82,365	80,538
Sanpete	138,041	137,896	137,881	130,712	129,992	129,844
Outflow Sevier-Bridge	47,139	49,467	50,391	57,839	61,145	63,081

flows for environmental reasons. In many of the previous solutions, Sanpete County's total stream flows were totally diverted to crop use when new irrigation systems were adopted. The diversion of all (environmental and recreational) waters from the stream would eliminate most instream flow values of that water and also ground cover along the stream bank, thus affecting the ecosystem.

In this scenario, outflows were parametrically increased from those associated with scenario 8 as a means of maintaining stream flows at various levels. Outflows were increased in 10 percent increments until a 50 percent increase was achieved. For example, outflow from Garfield was 74,000 acre-feet in scenario 8. The first run in scenario 10 increased this outflow by 10 percent or 7,400 acre-feet to 81,400 acre-feet. Outflows were constrained to progressively larger 10-percent increments to the 111,000 acre-foot maximum. This procedure was followed for outflow from four counties.

The results as summarized in Table 21 and Figure 15 show that marginal losses to agricultural productivity increase as instream flow requirements are increased. A 10 percent increase reduced basin output by $210,000. The increase from 40 percent to 50 percent of base level outflow over the long run would cause a $704,000 incremental decrease in basin outputs and a total decrease of $2,279,000.

Piute and Garfield Counties would suffer the greatest losses. Sanpete County's output remained roughly constant. The key to instream flow maintenance appears to be in the headwater counties (Garfield and Piute). Increased headwater flows resulted in downstream outflow volume requirements being met.

The lower flow requirements were essentially met by holding total acreage constant by reducing the amount of sprinkler irrigated acreages. The 10 percent increase in outflow had the largest incremental impact on technologies with approximately a 22,000-acre reduction in sprinkler systems. The breakdown of the 22,000-acre reduction entailed a 13,000-acre reduction in Garfield County, a 5,000-acre reduction in Piute County and a

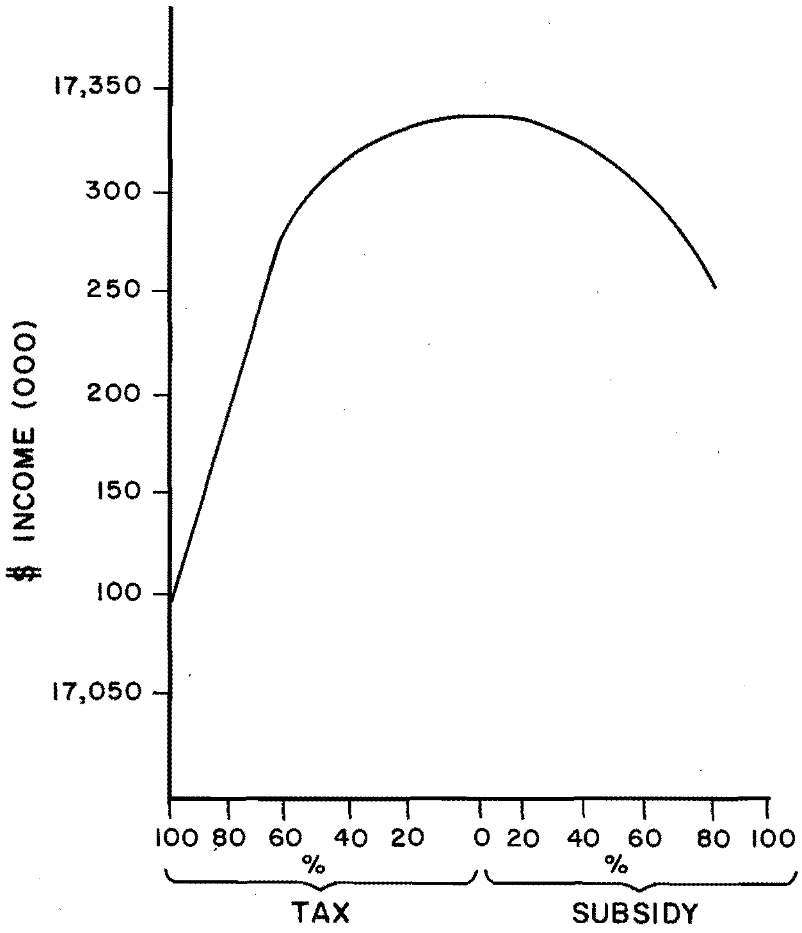

Figure 14. Impacts of tax and subsidy policies on sprinkler adoptions.

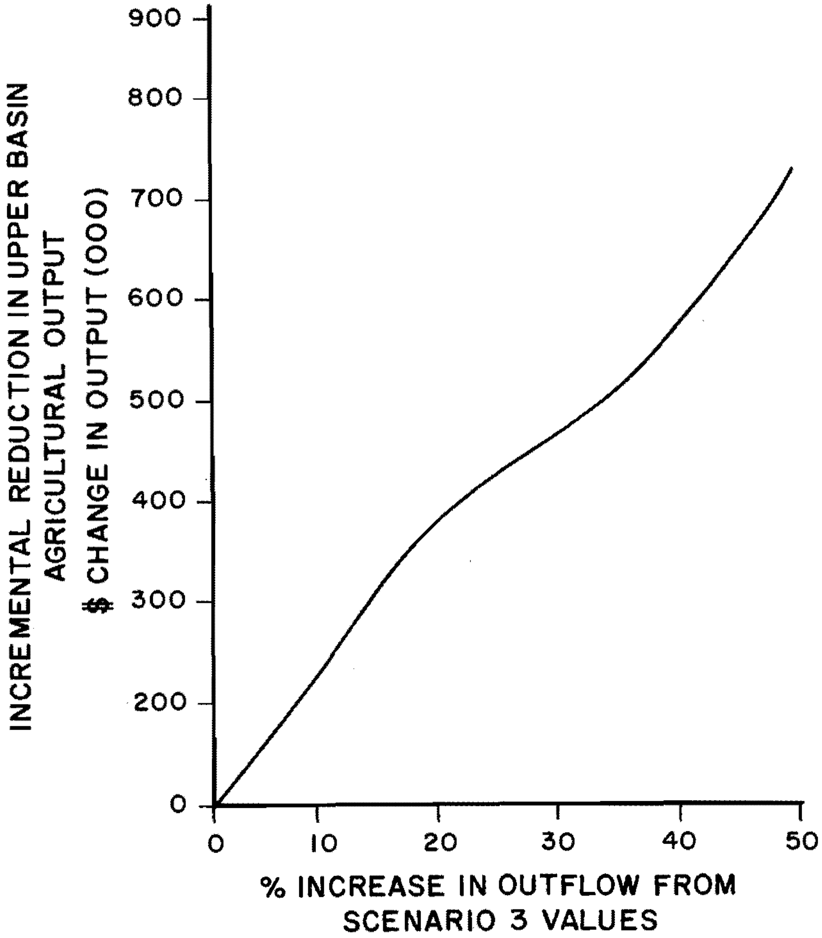

Figure 15. Streamflow impact curve.

Table 20. Social costs and gains from a tax policy.

	Tax		
Rate of Tax	Fiscal (cost) or Revenue	Private Loss	Social (cost)
100% (Basin)	588	(838)	(250)
Garfield	17.1	(48.3)	(31,197)
Piute	4.8	(17.9)	(13,125)
Sevier	65.6	(248.4)	(182,827)
Sanpete	500.5	(523.8)	(23,347)
80% (Basin)	496	(663)	(167)
Garfield	16.2	(43.8)	(27,585)
Piute	4.0	(16.6)	(12,638)
Sevier	110.6	(237.5)	(126,959)
Sanpete	365.2	(365.7)	(578)
60% (Basin)	328	(393)	(65)
Garfield	19.3	(32.7)	(13,450)
Piute	2.0	(14.6)	(12,638)
Sevier	114.1	(145.0)	(30,878)
Sanpete	192.0	(199.8)	(8,830)
40% (Basin)	244	(275)	(31)
Garfield	12.9	(26.4)	(13,450)
Piute	1.3	(13.9)	(12,638)
Sevier	85.5	(103.5)	(18,009)
Sanpete	144.3	(132.3)	11,972
20% (Basin)	151	(163)	(12)
Garfield	7.8	(20.4)	(12,649)
Piute	3.0	(10.4)	(7,415)
Sevier	58.0	(58.0)	0
Sanpete	81.7	(74.2)	7,495

4,000-acre reduction in Sevier County. A 5,500-acre shift from lined to unlined ditches was necessary in Sanpete County.

As the outflow requirement increased, the water was released by retiring less productive land, mostly in Piute County. Only for the 40 percent and 50 percent flow increases did acreages drop in Garfield County. The increased stream flows were generally brought about with about a 4,000-acre reduction in area irrigated from unlined ditches in Sevier County.

After the initial 10 percent increase in outflow, the model was able to increase Garfield and, in part, other county outflows by converting all of the off-farm conveyance systems to pipe in Garfield. One of the benefits of requiring higher stream flows was that inflows into the Sevier Bridge Reservoir increased by 24, 21, 17, 15, 13 percent respectively with the final outflows approximately equal to those of 1969 as shown in Table 22.

Generalizations on the Adoptions of Modern Irrigation Systems

Sprinklers

Table 22 shows that sprinklers most often proved profitable for irrigating class IIe land where optimal adoption rates ranged between 80 percent and 89 percent. Class IIe land is characterized by medium soil textures (85 percent) with slopes of 1.5 to 2.9 percent (66 percent) and 3.0 to 5.9 percent (27 percent). Class IIs, also, had a high rate of adoption, and this land was generally in small grains when irrigated with sprinklers. If it was irrigated with the border-furrow option, the main crop was alfalfa. The high adoption rate under scenario 3 of class IVs relates to the small amount of acreage cultivated in that class of land. Land classes IIIc, IVs, and IVe entered into the solutions only for growing either small grains or alfalfa seed.

The least likely land classes to be sprinkler irrigated were class IIc and the wetlands; IIw, IIIw, IVw. The exception was that in the scenario 3 solution Millard County went to 13,000 acres of IIw land irrigated with sprinkler-lined ditch systems for corn for grain.

Lined Ditches

With sprinklers. Sprinklers using lined ditches entered into the solution in only two counties, Sanpete and Millard. Any time corn for grain was grown in Millard as a cash crop, usually on class IIw and IIc land, this combination was used. Alfalfa grown on class IIe and IIIe land utilized this combination in Sanpete County, while wheat and barley were irrigated this way in Millard County on class IIe land.

With flooding. In most instances, lined ditches for flood-border irrigation were not adopted by the model. The only exception was when a tax was applied on sprinklers. In Garfield County, this method was adopted for 2,800 acres of alfalfa on class IIIw land when a 20 percent tax was applied, and the amount reached a maximum of up to 3,200 acres with the 100 percent tax. In Sanpete County, a 100 percent tax resulted in 3,200 acres of class IIIc land being irrigated this way for alfalfa growth. Maximum lined ditch acreage was less than 2 percent of the total lands irrigated.

Crops and Sprinklers

Table 23 shows the extent of adoption of sprinkler based systems by crop. In general, the systems for irrigating cash crops (potatoes, alfalfa seed, and wheat) were the first to be converted to sprinklers. The first adoptions in all counties occurred with potatoes. In all counties except Millard, alfalfa seed was the second crop to be converted. Alfalfa irrigated by sprinkler was primarily grown on class IIe and IIIe land, and occasionally on IVe and IIIs land. In Garfield County, class IIIw land was used. For most scenarios in Millard County, alfalfa for seed was predominantly irrigated by an unlined flooding system. As diversion and/or acreage constraints were relaxed, the amount of seed acreages under irrigated

Table 21. The impact of increased outflows to meet minimum stream flows for ecological purposes--upper basin.

	Open Land and Water	10% Increase in Flow	20% Increase in Flow	30% Increase in Flow	40% Increase in Flow	50% Increase in Flow
Total Profits Upper Basin (000)	17,367	17,157	16,785	16,343	15,792	15,088
Incremental Change in Upper Basin Output		-210	-372	-442	-551	-704
Incremental Change in Output						
Garfield	2,262	-22	-61	-63	-139	-532
Piute	2,009	-170	-292	-350	-348	-143
Sevier	6,047	-17	-20	-28	-28	-28
Sanpete	7,047	-1	--	--	--	--
Acreage Irrigated						
Garfield	31,793	30,071	32,572	33,807	29,745	26,502
Piute	26,060	24,632	23,116	20,513	13,277	6,673
Sevier	69,731	69,731	69,025	68,497	67,869	67,443
Sanpete	97,635	98,342	98,342	98,342	98,342	98,342
Upper Basin Totals	225,219	222,776	223,053	221,159	209,233	198,960
Sprinkler Acreages						
Garfield	17,733	4,635	4,635	4,635	4,635	4,635
Piute	5,680	486	486	1,333	1,333	1,333
Sevier	37,117	33,178	30,076	26,012	21,957	17,903
Sanpete	10,904	10,904	10,904	10,904	10,904	10,904
Upper Basin Totals	71,433	49,203	46,092	42,884	38,829	34,775
Land in Lined Ditch and Sprinkler--Sanpete	47,434	41,968	41,968	41,968	41,968	41,968
Inflow Sevier Bridge-Yuba Dam	82,274	58,413	70,668	82,923	95,178	107,432
Outflow						
Garfield	74,400	81,840	89,280	96,720	104,160	111,600
Piute	113,990	125,389	136,788	148,187	159,586	170,985
Sevier	122,548	134,803	147,057	159,312	171,567	183,822
Sanpete	107,432	118,175	128,918	139,661	150,404	161,148

Table 22. Percentage by land classification of area irrigated from sprinkler systems.

Scenario	Land Class										
	IIw	IIs	IIc	IIe	IIIw	IIIs	IIIc	IIIe	IVw	IVs	IVe
3-"Long-run" Solution	44.9%[a]	58.0%	0.0%	80.0%	8%	4%	0.0%	21.0%	0%	86.0%	1.0%
6-"Open Land," Irrigation of New Lands Possible	17.0%	79.8%	7.6%	88.2%	16%	21%	17.6%	47.4%	0%	41.9%	20.0%
8-Open Land and Water	17.0%	79.8%	7.6%	88.8%	14%	19%	38.9%	48.5%	0%	41.9%	16.9%

[a] Primarily corn for grain grown in Millard County.

Table 23. Percentages by crops of area irrigated from sprinkler systems.

Scenario	Alfalfa	Alfalfa Seed	Potatoes	Small Grains[a]	Corn for Grain	Corn for Silage
3-"Long-run" Solution	33.7%	31.7%	100%	100%	100%	NA
6-"Open Land," Irrigation of New Lands Possible	38.0%	27.6%	100%	100%	100%	NA
8-Open Land and Water	30.9%	27.6%	100%	96%	100%	NA

[a] Excludes barley grown as an establishment crop.

NA - not irrigated by modern systems.

sprinkler continued to decrease within Millard County.

Overall, cash crop and cash-feeder farms would always be sprinkler irrigated except in Millard County where alfalfa seed is grown extensively as a cash crop irrigated by unlined flood irrigation methods. As previously indicated, alfalfa grown on class IIe and IIIe land makes up the majority of sprinkler irrigated alfalfa.

Counties and Sprinklers

Throughout the analysis, Garfield was the only county to adopt any form of off-farm conveyance (pipe in scenario 10). It was one of the few counties (Millard being the other) to grow barley as a nonestablishment crop (scenario 1). The development of potentially irrigable land was small in Garfield, but occurred on class IIIw and IVe land and was done only with sprinkler irrigated cash crops.

Piute was the county least favorable for the adoption of sprinklers. A maximum of 6,000 acres were being irrigated by sprinkler in Piute County. Potential land development occurred in the class III lands both by sprinkler and conventional methods.

Cash crop production was very sensitive to taxes on sprinklers in Sevier County. However, the use of subsidy had very little impact within this county. The amount of acres of sprinklers adopted was highly variable depending on the assumption underlying the various scenarios.

The Sanpete County irrigation system was least sensitive of all the counties to differences among the scenarios. The only changes that normally occurred were in canal lining to serve the sprinkler system and these came with the relaxation of diversion and acreage limitations. In addition, extensive potential land development occurred in both Sevier and Sanpete Counties when acreage limitations were released. This is primarily due to the large amounts of better class lands not presently irrigated. Generally all of class II, and IIIw and IIIe lands are considered better class land.

The total irrigated acreage in Juab County is little affected by the scenarios, primarily because there is no direct access to the Sevier River from most of the agricultural lands. The major impact in this county is in drastic shifts of cropping patterns. For example, as the scenarios go from 1 to 6, irrigated wheat goes from highly productive land classes IIe and IIIe to poor quality land classes IVe, IVs, and IIIs.

Millard County has the largest amounts of irrigated and potentially irrigable land in the basin. However, because of its leaching requirements, higher irrigation costs, and cash crop orientation, it often reacted differently to the scenarios than did the other counties. For example, in all other counties, alfalfa seed, wheat, and barley were irrigated by sprinklers. But these crops were not generally irrigated by sprinklers in Millard County.

CHAPTER VI

SUMMARY

Results of the Study

The development of newer and more "efficient" irrigation systems give the irrigator an economic incentive to expand his acreages and consumptive use of water. In an attempt to improve downstream water quality by encouraging farmers to convert to irrigation methods that wash less salts into the stream, federal and state agencies have encouraged the accelerated adoption of these new technologies through subsidies and technical assistance. Initially, these programs have increased farmers' incomes and basinwide outputs. However, the adoption of these systems have also changed the consumptive use patterns and the amounts of water going to the downstream water right holders. These changes alter the economic incentives affecting irrigation technology choices for downstream lands and hence total economic output from the basin.

To study the impact on the total system of these technological adoptions, an empirical linear programming model was designed for the Sevier River Basin. In the model, irrigation choices depend on soil types, slopes, crops, and crop yields. Irrigation technologies considered were sprinklers, lined ditches, and pipelines; institutional constriants were acreage limitations and diversion requirements. The model was used to evaluate the impact of adoption of these irrigation technologies on the value of the crops produced and on outflows and diversions which may conflict with established water rights.

The empirical model examined six counties in terms of 11 SCS land classifications, 8 crops, and 4 irrigation systems. Surface and groundwater diversion requirements and irrigated acreage limitations were established for each county. Crop consumptive use requirements by county, for the growing season from May to October, were determined.

Findings

1. Increased adoption of modern technologies will occur under the present institutional water and acreage constraints because of increased benefits to the farmer. Adoptions are accelerated by assistance from governmental agencies. Given the present irrigated area and water use, the adoption of sprinkler systems would increase output by over two million dollars; $850,000 as a direct result of adopting sprinkler systems and the remainder as a result from shifts in cropping patterns. Over 94,500 acres would be irrigated with a combined unlined ditch-sprinkler system. In addition, sprinklers would be used with lined ditches on over 33,500 acres. The largest areas of adoption occur in Sanpete, Sevier, and Millard Counties.

2. Increased adoption of modern irrigation systems would also cause stream flows to decline within the basin. In fact, flows would be so low that diversion requirements in Sanpete and often Sevier and Millard Counties would not be met on the annual basis. Furthermore, inflows into Sevier Bridge-Yuba Dam at the border dividing Sanpete and Juab Counties declined to the point where water released would not meet diversion requirements for Juab and Millard Counties. When water releases at Yuba Dam were based on the inflows to the reservoir, the value of basin output declined over a million dollars. The largest decline occurred in Millard County due to a water requirement for leaching; and, in addition, diversions (water rights) could not be met in Juab and Millard Counties.

3. When institutional restrictions were relaxed (new lands permitted to come under irrigation and water rights permitted to shift location), the "basinwide" solution produced the highest output, over $27,350,000 or over 5.5 million dollars more than the farm income from irrigation with the 1969 system. The largest output gains occurred in Sevier, Sanpete, and Millard Counties. However, this analysis contained no reservoir-management policy. As such, the inflows into the Sevier Bridge Reservoir-Yuba Dam Complex were at their lowest point of 36,726 acre-feet or 86,000 acre-feet below the average inflow associated with 1969 irrigation technology of 122,730 acre-feet.

4. Since 1969, the Utah Department of Water Resources has sponsored programs which have installed 158 miles of canal linings and pipelines to convey irrigation water to basin farmers. These installations are estimated by the model to increase average annual farm output by $750,000 and decrease the more expensive pumping of groundwater by reducing conveyance losses. However, the analysis indicates a major negative impact of these state sponsored programs in the decline of flows at the Sevier Bridge Reservoir by over 20,000 acre-feet.

5. Government subsidy programs to assist the irrigator in installing new

on-farm technology have had similar results to the state programs for improving off-farm conveyance facilities. Output, consumptive use, and sprinkler acreages all increased, but inflow into the reservoir decreased. There is some indication that at the onset of the development of sprinkler systems the farmers have delayed adoptions (despite being profitable) in order to have the government pick up the cost through the subsidy program. The 1974 Census of Agriculture showed the adopted acreages to be below what the economic incentives as modeled would indicate.

Alternative explanations include conservatism in the face of uncertainties and financing difficulties. An 80 percent subsidy is estimated to increase sprinkler acreages above the long-run solution by as much as 30,000 acres. Furthermore, flows into the reservoir would decline, indicating that the federal subsidy program would aggravate downstream third party effects.

6. One method of discouraging adaptations of new irrigation technology that would decrease flows into Sevier Bridge Reservoir would be to place a tax on sprinklers. Analysis, however, showed that a tax as high as an annualized 100 percent of capital cost would increase flows into the reservoir by only 33 percent, an amount far less than the decrease to be expected if land and water use in the basin are allocated to maximize farm output. This level of taxation would cause a major decline in farm output.

7. With the expected reduction in flows to result from adoption of sprinkler systems, ecological factors such as the maintenance of wildlife habitat become important. One method of preventing ecological damage would be to maintain stream flows to meet diversion requirements by regulations holding outflows to a minimum level. If, for example, the level fell below a minimum rate, diversions to all areas above the point could be curtailed. Regulations to maintain 1969 flow levels would reduce agricultural output from the upper basin (Garfield, Piute, Sevier, and Sanpete Counties) by over two million dollars annually. It is important to recognize that holding subbasin outflows to 1969 levels will not preserve cropping or technological patterns. Instead, the result would be cropping pattern changes retiring poorer quality land and increasing productivity on better quality land resulting in a redistribution of incomes.

8. Modern sprinkler irrigation systems were adopted more extensively on class IIe, IIs, IIIe, IIIs, and IIIc lands. These land classes are generally the mid to high yield lands that are moderately sloping and have minimal soil problems, i.e., sandy soil or shallow soils. The sprinkler systems were least likely to be adopted on IIw, IIIw, IVw class lands where drainage and salinity are problems and on class IVs and IVe lands where soil and slopes are a major factor. Sprinklers with lined ditches were adopted extensively in Millard and Sanpete Counties where diversion rights were often not met but productivity was high. On-farm lined ditches for flood irrigation and improvement of off-farm conveyance systems generally were not found to be economically justified.

9. Alfalfa seed and potatoes were found to be the most favorable cash-crops for sprinklers. Alfalfa irrigated by sprinklers was usually limited to class IIe and IIw acreages although other classes did appear in the solutions. In general, all cash crops would be sprinkler irrigated.

10. Estimated impacts of new irrigation technology by county were:

Garfield County: The rate of adoption and the effects of various water management policies on adoption within this county were highly variable. Garfield was the first county to respond to policy changes with technological adjustments because it is located at the headwater and whatever happens in Garfield County is felt throughout the basin.

Piute County: This county was the least sensitive and changeable of all, primarily due to lower acreages of land productive enough to justify sprinkler irrigation. Only 6,000 acres were converted to sprinklers.

Sevier County: The amount of sprinkler-irrigated acreage within Sevier County varied among the different water policy and technology scenarios, the primary reason being the relative large acreages of class II and class III quality lands and little cash crop acreages. Thus, when conditions changed, it was sprinkler acreages that were adjusted.

Sanpete County: Sanpete was found to be the most favorable county for adopting sprinklers in the different land classes, and this result was not sensitive to policy changes. The predominant change that did occur was the shifting of sprinkler acreages between water supplied from lined and unlined ditches.

Juab County: In this county without direct access of the irrigated land to the Sevier River, the primary impacts of new irrigation technology were cropping pattern shifts.

Millard County: Irrigated crop acreages fluctuated more than in any other county due to variations in the availability of water and the higher water costs associated with leaching requirements. The larger cash crop acreages within the county allowed more switching between water intensive crops and water extensive crops. In addition, the large acreages in sprinklers led to more switching among land classes, technologies, and crops.

12. The cash crops (potatoes, alfalfa seed, wheat, and barley) were the most likely

to be irrigated with sprinklers. Sprinkler irrigated alfalfa was normally done on class II and IIIe land. Corn for grain was irrigated in conjunction with potatoes on high center pivot systems in Millard County. Irrigated pasture land was not economically feasible in any scenario.

13. With the exception of the response to regulated outflows from Garfield County, off-farm conveyance system improvements were not found by the model to be economically justified. Pipelines became feasible when minimum outflows were increased by 20 percent or more in the last scenario.

Recommendations for Further Study

1. The model did not take into account the timing of water availability and irrigation needs during the growing season. Further research is recommended to determine the availability of water at critical times and to develop a model using this information in system optimization. For example, water is critical in the latter stages of potato growth. The impact of sprinkler irrigation on lag times for return flows must also be considered. The economic model needs to be made interactive with a hydrologic model replicating flow routing.

2. The adoptions of various technologies were selected by the model on the basis of economic "efficiency" with respect to water use. However, sprinkler technologies also impact the amounts of dissolved solids in the soils and streams. Thus, water quality may be an additional benefit of new irrigation technology. Further research is needed to expand combined economic-hydrologic modeling to cover hydrosalinity considerations as well.

3. The model assumed that irrigation required that the full water requirements for each crop be met. The model did not evaluate the option of partial water supplies nor determine the optimal partial level of irrigation given a price for water.

4. The model optimization was based on water availability during an average year. Water availability in fact varies considerably from wet to dry years, and known water availability information influences spring planting decisions. These variations and the uncertainties associated with water availability need to be evaluated.

5. The model used a homogeneous land classification for each farm. Additional study is needed to examine the desirability of adoption of various types of irrigation systems on farms of mixed land classes.

6. The land classification mapping needs to be refined as does the descriptive information on soil characteristics. The model identified considerable acreages of land that are not being irrigated but which if irrigated would be more productive than much of the currently irrigated land. The situation should be examined to verify that these lands are indeed as productive as the information used in this model would indicate.

7. The model assumed that new water deliveries to potentially irrigable lands would not require any major new off-farm systems. The modeling does not include an estimate of off-farm systems development costs, and further study would be required to estimate these costs and determine their effect on the economic justification of irrigating additional lands.

8. The modeling was essentially based on average or general data, therefore, more specific information on yields by land class, subclass, soil type, and land slope would refine the resulting estimates.

9. This study does not differentiate between the cash-crop farmer and the livestock oriented farmer. Further studies should take into account start-up costs, salvage costs, and conversion costs between the two types of farms. The results would indicate the optimum mix of farms and the desirability of specializing in a given area on one type of farm or another, e.g., more cash-crop and less livestock or vice versa.

General Conclusions

The empirical linear programming model developed to represent the agricultural economy of the Sevier River Basin was able to provide reasonable replication of cropping patterns, water use, and instream flows in the basin. This success generates some confidence in the model's ability to estimate the effects of adaptations of new irrigation technology and various basin water management policies on the cropping decisions made by basin farmers. The estimates made by the model provide a valuable tool for equitable water rights administration, but the results would be much improved if refined to incorporate hydrologic routing, hydrosalinity effects, optimal irrigation levels, and year-to-year variation in water availability.

Management policies that provide greater flexibility for land and water use can increase the basin's overall output. Table 24 reviews the results of three such policy options when compared to the situation in 1969 before the adoption of the new technologies.

Comparison of the four scenarios in Table 24 shows that optimal adoption of new on-farm irrigation technology in the Sevier River Basin can through revised cropping patterns on presently irrigated land increase agricultural output by over $3,000,000. By providing or encouraging inter-county transfers of water rights, the selective adoption of sprinklers and irrigation of some new higher productive lands, the gain in output would be realized.

Table 24. Summary data on results with selected scenarios.

	Output (1000s)				Sprinkler Acreages			
	1969 Conditions	Long-run Solution	Long-run Solution, Sevier Bridge-Yuba Dam Water Control	Open Land With Sevier Bridge-Yuba Dam Water Control	1969 Conditions	Long-run Solution	Long-run Solution, Sevier Bridge-Yuba Dam Water Control	Open Land With Sevier Bridge-Yuba Dam Water Control
Scenarios:	1	3	4	7	1	3	4	7
Basin	21,667	23,702	22,596	24,631	-0-	144,113	133,634	159,043
Garfield	1,774	2,208	2,208	2,244	-0-	4,075	4,075	4,635
Piute	1,732	1,908	1,886	1,963	-0-	5,047	696	547
Sevier	5,206	5,339	5,334	5,944	-0-	27,758	25,883	34,702
Sanpete	5,435	5,999	5,769	6,488	-0-	40,728	40,728	46,952
Juab	1,422	1,459	1,459	1,663	-0-	3,131	3,131	9,630
Millard	6,103	6,788	5,940	6,336	-0-	46,015	35,912	36,762

	Actual	Changes in Consumption			Diversion Requirements			
	1969 Conditions	Long-run Solution	Long-run Solution, Sevier Bridge-Yuba Dam Water Control	Open Land With Sevier Bridge-Yuba Dam Water Control	1969 Conditions	Long-run Solution	Long-run Solution, Sevier Bridge-Yuba Dam Water Control	Open Land With Sevier Bridge-Yuba Dam Water Control
Scenarios:	1	3	4	7	1	3	4	7
Basin	397,592	30,718	7,127	26,126				
Garfield	16,613	2,900	2,900	2,922	Y	Y	Y	Y
Piute	29,644	23	1,862	5,623	Y	Y	Y	Y
Sevier	78,723	5,441	4,250	7,065	Y	Y	Y	Y
Sanpete	92,993	10,934	10,934	7,962	Y	N	N	N
Juab	42,778	761	761	(1,008)	Y	Y	Y	N
Millard	136,841	10,659	10,878	9,525	Y	N	N	N

	Outflows Sevier Bridge and Sevier Lake			
	1969 Conditions	Long-run Solution	Long-run Solution, Sevier Bridge-Yuba Dam Water Control	Open Land With Sevier Bridge-Yuba Dam Water Control
Scenarios:	1	3	4	7
Basin				
Sanpete	124,754	82,274	110,485	126,894
Millard	171,272	176,722	142,606	134,468

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