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ECONOMIC IMPACTS OF WATER CONSERVATION MEASURES IN AGRICULTURE AND ENERGY WITHIN THE UPPER COLORADO RIVER BASIN

by

Douglas R. Franklin

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Economics

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1982

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Douglas R. Franklin

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
LIST OF FIGURES	v
LIST OF TABLES	vi
ABSTRACT	ix
Chapter	
I. INTRODUCTION	1
Statement of the Problem	2
Study Area	5
Objectives of the Study	7
Methodology	11
Potential Water Conservation Practices	12
II. REVIEW OF LITERATURE	17
Conservation in Agriculture	18
Conservation in Energy	21
Phreatophyte Control	21
Evaporation Suppression	22
III. ECONOMIC ANALYSIS	24
Model Formulation	26
Scenarios	33
Scenario I	33
Scenario II	33
Scenario III	34
Scenario IV	35
Scenario V	35
IV. DATA ACCUMULATION AND DEVELOPMENT	36
Water Resources	36
Water availability	36
Water quality	36
Current and future water uses	39
Agricultural Activities	39
Objective function coefficients	39
Land	39
Irrigation and agricultural water consumptive use coefficients	46

TABLE OF CONTENTS (continued)

Chapter Page

Energy Activities 46

Objective function coefficients 46
The energy conversion process efficiency 48
The energy water consumptive use coefficients . . . 48
Energy production capacities and resource availabilities 48

Non-Agricultural and Non-Energy Activities 56

Objective function coefficients 56
The water consumptive use coefficients 56

V. MODEL RESULTS 59

Case 1, 14.9 MAF Annual Flow 59

1974 model results 59
1985 model results 62
2000 model results 71

Case 2, 13.8 MAF Annual Flow 76
Case 3, Summer Flow 81

VI DISCUSSION 87

Public Policy Analysis 87
Trade-Off Analysis 92
Concluding Remarks 97

BIBLIOGRAPHY 100

VITA 110

LIST OF FIGURES

Figure Page

1. Upper Colorado River Basin 6

2. Public sector's decision framework 10

LIST OF TABLES

Table		Page
1.	MAJOR CHARACTERISTICS OF THE UPPER COLORADO RIVER BASIN	8
2.	UPPER BASIN STATES WATER SHARES UNDER ALTERNATIVE SUPPLY AND INSTITUTIONAL ASSUMPTIONS	37
3.	NET WATER AVAILABLE FOR IRRIGATION AND ENERGY USES IN EACH SUBBASIN UNDER ALTERNATIVE WATER SUPPLY ASSUMPTIONS	38
4.	AUTHORIZED AND PLANNED SALINITY CONTROL PROJECTS AND THEIR ESTIMATED EFFECTS	40
5.	NET WATER AVAILABLE FOR ENERGY AND AGRICULTURE UNDER ALTERNATIVE SUPPLY AND INSTITUTIONAL ASSUMPTIONS	41
6.	ESTIMATE OF ANNUAL CROP YIELDS PER SPRINKLER IRRIGATED ACRE	42
7.	NET ANNUAL RETURNS OF SPRINKLER IRRIGATED CROPS PER ACRE	43
8.	TOTAL ACREAGES OF IRRIGATED LAND FOR SELECTED FIELD CROPS	44
9.	PROJECTED NEW IRRIGATED ACRES IN 1985 AND 2000 BY SUBBASIN	45
10.	ANNUAL CONSUMPTIVE USE DURING AN AVERAGE GROWING SEASON FOR SPRINKLER IRRIGATION	47
11.	AVERAGE PRICE, COST AND NET RETURN OF ELECTRICITY FOR ALTERNATIVE COOLING TECHNOLOGIES BY SUBBASIN FOR COAL FIRED POWER GENERATION	49
12.	AVERAGE PRICE, COST AND NET RETURN OF ELECTRICITY FOR ALTERNATIVE COOLING TECHNOLOGIES BY NUCLEAR POWER GENERATION IN SUBBASIN 3 FOR THE YEAR 2000	50
13.	ESTIMATE OF WATER REQUIREMENT FOR ENERGY PRODUCTION	51
14.	CAPACITIES OF ENERGY FACILITIES BY SUBBASIN	52
15.	ESTIMATE COST OF WATER SALVAGE ALTERNATIVES	57
16.	ESTIMATES OF WATER SALVAGE FROM ALTERNATIVE METHODS	58
17.	PREDICTED AND ACTUAL CROP PRODUCTION IN 1974	60
18.	CONSUMPTIVE USE OF AGRICULTURAL AND ENERGY PRODUCTION BY SUBBASIN IN 1974 AS PREDICTED BY THE MODEL	61
19.	ESTIMATED NET RETURNS TO AGRICULTURE AND ENERGY IN 1985	64
20.	PRODUCTION OF IRRIGATED LAND IN 1985 BY SUBBASIN	64

LIST OF TABLES (continued)

Table Page

21. ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE AND ENERGY IN 1985 BY SUBBASIN 65

22. ESTIMATED WATER CONSUMPTIVE USE BY STATE IN 1985 65

23. ESTIMATED WATER CONSUMPTIVE USE IN SCENARIO II IN AGRICULTURE AND ENERGY IN 1985 WITH THE MAGNITUDF OF REDUCTION AS COMPARED TO SCENARIO I 68

24. ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE UNDER CONDITIONS OF GOVERNMENT REGULATION AND ZERO PUBLIC INVESTMENT IN 1985 AS COMPARED TO SCENARIO I 68

25. COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 1985 UNDER CONDITIONS OF 14.9 MAF ANNUAL FLOWS 70

26. ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE AND ENERGY IN 2000 BY SUBBASIN 72

27. ESTIMATED WATER CONSUMPTIVE USE BY STATE IN 2000 72

28. ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE UNDER CONDITIONS OF A SALINITY REGULATION AND ZERO CONSERVATION INVESTMENT IN 2000 WITH THE MAGNITUDE OF CHANGE AS COMPARED TO NO SALINITY REGULATION 75

29. COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 2000 UNDER CONDITIONS OF 14.9 MAF ANNUAL FLOW 77

30. COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 1985 UNDER CONDITIONS OF 13.8 MAF ANNUAL FLOW 79

31. PERCENT CHANGE IN SALT CONCENTRATION AND THE COLORADO RIVER OUTFLOW AT LEE'S FERRY UNDER CONDITIONS OF 14.9 AND 13.8 MAF ANNUAL STREAM FLOW GIVEN ALTERNATIVE LEVELS OF GOVERNMENT POLICY IN 2000 82

32. COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGE UNDER FOUR ALTERNATIVE SCENARIOS IN 1985 UNDER CONDITIONS OF SUMMER FLOW 84

33. COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 2000 UNDER CONDITIONS OF SUMMER FLOW 86

LIST OF TABLES (continued)

Table Page

34. PUBLIC INVESTMENT EXPENDITURES IN 1985 AND 2000 UNDER ALTERNATIVE PUBLIC POLICIES FOR 14.9 MAF ANNUAL FLOW 90

35. PUBLIC INVESTMENT EXPENDITURES IN 1985 AND 2000 UNDER ALTERNATIVE PUBLIC POLICIES FOR 13.8 MAF ANNUAL FLOW 91

36. NET BASIN RETURNS, NET AGRICULTURAL RETURNS, AND PUBLIC INVESTMENT EXPENDITURES IN 1985 AND 2000 AS NET AGRICULTURAL RETURNS INCREASE 94

ABSTRACT

Economic Impacts of Water Conservation Measures
in Agriculture and Energy Within the
Upper Colorado River Basin

by

Douglas R. Franklin, Doctor of Philosophy
Utah State University, 1982

Major Professor: Rangesan Narayanan
Department: Economics

The demand for water is increasing in the western United States. Coupled with growing emphasis on development of the western resources, the limited supply of water will create an expanding competitive market for water by agricultural, energy, industrial and municipal users.

The Upper Colorado River Basin is faced with a question of what water conservation measures in the agricultural and energy sectors can be instigated without reducing agricultural output. If the decision is made to adopt water conservation technology measures, this study addresses the impacts in the private and public investment sectors under alternative public policies, i.e., regulation or non-regulation of salinity, to invest or not to invest in water conservation measures such as evaporation suppression and phreatophyte control, and to invest or not to invest in salinity control projects.

A linear programming model was developed to determine the optimal allocation of water between agriculture and energy as well as the trade off associated with the various policy alternatives of the public

sector. The agricultural sector incorporated consumptive use of crops and various irrigation systems. The energy sector incorporated consumptive use of various water conservation technologies and production capacities.

(120 pages)

CHAPTER I

INTRODUCTION

The Upper Colorado River Basin states, Wyoming, Utah, Colorado, and New Mexico contain large deposits of energy resources, including oil shale, tar sands, crude oil, coal, and natural gas which are used to produce refined petroleum products, natural and synthetic gas, and electrical power. Agriculture is the predominant water consuming industry of the basin, accounting for over 80 percent of the total depletions. With rapid development of energy projects, population growth and growth of affluence, the demand for water for agricultural production and energy uses is expected to increase. Future anticipated energy development and production in the energy rich areas of the Upper Colorado River Basin may compete with agriculture for the limited supply of water by bidding up the price of water.

Any increase in the price of water will give incentives in the agricultural and energy producing sectors of the economy to reduce present water use by substituting other factors for water. Adopting water management practices can effectively reduce the demand for water. The United States Water Resources Council (1978) stated in regards to water conservation that without intensified dedication to careful management of water resources, pressures from our technological society will continue to deplete and degrade the Nation's water supply.

The word conservation has many connotations to many different individuals. In economic terms, conservation is defined as the care and preservation in such a way as to prolong the use of natural resources or make for their most effective use. (Sloan and Zurcher, 1970). Since water is a renewable resource, there is not a need to preserve water,

but water can be stored for future use. Water conservation, as defined by the U.S. Water Resources Council, is to avert critical water shortages and to get the greatest use from existing supplies by increasing the average physical product of water through better management and technology. Sometimes, by the adoption of water conservation measures, the supply of water may decrease to the downstream user due to reduced return flows caused by increases in upstream consumptive use. The return flow of water from upstream uses is part of the supply of water to a downstream user. Therefore, the welfare of the entire basin must be evaluated in the determination of benefits to water conservation measures. Water conservation practices in response to increases in the price of water such as improvements to water conveyance systems and improved irrigation capital technology could reduce water diversions in irrigated agriculture, thus increasing the efficiency of these systems. In the energy sector, the demand for water can be reduced by conservation measures such as, by the use of waste water treatment programs in energy development projects, alternative methods of mining, and dry or hybrid cooling towers in power generation. Other water conservation practices that could be undertaken (not available to the private sector) include reduction of water evaporation in reservoirs and the consumption of water by phreatophytes along canals and river banks. In the long run, capital substitution for water can take place through alternative water-use technologies and conservation measures.

Statement of the Problem

In studies concerning water quality, questions arise regarding downstream effects associated with increased water use (Padungchai, 1980;

Hyatt, 1970). Management programs are created to distribute supplemental surface supplies in order to decrease adverse downstream effects. Water management programs are instigated by individual water users when water use or water rights problems, such as increased salinity or competition for the same water supply, can be effectively solved. However, the time at which efficient use and management of water and water rights are instituted is determined by the water user. When water use problems cannot be effectively solved on an individual basis, such as may be the case in the Colorado River Basin, the public sector may act to achieve a balance. In most cases, the government policy has been an imposition of a regulation. In the Upper Colorado Basin, the government policy is a salinity standard administered by the Environmental Protection Agency. Salinity does not impose major damage to the water users in the Upper Basin. Significant damages are imposed in the water users of the Lower Basin in the form of crop damage, decreased soil productivity, high treatment costs, pipe corrosion, and greater use of detergents and chemicals.

By an agreement reached between the Upper Basin states and the Environmental Protection Agency, EPA, in 1974, salinity shall be maintained at or below 1972 levels. In 1976, salinity standards were imposed by the EPA below Hoover Dam, below Parker Dam and at Imperial Dam in the Lower Basin. The planning model developed in this study focuses on the impact of the government regulation.

Another public policy alternative would be to invest in water quality improvement programs in the non-agricultural sector such as evaporation suppression, and in phreatophyte control and in the agricul-

tural sector such as sprinkler irrigation systems and the lining of irrigation canals.

The optimal utilization of water use is altered by changes in the value and availability of water and the cost of resources. The adjustment to changes in factor availability is determined by the efficiency of resource use and the limits to growth of resource use. New technologies have provided the agricultural sector with more efficient farm use of water. While crop yields per unit of water can generally be increased through technology and greater use of substitute and complimentary inputs, i.e., fertilizer, and the demand for water diversions can be reduced through investment and improved water management practices, there are economic and physical limitations to such changes. The adjustment process becomes more complicated and crucial to the economic viability of a region when water becomes more costly.

The range of alternatives to be considered is probably the most important element in a planning process. This study was confined to alternative methods of reducing the demand for water in the agriculture and energy producing sector. The methods of reduction are increased efficiency in agriculture, increased efficiency in energy, transfer of water from agriculture to energy and from energy to agriculture, and the reduction of phreatophyte and reservoir evaporation losses. For each method and alternative it is important to consider both the quantity and the cost of conserving water, i.e., the supply functions. Water quality constraints are considered. It is important to specify financing of the particular conservation or water management practice for each alternative. Financing for the water conservation and water quality projects is assumed to be from public sources. For example, financing reduced

water evaporation on reservoirs or reduced evapotranspiration from river bank phreatophytes might be accomplished by the government sector since the benefits received under such a program are realized by the downstream users of the "extra" water. Since the benefits received by additions of a sprinkler irrigation system will accrue to the individual farmer, the investment opportunity might be assumed to be from the private sector. Government incentives in the form of tax exemption or low cost loans may facilitate these investment expenditures. For this study, the financing of sprinkler irrigation systems and canal linings was assumed from the public sector. The irrigator will have the opportunity to repay the project cost with interest, however, the repayment schedule and feasibility is not investigated here.

There is a large choice of technical alternatives from which the agricultural and energy sectors can choose to achieve the economically efficient level of conservation of water use given the existing level of technology. It was the purpose of the study to determine the welfare cost of alternative government policies on the allocation of water in the Upper Colorado River Basin.

Study Area

The study area is the Upper Colorado River Basin located in the states of Wyoming, Colorado, Utah, New Mexico and Arizona (see Figure 1). The 1,440 mile long Colorado River rises near the eastern part of the basin in Colorado at an elevation of 13,000 feet and flows in a general southwesterly direction into Arizona through Utah. The Green River, 437 miles long, is the largest tributary, beginning in the northern end of the basin in Wyoming and passing through eastern Utah. The San Juan

Figure 1. Upper Colorado River Basin

River is the second largest tributary and rises in the southwestern part of Colorado, flowing westward to from the main stem in southeastern Utah. Most of the water for the basin comes from precipitation in the mountains, primarily from snow, with a maximum flow usually in May and then subsiding to a base flow near the end of July. The major features of the Upper Colorado River Basin are summarized in Table 1.

The study are was divided into eight water resources divisions according to geographic and state boundries. The Upper Colorado River Basin is both one of the fastest growing energy areas of the United States, and a water-scarce area, so that an economic and technological analysis of alternative water conservation technologies may be quite fruitful.

A diagrammatical representation of the public sector's decision framework used in this work is given in Figure 2. Lying in the heart of the model is the choice of alternative public investment activities for non-agricultural water conservation and salinity control investment given the alternative salinity regulations for the Colorado River.

Objectives of the Study

This study focuses on the substitution of capital for water within and between the agricultural and energy sectors of the Upper Colorado River Basin Economy.

A question that is often raised is the extent to which water conservation measures may be applied to irrigated agriculture and to the energy sector without reducing agricultural output: That is, given increasing water demand, how might farmers and energy managers substitute other factors of production so that the agricultural base is maintained in the

TABLE 1

MAJOR CHARACTERISTICS OF THE UPPER COLORADO RIVER BASIN

Subbasin	Geographic Area	Political Units	Major Urban Areas	Major Geographic Features
1	Southwestern Wyoming	Lincoln Sweetwater Sublette Uinta	Green River (WY) Kemmerer Rock Springs	Flaming Gorge Reservoir Green River
2	Northwestern Colorado	Moffat Rio Blanco Routt	Craig Meeker	White River Yampa River
3	Northeastern Utah	Carbon Daggett Duchesne Emery Uintah	Green River (UT) Price Roosevelt Vernal	Flaming Gorge Reservoir Duchesne River Green River Price River White River
4	South Central Colorado	Delta Hinsdale Gunnison Ouray	Delta Montrose	Blue Mesa Reservoir Gunnison River

TABLE 1 (CONTINUED)

Subbasin	Geographic Area	Political Units	Major Urban Areas	Major Geographic Features
5	Central Colorado	Garfield (CO) Grand (CO) Eagle Mesa Pitkin Summit	Grand Junction Rifle	Colorado River
6	East Central Utah West Central Colorado	Grand (UT) Delores Montrose San Miguel	Moab Montrose	Colorado River Delores River
7	Southwestern Colorado Northwestern New Mexico	Archuleta La Plata Montezuma San Juan (CO) San Juan (NM)	Durango Bloomfield Farmington	Navajo Reservoir San Juan River
8	Southwestern Utah	Garfield (UT) Kane San Juan (UT) Wayne	Bluff Monticello	Lake Powell Colorado River San Juan River

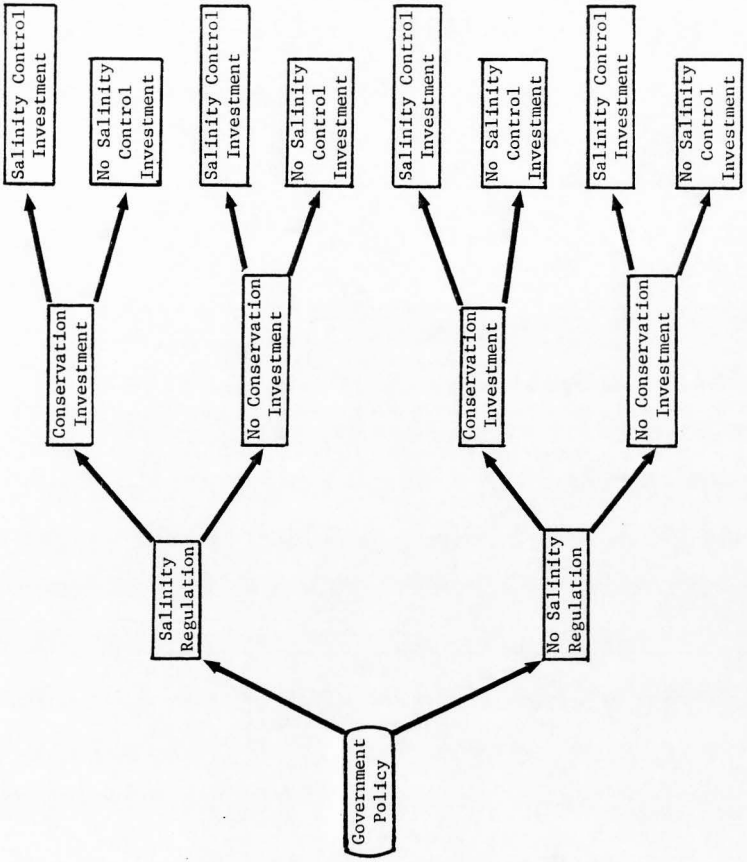

Figure 2. Public Sector's Decision Framework

face of reduced water allocations? Maintaining the agricultural base may be desirable from a political perspective or because an agricultural base will be desirable after the oil, coal, oil shale, and other energy developments are physical or economically depleted. The specific objectives of this study are:

1. to identify the need for government sponsored water conservation measures as well as to evaluate water saving techniques employed by different sectors of the economy in response to increased water prices;
2. to determine the cost of public sector investments in water conservation measures given a salinity regulation;
3. to select the technological process which optimally allocates water in agriculture from a social point of view;
4. to examine the welfare cost of public policies aimed at changing water allocations; and
5. to determine which water conservation measures in the agricultural and energy sectors to maximize net sectoral returns.

Methodology

A mathematical programming model will be used to maximize net income for the agriculture and energy sectors of the Upper Colorado River Basin and to measure the extent of externalities caused by the adoption of water conservation measures. Different levels of water allocations will be determined by altering the various water conservation measures in the sectors. The water conservation measures that maximize net sectoral income with the lowest welfare cost will indicate the optimum allocation of water and water conservation.

It is assumed for the analysis that

1. water rights are negotiable and transferable,
2. water demand for such uses as aquatic and wildlife, exports, and municipal and industrial needs, are fixed,
3. the agricultural and energy sectors are price takers in the input and output market, and,
4. the energy sector will not return waste water to the river.

Potential Water Conservation Practices

The water required for production of energy units and the consumptive use in agriculture is more or less constant. The total water supply in the Colorado River is also constant. One of the major problems associated with development in the Upper Colorado River Basin is the large "losses" of water occurring primarily from evaporation and evapotranspiration from phreatophytes. Investments in water conservation practices to reduce these "losses" and to reduce the canal losses in agriculture is investigated in this report.

The degree of water conservation depends on the effectiveness of the prevention of seepage and evaporation losses, the level of treatment of wastewater, and the level of use of saline water technology. The overall level of conservation practices are given below.

Phreatophytes, which are high water-use plants, inhabit the flood plains over much of the southwest United States. In order to estimate the effects of phreatophytes on regional water sources and to determine the potential water salvage which might result from the replacement of high water-use phreatophytes with low water-use plants, accurate estimates of the water used by phreatophytes are necessary. In the

seventeen western states it is estimated that phreatophytes consume 25 million acre-feet annually (Robinson, 1958). To dramatically illustrate the water lost by phreatophyte use, for every 10 acre-feet of water used in agriculture, 8 acre-feet of water is consumed by phreatophytes. However, the amount of water salvaged from the mechanical removal and/or spraying of phreatophytes and reseeding the area in low water use grasses, etc., is on the order of one to two acre-feet of water per acre.

Reduction of evaporation from reservoirs does offer some reasonable means for saving water. Evaporation estimates range from slightly over 200,000 to over 1,000,000 acre-feet annually for the major reservoirs and all wetland and reservoirs in the Upper Basin States of the Colorado River, respectively. It is estimated that on Lake Powell, alone, fresh water evaporates at an annual rate of 656,700 acre-feet (Hughes, et. al., 1974).

Water diverted per acre of irrigated agriculture can be reduced as other factors of production are substituted for water. Under Pareto Optimality conditions, if the upstream user of water has higher costs and lower revenues due to the substitution of other factors for water in order to maintain the supply of water to the downstream user, then the substitution for water use is not an improvement. However, if the upstream user can be compensated for his higher cost while the downstream users cost/revenue position improves, then the reduced water use would be a potential Pareto improvement. It is important to analyze Pareto conditions to determine the welfare effects of alternative water conservation measures in a region. Total water diverted can be reduced in agriculture by a variety of methods. By shifting to a less water

intensive crop, better maintenance of current irrigation distribution systems, or larger capital-intensive water distribution system, i.e., introduction of lined canals or pipelines to sprinkler systems, demand for diverted water by agriculture can be reduced. Capital substitution is thought to be a major source of water conservation of water policy planners. However, as indicated by Frickel (1980), increased conveyance efficiency through capital substitution does not imply water conservation. As a farmer adopts a more capital-intensive distribution system to reduce diverted water per acre, he can increase his irrigated acreage for the same given level of water diversions. The farmer will use water up to the point where his marginal benefits are equal to his marginal costs. However, the equality of the marginal physical products of water between the upstream and the downstream users may not hold which causes a basin-wide inefficient water allocation. Water policy planners must be aware of the potential for added production. Even if the knowledge and profitable technologies are available for water conservation, farmers may not adopt these measures immediately. A study by Phelan (1964) concluded that knowledge alone is not a criteria for the adoption of improved irrigation efficiencies.

Marion Clawson (1977, p.5.) wrote, "The west will use its limited water supply and its limited area of first class cropland more intensively in the decades ahead. Agriculture has been encouraged to waste irrigation water, by the system of water rights which make water transfers away from irrigation so difficult and also by the extensive subsidization of irrigation water costs. Irrigation use of water will come under increasing pressure to yield value products as great as might be achieved with the same water elsewhere." Thus, the efficient use of

irrigation water is the mechanism to maximize marginal value products in agriculture.

The technology is available to decrease water consumption in energy production. Therefore, physical water availability will not constrain development of energy resources in the Upper Colorado River Basin. For example, Abbey (1979) discusses several options available to energy producers and developers for the substitution for water. These options include dry cooling, which reduces the water requirement of electric power generation plants from 5,000-20,000 acre feet per year to 1,000-2,000 acre feet per year per 1,000 MW, and hybrid cooling system which combines dry and wet tower cooling. The costs of a dry or a hybrid cooling system is very high when compared to the value of water in agriculture. Abbey estimated the opportunity cost of water saved by a 100 percent dry cooling system at $5,500 per acre-foot compared to a wet cooling system; for a 40 percent wet system, cost is estimated at $870 per acre-foot of water saved. When compared to the agricultural value of water which ranges from $5 to $20 per acre-foot depending on the soil, crops, etc., the energy sector cost clearly outweigh agricultural benefits. Since relatively low cost water supplies are available by transferring water from agriculture as an alternative to dry cooling in power generation, it can be assumed that water availability will have a small effect on the price of electricity.

To impose new requirements for water rights on long established state water rights would upset the social and economic structure of the region, even though water rights changes can also be used to reallocate water. Social and legal difficulties associated with water ownership must be resolved for optimal utilization to occur. Most western states

follow the doctrine or prior appropriate in appropriating the waters within the state. This doctrine states "first in time, first in right" which means that the first users of water in the state have the right to do as they please with their use of water with respect to future users of water. Under Utah law, no one has the right to water without making "beneficial use" of that water. The State Engineer will grant a water right if (a) the water applied for is unappropriated, (b) that the proposed use will not impair existing rights, (c) that the proposed used is physically and economically feasible, and (d) the proposed use will not have any adverse effects on the environment and the welfare on the public. In Utah, a water right is a property right and therefore can be sold or transferred independent of the land, whereas in Wyoming the water right is not independent of the land. The sale of the water right is the means by which water can be efficiently allocated within the agricultural and energy producing sectors and between these two sectors.

The potential water conservation practices are to be analyzed to provide water policy planners a base from which to determine future energy and agricultural growth and related impacts on water allocation, water quality, and water quantity within the Upper Colorado River Basin.

CHAPTER II

REVIEW OF LITERATURE

A number of studies have looked at the optimal allocation of water in a river basin. Among these are Keith, et. al. (1978), Narayanan, et. al. (1979), Morris (1977), Cummings et. al. (1977), and Frickel (1980). In each of these studies a mathematical program was developed to simulate a river basin model. Keith, et. al., Narayanan, et. al. and Morris simulated the Upper Colorado River Basin with Keith, et. al. investigating the water allocations pertaining to Utah in particular. Morris used an interregional input-output model tied to natural resource constraints within a linear programming framework. Both Keith, et. al. and Narayanan, et. al. model the river basin in a linear programming scheme. In particular, Keith, et. al. examined the economically efficient allocation of water in the agricultural and energy sectors of Utah, Narayanan, et. al. analyzed the effect of potential energy development on water allocation and water quality and Morris addressed the feasibility and consequences of energy development in the Upper Colorado River Basin. Cummings and Gisser evaluated the economic impacts of reduced water allocations to irrigated agriculture using a linear programming model for a ground water basin in New Mexico. Frickel measured the economic impacts of the adoption of irrigation technologies through a linear programming model in the Sevier River Basin in Utah. All of these studies, except Morris, maximized net income by specific sectors of a basin subject to resource and market constraints to predict changes in output, development and water quality as water is allocated among alternative uses.

An article that reviews and analyzes the philosophical arguments of conservation is presented by Kury (1977). The author suggests that conservation cannot be discussed outside of a normative context. Kury's definition of conservation is "the act of rational behavior in the context of social and natural limitations." However, Kury does not discuss positive value and negative value in conservation, i.e., if the source is valued positively, then it can be conserved.

According to Ciriacy-Wantrup (1968) conservation is defined "as changes in the time distribution of use rates of individual resources in which the aggregate weighted change in use rates is greater than zero, i.e., a change in the use rates of a resource, not to a time distribution of use rates. If conservation is termed "the greatest use to the greatest number over the greatest length of time" or "wise use", then conservation has little meaning and is of no such value in economic evaluation of a resource. Conservation in this study is defined as eliminating loss or waste by inefficient physical or economic use.

The increasing demand for water in the arid west has depleted surface and ground water supplies in some parts of the region. Other areas are experiencing decreased quality of water. The demand for water has partially been met by impounding water and importing supplies. This study considers water conservation measures (technologies) in agriculture and the developing energy sectors, phreatophyte control or reduction, and evaporation suppression.

Conservation in Agriculture

Some studies concentrating on water conservation in agriculture are Leonard (1968), Hedlund (1975), National Water Commission (1973), U.S.

Department of the Interior (1978), and Stone (1977). Leonard discusses reducing water use in irrigation through efficient management practices. Hedlund indicates that if a program resulting in high use efficiency could be implemented, then gross irrigation withdrawal and incidental losses could be reduced by 48 million acre feet and 7.4 million acre feet respectively by the year 2000 through the United States. However, Hedlund terms increased irrigation efficiency as conservation, which in fact it is not. Increased efficiency could result in more acreages and increased water use as a whole. Frickel (1980) points this out.

The National Water Commission report contains the findings and recommendations of the National Water Commission. The report suggests that water pricing be based on the principle of marginal cost pricing, that free bargaining of water rights to allocate water more efficiently be established, and methods of improving irrigation efficiency through reservoir location, lining of canals, trickle and sprinkler irrigation, and the eradication of phreatophytes be adopted. This report did contain a good general discussion of aspects of water conservation, the treatment of sewage/wastewater, and improvement of municipal water use.

Stone conducted a three-year study focusing on crop yield and supplemental water application for corn and grain sorghum at Kansas State University. Five irrigation treatments treatments, ranging from no in-season irrigation to three in-season applications were duplicated, for each of the crops. The results indicated that both crops showed improved yields after at least one in-season irrigation and the three in-season application brought significant increases in corn yields but not a sufficient increase in grain sorghum yields to justify the addi-

tional irrigation expense. This study is useful in the analysis of the timing of irrigation water.

President Carter proposed in a speech in May, 1977, that the Federal Water Policy should be revised "with water conservation as its cornerstone". In light of this statement, the Comptroller General of the United States (1977), the Commission on Natural Resources Ad Hoc Committee on Water Resources (1978) and the Office of Science Technology and Policy (1978) produced water conservation studies.

The Comptroller General of the United States underscored the need for a coordinated effort on the part of local, state and federal governments to reduce seepage losses from irrigation conveyance systems. The Commission on Natural Resources Ad Hoc Committee on Water Resources summarized five consultants' reports covering water conservation techniques in agriculture, municipal, industrial, and steam electric power. This report stresses the need for more research.

The Office of Science and Technology Policy cites twelve water resource policy issues and discusses the policy recommendations and directions for research in each category. The issues are: climate and water supply, floods and droughts, ground water, water conservation in irrigation, water quality, erosion and sedimentation, water for energy, methods for increased water supply, future water demends, urban water programs and a system approach for water.

The report suggests a greater efficiency is needed in irrigation. Davenport and Hagan (1980) define the types of water losses in irrigated agriculture and outlines potentials for water conservation.

Conservation in Energy

Abbey (1979), Probstein and Gold (1978) and Keefer and McQuivey (1979) contain information on the rates of water use in energy production under alternative technologies. Abbey estimated water consumption for dry tower cooling, wet tower cooling and hybrid cooling (combination of wet tower and dry tower cooling) of two, ten, twenty and forty percent wet tower cooling. Probstein and Gold estimated water consumption for several conversion processes in coal gasification, coal liquifaction and oil shale production. Keefer and McQuivey contained water availability and water consumption estimates for tar sands development in Utah. These reports, however, did not contain information pertaining to the probability of energy development. Their water consumption figures were estimates and not actual measurements. The literature contains estimates which range from small to large consumption per year for the same technology. For the purpose of this study the most common estimate was used. In some cases, the water consumption figures were the average of the water consumption estimates of several reports.

Phreatophyte Control

Phreatophytes, which are deep-rooted, high water use plants, inhabit the flood plains and canals over much of the western United States. Robinson (1952) has estimated in the 17 western states that phreatophytes occupy over 15 million acres and consume 25 million acre-feet annually. Horton and Campbell (1974) in a USDA Forest Service research paper estimated that if 4 million acres of phreatophyte growth were treated, 4 to 8 million acre feet per year of water will be added to western stream flow.

Most phreatophytes have a low economic value. In recent years, however, there has been increasing interest in wildlife habitat, fish habitat, recreation, and the esthetic values attributed to the phreatophyte areas. The elimination of phreatophyte areas must take into account the economic value lost (Horton and Campbell, 1974). Although the water consumed by phreatophytes could be salvaged, it may not be economically feasible to salvage all the water (Robinson, 1958). Between one and two acre feet per acre of water savings is as close an approximation as possible with the limited data available.

Along the 437 mile course of the Green River it is estimated that a total of 40,000 acres of flood plains are covered by phreatophytes. The average daily depletion in stream flow for a 21-day period in September 1948 was calculated to be 552.4 acre-feet. That approximates to 201,626 acre feet of water or 4.4 percent of the Green River stream flow at Green River, Utah consumed by phreatophytes annually. That is two times the water proposed for development by the Bonneville Unit of the Central Utah Project. Koogler (1952) and Cramer (1952) give associated costs and method of control for the elimination of phreatophytes. Methods of control include either mechanically and/or chemically preventing plant growth through mowing and spraying or removing the water supply by ground water pumping, channelization, or lining or piping water around phreatophyte growth. Evaporation by phreatophytes and the ground surface could still occur but was not calculated into the costs of water salvaged.

Evaporation Suppression

Evaporation suppression on reservoirs has been researched by the Bureau of Reclamation since 1958. A large amount of literature and

research has been conducted throughout this century. A detailed account of the literature is given in a two volume Utah Water Research Laboratory publication titled Water Salvage Potentials in Utah (Hughes, Richardson, and Franckiewicz, 1974, 1975). The report summarizes the effectiveness of existing techniques for surface retardation of evaporation and evaporation suppression by reservoir destratification.

CHAPTER III

ECONOMIC ANALYSIS

Alternative water conservation measures in irrigated agriculture and energy development will have a variety of economic and social impacts on the economy of a river basin. The economic and social impacts of non-energy surface water development, i.e., reservoir construction, pipelines, etc., will tend to be outweighed by the impacts associated with tar sand and oil shale production. The major impact associated with surface water development will be the depletion of stream flows, the ecological effect on fish habitat and either a decrease or an increase in recreation use/opportunities associated with development or non-development. In any development of surface-water supplies throughout the Upper Colorado River Basin will have to take into effect the existing legal and political agreements pertaining to the preservation of endangered species and river compacts between states.

Under the water rights system within each state (Wyoming, Colorado, Utah, and New Mexico), it is possible that water can be transferred from the agricultural sector to the energy sector. Given an efficient agricultural sector, as water is transferred away from agricultural productivity there is a loss in agricultural output. However, the transferred water will result in a gain in output and income in the energy sector. The net change is calculated from a comparison of the income loss to the income gain. If the agricultural sectors income loss is less than energy sectors income gain, the optimal solution is to allow the transfer of water. If the agricultural sectors income loss is greater than the energy sectors income gain, the transfer of water will not take place. As indicated by a study on the availability of water

for energy development in the Upper Colorado River Basin (Colorado Department of Natural Resources, 1979a), the gain in income in the energy sector would be 10 to 100 times greater than the loss in agricultural income. Thus, the transfer of water should take place in accordance to each state's water rights system.

Better on-farm management of water for irrigation purposes would generally result in increased yields and crop quality and reduced variable costs for the farmer at a higher capital cost. An important consideration with increased irrigation conveyancy efficiency is to account for changes in damage to crops and salinity in the soil.

Within the Upper Colorado River Basin, agriculture consumes the major portion of the water depletions. In a full allocated water market, it is from the agricultural sector that energy development will be supplied the water it needs. The maintaining salinity control for water quality on the Colorado River and its tributaries through dilution will come from the lowest value of water sector. In most cases, this will be from the agricultural sector.

Of the estimated 7.17 million acre-feet of water diverted for irrigation purposes a year, 2.46 million acre-feet is consumptively used by crops and the rest is returned to the stream as return flow and seepage. Evapotranspiration by phreatophytes consumes approximately 2 million acre feet a year. Consumptive use by crops as a function of soil moisture, soil salinity, type and density of crop, and climate. Climate is precipitation, temperature, relative humidity, wind velocity, daylight hours and the length of the growing season.

Padungchai (1980) estimated the overall average irrigation efficiency in the Upper Basin states at 46 percent with under 10 percent

of crop acreages is sprinkler irrigated. Padungchai noted that the irrigation efficiency is much higher on a basin-wide basis because return flows from upstream irrigators are reused by downstream irrigators. The irrigation water that is not consumed by crops or phreatophytes either returns to surface flows or percolates into aquifers. Loss of water due to both the evapotranspiration process and over-irrigation increases the salinity downstream.

Major deposits of coal, oil, natural gas, oil shale, and tar sand are located in the Upper Colorado River Basin. Major deposits of oil shale are located in subbasins 2, 3 and 5 and tar sand is located in subbasins 3, 6 and 8. The major impacts of developing these resources will take place on the White River in Utah and Colorado and the Colorado River between Rifle and Grand Junction, Colorado. At the present time, coal, oil and natural gas are commercially mined in the basin. Coal gasification is a potential energy industry planned for New Mexico and Wyoming. Further steam electric power generating plants are planned for most areas of the Upper Basin.

Environmental problems, both air and water pollution, must be solved before any development can take place. Adoption of water conservation measures can minimize water pollution in some areas at additional costs. Both economic feasibility and environmental impacts will determine the efficiency and timing of the development of these resources.

Model Formulation

The empirical model is a linear programming model which maximizes net income for the agricultural and energy sectors by allocating water within and between the two sectors of the economy. Different levels

of water allocations will be determined by including the various water conservation measures in the two sectors. The cost of the water conservation measures that maximizes net sectoral income with the lowest social cost, i.e., lowest cost of control to the basin, will determine the optimum allocation of water.

The mathematical formulation of the linear programming model is as follows:

$$\text{Max } Z = N_A + N_E - \sum_{r=1}^{R} \sum_{s=1}^{S} \beta_s^r \; Q_s^r$$

(net sector income)

where $N_A = TR_A - TC_A$

(net agricultural income)

$N_E = TR_E - TC_E$

(net energy income)

$$TR_A = \sum_r \sum_i \sum_j \sum_k P_i^r \; A_{ijk}^r \; Y_{ijk}^r \qquad \begin{array}{l} r = 1,\ldots,R \\ i = 1,\ldots,I \\ j = 1,\ldots,J \\ k = 1,\ldots,K \end{array}$$

(total agricultural revenue)

$$TC_A = \sum_r \sum_i \sum_j \sum_k \; [C_{ijk}^r \; A_{ijk}^r + C_w \; w_{ijk}^r \; A_{ijk}^r] \qquad \begin{array}{l} r = 1,\ldots,R \\ i = 1,\ldots,I \\ j = 1,\ldots,J \\ k = 1,\ldots,k \end{array}$$

(total agricultural cost)

$$TR_E = \sum_r \sum_e P_e^r \; Q_e^r \qquad \begin{array}{l} r = 1,\ldots,R \\ e = 1,\ldots,E \end{array}$$

(total energy income)

$$TC_E = \sum_r \sum_e \sum_m \sum_n C_{emn}^r \; Q_{emn}^r \qquad \begin{array}{l} r = 1,\ldots,R \\ e = 1,\ldots,E \\ m = 1,\ldots,M \\ n = 1,\ldots,N \end{array}$$

(total energy cost)

subject to the following constraints:

$$\sum_r \sum_i \sum_j \sum_k A^r_{ijk} \leq A^r_p \qquad \begin{array}{l} r = 1,\ldots,R \\ i = 1,\ldots,I \\ j = 1,\ldots,J \\ k = 1,\ldots,K \end{array}$$

(irrigated acreage)

$$\sum_r \sum_i \sum_j \sum_k \sum_e \sum_m \sum_n \alpha^r_i A^r_{ijk} + w^r_{emn} Q^r_e \leq W \qquad \begin{array}{l} r = 1,\ldots,R \\ i = 1,\ldots,I \\ j = 1,\ldots,J \\ k = 1,\ldots,K \\ e = 1,\ldots,E \\ m = 1,\ldots,M \\ n = 1,\ldots,N \end{array}$$

(consumptive use)

$$\sum_r A^r_{ijk} \leq \overline{L}^r + L^r \text{ , } k = \text{lined canals} \qquad r = 1,\ldots,R$$

(current level of lined canals)

$$L^r \leq A^r_p - \overline{L}^r$$

(potential level of lined canals)

$$\sum_r A^r_{ijk} \leq \overline{S}^r + S^r \text{ , } k = \text{sprinklers} \qquad r = 1,\ldots,R$$

(current acreage of sprinklers)

$$S^r \leq A^r_p - \overline{S}^r$$

(potential acreage of sprinklers)

$$W + \sum_r \sum_s \omega^r_s Q^r_s \geq 0 \qquad \begin{array}{l} r = 1,\ldots,R \\ s = 1,\ldots,S \end{array}$$

(salvaged water)

$$Q^r_e \leq CAP^r_e$$

(energy production capacity)

A complete modeling of the water quality, return flow, efficiency of the energy conversion process and institutional restrictions are in Narayanan, Padungchai and Bishop (1979). The variable notation is as follows:

r	subbasins	$r = 1,2,\ldots,8$
i	type of crop	$i = 1,2,\ldots,I$
j	what application level	$j = 1,2,\ldots,J$
k	irrigation distribution technology	$k = 1,2,\ldots,K$
e	energy use (coal, oil shale, tar sands, power generation, coal gasification, etc.)	$e = 1,2,\ldots,E$

m	water technology (wet tower cooling, dry tower cooling, surface mining, insitu mining, etc.) $m = 1,2,\ldots,M$
n	other energy factors of production $n = 1,2,\ldots,N$
s	water conservation measure such as sprinkler irrigation, canal lining, phreatophyte control, evaporation control, and salinity control projects $s = 1,2,\ldots,S$
A	Agriculture
E	Energy
β_s^r	cost of water conservation measure s in subbasin r
Q_s^r	quantity of water conservation measure s in subbasin r
P_i^r	price less the return to water to grow the ith crop in the rth subbasin per acre
A_{ijk}^r	ith crop acreage grown in subbasin r using water application j and irrigation conveyance k
Y_{ijk}^r	yield or productivity of per acre of crop i, application j, and distribution k in the rth subbasin
C_{ijk}^r	cost of production using input prices of fertilizer, seed, feed, land labor, and farm machinery for crop i, water application j, and distribution k in subbasin r
C_w	cost of water per acre foot
w_{ijk}^r	water application per acre for the ith crop, jth application, and kth distribution system in subbasin r in acre feet.
P_e^r	price less return to water of each energy use e in subbasin r
Q_e^r	quantity produced for each energy use e in subbasin r
C_{emn}^r	cost of energy use e using water technology m and other factors of production n in subbasin r

O^r_{emn} quantity of water technology m and other factors of energy production n such as raw materials, labor and capital equipment in energy use e in subbasin r

A^r_p potential irrigated acreage in subbasin r

α^r_i consumptive use requirement per acre of crop i in subbasin r

w^r_{emn} water required to produce one unit of energy use e using water technology m and factors n in subbasin r

W water allocation level

$\overline{L}^r$ level of existing lined canals in subbasin r

L^r potential level of new lined canals in subbasin r

$\overline{S}^r$ acres of existing sprinklers in subbasin r

S^r potential acres of new sprinklers in subbasin r

ω^r_s water salvaged by water conservation measure s in subbasin r

CAP^r_e capacity of energy use e in subbasin r

The Upper Colorado River Basin is divided into eight subbasins. The model maximizes net farm income in each subbasin subject to profit-maximization or cost-minimization constraints. The constraints are irrigation acreage, crops, crop rotation, water intensity or application levels, the irrigation distribution technology, salinity, and water availability.

The agricultural sector can modify its water use by changing the irrigation distribution systems or application of water. As the agricultural sector reduces water use per acre, then the sector is conserving water per acre. If the total acreage does not increase, then the sector conserves water throughout the basin.

Adjustments in crop selection, fertilizer use, and capital investments are made such that the maximum amount of net income is generated

from water use and the irrigation technology. At the same time, it is implicitly assumed that the distribution of water across users is "fair". The trade-off of capital for water will be used as a means for maintaining irrigated agricultural activities. As the factors of production are substituted for water in irrigated agriculture, then water can be reduced.

Water conservation in the energy sector measures will also be modeled to determine the trade-off of capital for water, such as the savings of water used by converting to "dry tower cooling" from "wet tower cooling" in power generation. Other water conservation measures such as "hybrid" cooling systems and evaporation ponds will be analyzed by comparing the water use rate with the capital cost of each system for each energy use, i.e., power generation, gasification, oil shale development, etc.

The model maximizes net energy income less returns to water in each subbasin for each energy use such as power generation, gasification, oil shale, tar sands, etc., subject to water technology, labor, raw materials and capital equipment.

It will be noted that each water technology affects costs differently, i.e., "dry cooling" is more capital intensive and thus more expensive than "wet cooling" in power generation but the water savings are greater in the former than in the latter.

The model maximizes the objective function subject to constraints imposed in the agricultural and energy sector and additional costs contributed by the public sector in the form of the adoption of salinity control projects, evaporation control measure, and phreatophyte control measures. The adoption of these projects will, in effect, reduce salinity in the stream flow and reduce the demand for non-agricultural

and non-energy water use, thus increasing the available water for agricultural energy. These costs are subtracted from net sector income in that the costs of these projects are borne by the Upper Basin. Any water conservation policy or program that is adopted benefits the users and is thereby assumed to be a cost subtracted from the net sector income. The constraints are imposed in the manner of additional costs to the basin which are financed through public investment.

By forming the Lagrangean equation, the maximization of total net sector income of the basin is determined by differentiation with respect to water use in each activity in the equation and setting equal to zero. This results in the marginal revenues of each particular use in the agricultural and energy sectors in each subbasin equaling the marginal cost of water. Water is allocated among uses and technologies until revenues are equal to costs at the margin. As the demand for water increases, so that the upper bound of water supply is reached, the user of water with the greatest marginal net revenue will obtain the water resource first. The optimum economic efficiency of water implies that clear transfer rights to the water under a perfectly competitive situation exists. This results in the marginal value product of water to be equated in all subbasins.

In an imperfectly competitive market, where restrictions are placed on the use or the transfer of water from one sector to another sector (as exists in the Upper Colorado River Basin states) the optimum economic efficient allocation of water will not result. However, the linear program used for this study will still achieve and optimum allocation of water given the additional constraints imposed on water in the Upper Colorado River Basin.

Scenarios

To measure the agricultural output and the energy sectors output and the impacts on the level of water use due to the adoption of water conservation measure, five scenarios are analyzed for this study. An initial unconstrained scenario is analyzed to determine an optimal allocation of water between sectors if the initial allocation of water was not optimal, i.e., the marginal value of water in and between sectors is not equal to its opportunity cost. As the demand for water increases, it is possible to determine the appropriate water conservation policy to be enacted by policy planners in order to increase the economic welfare of the basin.

Scenario I

For Scenario I, the model maximizes net sector income subject to diverted water and availability, capital, capacity, and other agricultural and energy inputs. The level of water quality is allowed to adjust. Water is allocated to the agricultural and energy producing sectors until the value of the marginal product (VMP) of water equals the cost of water. The optimal solution of this scenario is the efficient allocation of water to the two sectors given current market prices of inputs and outputs. The value obtained for the net income of the economy is compared to the following scenarios.

Scenario II

Scenario II maximizes net sector income subject to maintaining the level or water quality to the EPA standards of 1974. This scenario allows for government regulation and investment in water conservation

practices. Investments in water conservation technologies for energy production decreases the amount of water demanded by energy production thereby increasing the marginal physical product of water in energy sector. As the value of water increases and the demand for water decreases, energy producers have the incentive to use water at the value of the opportunity cost, i.e., energy producers conserve water. This is also true in the agricultural sector. If the supply of water is perfectly inelastic, however, then the investment may not decrease the use of water at all. In general, this scenario increases the price of water from the level in Scenario I depending on the elasticity and the amount of the investment in all conservation measures. The investment on water conservation technologies is a method to conserve water in energy and agriculture production. The smaller the value of the marginal product of water the less the adoption and therefore the investment in water conservation practices.

Scenario III

Under Scenario III, the level of public investment in water conservation projects and in salinity control projects is zero. Additional cost are suffered by farmers to meet the EPA salinity standard. The allocation of water according to the VMP's is not optimal. This scenario causes an improvement of the irrigation efficiency in the water distribution system from the point of diversion to the point of discharge on the farm. This scenario induces farmers to increase irrigation capital investment in order to conserve water in the agricultural sector. This scenario allows for maximum private investment needed to maintain the agricultural base of the economy under conditions of tight fiscal

control by federal and state governments. The comparison of Scenario II and Scenario III yields public investment strategies in sprinkler irrigation and canal lining levels without other water conservation projects.

Scenario IV

The fourth scenario is a combination of downstream (Lower Basin) damage cost on the net income of the Upper Basin and public investment to induce conservation. The analysis determines if the damage cost is large enough to increase the level of investment of irrigation capital or in water conservation practices. The damages are subtracted off of net sector returns to the Upper Basin as a cost per milligram per liter of increased salinity downstream. It was assumed throughout this study that any salinity control investment will be made by the public sector. The private sector, in particular, the irrigator will not be expected to pay for any salinity control investment. In fact, it is quite clear that the irrigator will not be able to pay back any investment given historical records of the Bureau of Reclamation.

Scenario V

The fifth scenario includes the damage cost due to increased levels of salinity downstream attributed to the Upper Basin and a zero funding level of public investment. This allows for the increase in private investment until the marginal cost of private investment equals the marginal cost of damages to increased salinity downstream from Lee's Ferry.

The optimization of net farm income and net energy income within each scenario achieves different and predictably lower levels of agricultural income while maintaining the higher value of energy output.

CHAPTER IV

DATA ACCUMULATION AND DEVELOPMENT

The agricultural and energy sector's production coefficients, water resource availability, water quality, water consumptive use, and economic and market data have been cited from several sources. The majority of the data has been developed in two Utah Water Research Laboratory publications. The first study, authored by Narayanan, Padungchai, and Bishop (December, 1979) is titled "An Economic Evaluation of the Salinity Impacts from Energy Development: The Case of the Upper Colorado River Basin". The second study, authored by Keith, Turna, Padungchai, and Narayanan (June, 1978) is titled "The Impacts of Energy Resource Development on Water Resource Allocations".

Water Resources

Water availability. The virgin flows for each subbasin are derived by using hydrologic data within each subbasin (Narayanan, et. al., 1979; and Padungchai, 1980). Table 2 gives the Upper Basin states water shares under 14.9 and 13.8 million acre feet total availability assumptions. The virgin flows for each subbasin is derived by using hydrologic and stream gauge data within each subbasin (U.S.G.S. Water Data Reports for Wyoming, Colorado, New Mexico, and Utah, for selected years). Table 3 indicates the net water available for irrigation and energy use by subbasin.

Water quality. The salinity concentration level associated with tributaries of each subbasin is a weighted average of salt and water flow of hydrologic units comprising a given water subbasin. The

TABLE 2

UPPER BASIN STATES WATER SHARES UNDER ALTERNATIVE SUPPLY AND INSTITUTIONAL ASSUMPTIONS (AF x 10^3)

	Basin Total	States			
		Colorado (51.75%)	New Mexico (11.25%)	Utah (23.00%)	Wyoming (14.00%)
Case 1					
Average Annual Flow	14,994				
Lower Basin Share	8,300[a]				
Upper Basin Share	6,694	3464	753	1540	937
Main Stem Evaporation	520	269	58	120	73
Net State Shares	6,174	3195	695	1420	864
Case 2					
Average Annual Flow	13,800[b]				
Lower Basin Share	8,300				
Upper Basin Share	5,500	2846	619	1265	770
Main Stem Evaporation	520	269	58	120	73
Net State Shares	4,980	2577	561	1145	697

[a] Lower Basin = 7.5 MAF, Mexico = 0.75 MAF, and Arizona = 0.05 MAF

[b] Average Virgin Flow (1922-1975)

TABLE 3

NET WATER AVAILABLE FOR IRRIGATION AND ENERGY USES IN EACH SUBBASIN UNDER ALTERNATIVE WATER SUPPLY ASSUMPTIONS (AF x 10^3).

	1975			1985			2000		
Subbasin	Case 1	Case 2	Summer Flow	Case 1	Case 2	Summer Flow	Case 1	Case 2	Summer Flow
1	1,773.5	1,628.7	1,168.6	1,670.2	1,525.4	1,063.5	1,492.6	1,347.8	929.7
2	2,213.2	2,025.4	1,560.8	2,203.6	2,015.8	1,509.5	2,187.9	2,000.1	1,481.8
3	1,072.6	970.4	507.1	923.6	821.4	417.1	914.3	812.1	408.0
4	2,250.1	2,075.5	1,452.4	2,249.3	2,074.7	1,410.7	2,247.3	2,072.7	1,394.4
5	3,381.3	3,065.9	2,308.4	3,133.3	2,817.9	2,061.6	3,070.7	2,755.3	1,994.4
6	648.8	594.0	257.8	546.8	492.0	207.5	543.8	489.0	204.0
7	2,315.2	2,136.2	1,248.9	2,287.1	2,108.1	1,197.6	2,286.3	2,106.3	1,184.4
8	441.6	406.0	190.6	439.0	403.4	184.0	436.1	400.5	180.8
Total	14,096.3	12,902.1	8,694.6	13,452.9	12,258.7	8,051.5	13,179.0	11,984.8	7,777.5

Source: Narayanan, Padungchai, and Bishop, 1979; and U.S.G.S. Water Data Reports for Wyoming, Colorado, New Mexico and Utah.

estimated salt loading and flow of hydrologic units are obtained from Padungchai (1980). Table 4 gives the several salinity control projects authorized and planned by the Bureau of Reclamation and the estimated effects as reported in Narayanan, et. al. (1979).

Current and future water uses. The level of current and projected levels of depletions for municipal, industrial, export, and other purposes for 1985 and 2000 are based on U.S. Water Resources Council (1978) and Narayanan, Padungchai, and Bishop (1979). Water availabilities for each subbasin in the model are derived by subtracting current and future water uses from the water supply for annual and summer flows. Table 5 shows the predicted levels of water use.

Agricultural Activities

There are nine irrigated crops selected for the study area. They are alfalfa and other hay (full and partial irrigation), barley, wheat, oats, nurse crops, corn silage, corn grain, potatoes and pasture.

Objective function coefficients. The annual prices, crop yields, costs of production, and net returns are obtained from Padungchai (1980) and Narayanan et. al. (1979). Ten percent higher yields were used for sprinkler irrigations based on Frickel (1980), Cummings et. al. (1977) and Franklin (1978) indicating that yields increased as application uniformity improved. Tables 6 and 7 are the estimated crop yields and net returns per acre for sprinkler irrigated crops.

Land. The actual and potential irrigated acreages of land used in production is taken from Padungchai (1980) and given in Tables 8 and 9.

TABLE 4

AUTHORIZED AND PLANNED SALINITY CONTROL PROJECTS AND THEIR ESTIMATED EFFECTS.

Subbasin	Project	Type of Project	Estimated Salt Reduction (1,000 Tons/Yr)	Cost ($ Mill.)	Annual OM & R Cost ($ Mill.)	Cost ($/Ton)	Water Loss (AF)
1	Big Sandy River	Desalting	80	N.A.			6,000
2	Uintah Basin	IMS & WSI[1)]	100	N.A.			
	Price & San Rafael River	Under Investigation	180	N.A.			5,000
5	Grand Valley	IMS & WSI	200	81.3	0	23	to 30,000 each
	Glenwood & Dotsero Springs	Desalting	250	69.5		65.2	
6	Paradox Valley	Evaporation Pond	180	21.1	.541	9.1	4,000
	Crystal Geyser	Evaporation Pond	3	2.69	.016	56.0	150
	Lower Gunnison Basin	IMS & WSI	300	N.A.			
7	McElmo Creek	Ponding & Desalting	40			30	6,200
8	Dirty Devil River	Under Investigation	80	N.A.			

1) Irrigation management services and water systems improvements.

Source: Narayanan, Padungchai, and Bishop, 1979.

TABLE 5

NET WATER AVAILABLE FOR ENERGY AND AGRICULTURE UNDER ALTERNATIVE SUPPLY AND INSTITUTIONAL ASSUMPTIONS (AF x 10^3).

State	Net State Share[a]	1975 Consumptive Use[b]	1975 Net Available[c]	1985 Consumptive Use[b]	1985 Net Available[c]	2000 Consumptive Use[b]	2000 Net Available[c]
Case 1							
Colorado	3195	604	2591	964	2231	1048	2147
New Mexico	695	97	598	125	570	125	570
Utah	1420	156	1265	308	1112	320	1100
Wyoming	864	41	823	144	720	322	542
Case 2							
Colorado	2577	604	1973	964	1613	1048	1529
New Mexico	561	97	464	125	436	125	436
Utah	1145	156	989	308	837	320	825
Wyoming	697	41	656	144	553	322	375

a/ From Table 2.

b/ Sums of non-irrigation and non-energy use, i.e., municipal, industrial, export, wildlife, etc.

c/ Net water available for energy or irrigation use under the case assumption.

Source: Narayanan, Padungchai, and Bishop, 1979.

TABLE 6

ESTIMATE OF ANNUAL CROP YIELDS PER SPRINKLER IRRIGATED ACRE

Subbasin	Alfalfa Full	Alfalfa Partial	Barley	Wheat	Oat	Nurse Crop	Corn Grain	Corn Silage	Potato	Pasture
1	3.865	3.003	55	55	55	55	35.62	14.41	96.25	4.95
2	3.542	3.135	55	55	55	55	107.338	16.918	67.21	7.48
3	3.865	3.344	68.7	55	68.2	55	60.973	13.75	116.93	7.48
4	3.865	3.444	60.5	55	55	55	109.78	18.084	49.93	7.48
5	3.865	3.444	61.7	55	55	55	107.338	16.918	160.27	7.48
6	4.595	3.553	68.2	55	55	55	96.404	19.492	233.618	7.48
7	3.729	2.684	55	55	55	55	96.404	12.98	99.275	7.48
8	3.729	2.684	68.7	55	68.2	55		11.825	171.875	7.48

TABLE 7

NET ANNUAL RETURNS OF SPRINKLER IRRIGATED CROPS PER ACRE
(DOLLARS PER ACRE)

Subbasin	Alfalfa Full	Alfalfa Partial	Barley	Wheat	Oat	Nurse Crop	Corn Grain	Corn Silage	Potato	Pasture
1	126.22	91.02	142.92	144.37	51.85	33.53			162.56	97.20
2	122.36	109.46	75.64	135.57	67.80	80.28			127.59	97.39
3	122.84	106.50	91.67	144.92	90.79	85.22	159.83	203.62	267.63	97.39
4	140.07	121.31	75.64	135.57	75.74	80.28	228.42	194.73	94.40	97.39
5	140.07	121.31	75.64	135.57	102.12	80.28	223.35	174.67	304.33	97.39
6	140.98	117.52	65.64	135.57	88.70	40.95	200.59	218.94	443.60	97.39
7	125.68	90.47	65.64	135.53	71.02	40.95	200.59	186.40	188.52	97.39
8	118.64	85.40	91.67	144.92	67.80	85.22		203.62	493.39	97.39

TABLE 8

TOTAL ACRES OF IRRIGATED LAND FOR SELECTED FIELD CROPS

Subbasin	Alfalfa Hay	All Other Hay	Pasture	Small Grains*	Corn Grain	Corn Silage	Potatoes	Total
1	51,456	118,147	89,084	11,327	109	58	4	340,185
2	20,947	50,876	19,640	1,677	195	365	14	93,714
3	52,747	23,014	72,033	9,049	2,205	7,671	11	166,730
4	19,743	46,580	36,389	6,499	3,347	4,156	53	116,767
5	65,033	51,356	51,569	6,730	8,155	6,219	108	189,170
6	21,632	9,864	28,189	22,675	3,877	7,713	2,613	96,563
7	30,123	14,608	52,025	5,355	747	2,956	178	105,992
8	15,170	2,545	12,110	4,068	0	915	112	34,920
Total	276,851	386,990	361,039	67,380	18,635	30,053	3,093	1,144,041

*Small grains include barley, wheat, oats, rye and sorghum for all purposes.

Source: Narayanan, Padungchai, and Bishop, 1979.

TABLE 9

PROJECTED NEW IRRIGATED ACRES IN 1985 AND 2000 BY SUBBASIN

Subbasin	1985	2000
1	0	0
2	14,400	0
3	25,240	4,300
4	11,300	0
5	9,000	3,700
6	45,500	1,360
7	118,000	0
8	0	0
Total	223,440	9,360

Source: Narayanan, Padungchai, Bishop, 1979.

Irrigation and agricultural water consumptive use coefficients. The coefficient values of present irrigation efficiency, the estimated costs of sprinkler and canal lining costs, and the yearly averages of water consumptive use (in acre feet) per crop in different subbasins are obtained from Keith et. al. (1978), Narayanan et. al. (1979), and Padungchai (1980). Ten percent higher consumptive use were used for sprinkler irrigation as yields increased based on Frickel (1980), Cummings and Gisser (1977), and Franklin (1978). Table 10 shows the consumptive use by subbasin of sprinkler irrigated crops.

Energy Activities

The energy sectors production outputs are divided into natural energy output and final output. The natural energy outputs include underground and strip mined coal, petroleum, natural gas, crude oil from oil shale, and crude oil from tar sands. The final outputs are converted from natural energy outputs. These include electricity from coal-fired electric generation plants and nuclear power plants, synthetic natural gas from coal gasification facilities and refined oil products.

Objective function coefficients. The prices of coal by county and by state, the prices of crude oil production and natural gas at the well head, shale oil prices, prices of refined products from crude oil, crude oil from tar sand prices, and coal gasification prices and the associated operating costs were reported in Padungchai (1980), Narayanan et. al. (1979), and Keith et. al. (1978). Specific details on the actual development and critique of the prices perceived and operating costs are given in the above named sources.

TABLE 10

ANNUAL CONSUMPTIVE USE (ACRE-FEET PER ACRE) DURING AN AVERAGE GROWING SEASON FOR SPRINKLER IRRIGATION[a/]

Subbasin	Alfalfa Full	Alfalfa Partial	Barley	Wheat	Oat	Nurse Crop	Corn Grain	Corn Silage	Potato	Pasture
1	2.31	1.21	1.32	1.837	1.76	1.76			1.925	1.925
2	2.145	.99	1.32	1.837	1.76	1.76			1.925	1.87
3	2.31	1.21	1.32	1.837	1.76	1.76	2.288	1.54	1.925	1.98
4	2.2	1.1	1.32	1.837	1.76	1.76	2.288	1.43	2.013	1.87
5	2.2	1.1	1.32	1.837	1.76	1.76	2.288	1.43	2.013	1.87
6	3.08	2.09	1.54	1.837	1.76	2.2	2.288	1.98	2.013	2.42
7	2.09	.99	1.43	1.837	1.76	1.76	2.288	1.98	2.013	2.2
8	2.09	.99	1.43	1.837	1.76	1.76		2.288	2.013	2.2

a/ C.U. for sprinkler irrigated crops is estimated to be 10% higher than non-sprinkler irrigated crops due to higher yield and uniformity of water application.

The average prices of electricity were obtained from Narayanan et. al. (1979). Cost data for alternative cooling technologies were obtained from Hu, Pavlenco, and Englesson (1978) and U.S. Environmental Protection Agency (1979). The average price, cost and net returns under alternative water conservation technologies are given in Table 11 and coal-fired power generation and Table 12 for nuclear power.

Alternative cost information for various oil shale, coal gasification, and tar sand developments were obtained from Probstein and Gold (1978) and Keefer and McQuivey (1979).

The final outputs of energy activities can be transported by rail or truck for coal and by pipeline or tank for petroleum. The transportation costs are obtained from Narayanan et. al. (1979).

The energy conversion process efficiency. When the Natural Energy products are converted to final outputs, energy losses occur due to the conversion process inefficiency. The energy conversion process efficiencies were derived in Keith et. al. (1978) and Narayanan et. al. (1979).

The energy water consumptive use coefficients. The major sources of data were obtained from Narayanan et. al. (1979), Keefer and McQuivey (1979), U.S. EPA (1979), Colorado Department of Natural Resources (1979a), Hu et. al. (1978), Keith et. al. (1978), and Probstein and Gold (1978). The estimates of water requirements for energy production are given in Table 13.

Energy production capacities and resource availabilities. The current and future planned energy production capacity for natural energy output and final outputs were obtained from Narayanan et. al. (1979) and Padungchai (1980) and given in Table 14.

TABLE 11

AVERAGE PRICE, COST AND NET RETURN (DOLLARS PER MWH) OF ELECTRICITY FOR ALTERNATIVE COOLING TECHNOLOGIES BY SUBBASIN FOR COAL FIRED POWER GENERATION

Subbasin	Cooling Technology	Price	Cost	Net Return
1	Wet tower	16.12	7.09	9.04
	40% wet	16.12	11.16	4.96
	10% wet	16.12	13.12	3.00
	Dry tower	16.12	18.78	-2.66
2	Wet tower	21.19	7.56	13.63
	40% wet	21.19	12.39	8.80
	10% wet	21.19	15.10	6.09
	Dry tower	21.19	20.13	1.06
3	Wet tower	16.12	8.79	7.33
	40% wet	16.12	13.57	2.55
	10% wet	16.12	14.66	1.46
	Dry tower	16.12	19.98	-3.86
6	Wet tower	21.71	11.78	9.93
	40% wet	21.71	16.38	5.33
	10% wet	21.71	19.06	2.64
	Dry tower	21.71	24.10	-2.39
7	Wet tower	21.71	11.78	9.93
	40% wet	21.71	16.38	5.33
	10% wet	21.71	19.06	2.64
	Dry tower	21.71	24.10	-2.39
8	Wet tower	16.12	8.79	7.33
	40% wet	16.12	13.57	2.55
	10% wet	16.12	14.66	1.46
	Dry tower	16.12	19.98	-3.86

Source: Narayanan et. al., 1979 and Hu et. al., 1978.

Note: Due to the quality and quantity of coal and water and the environmental constraints imposed on once-through cooling for electric generation, the once-through cooling technology will not be utilized within the Upper Colorado River Basin.

TABLE 12

AVERAGE PRICE, COST AND NET RETURN (DOLLARS PER MWH) OF ELECTRICITY FOR AATERNATIVE COOLING TECHNOLOGIES BY NUCLEAR POWER GENERATION IN SUBBASIN 3 FOR THE YEAR 2000

Subbasin	Cooling Technology	Price	Cost	Net Return
3	Wet tower	16.12	7.48	8.64
	40% wet	16.12	13.15	2.97
	10% wet	16.12	16.77	-.65
	Dry tower	16.12	22.60	-6.48

Source: Hu et. al., 1978.

TABLE 13

ESTIMATION OF WATER REQUIREMENT FOR ENERGY PRODUCTION

Energy Activity	Water Requirement	
Underground coal mining	344 AF/10^6 tons	
Strip coal mining	204 AF/10^6 tons	
Crude oil	53.1 AF/10^6 bbls	
Natural gas	1.67 gallons/MSCF	
Tar sands-surface extraction	61.38 AF/10^6 bbls	
Tar sands-insitu retorting	644.1 AF/10^6 bbls	
Oil shale-surface extraction	13,400-20,100 AF/yr	for a 50,000
Oil shale-underground extraction	6,800-10,600 AF/yr	bpd production
Oil shale-insitu retorting	3,000- 5,700 AF/yr	facility
Oil shale-modified insitu	5,000- 8,000 AF/yr	
Coal gasification-lurgi process	5,600- 9,000 AF/yr	for a 250 mmcfd
Coal gasification-synthane process	6,694-10,500 AF/yr	production
Coal gasification-synthoil process	9,655-13,000 AF/yr	capacity
Oil refinery	43 gallons/bbl	
Coal fired electric generation		
- wet tower cooling	9.0491-12.200 AF/yr/MW	
- 40% wet tower cooling	3.6179-4.4063 AF/yr/MW	
- 10% wet tower cooling	.9023-1.1038 AF/yr/MW	
- dry tower cooling	0 AF/yr/MW	
Nuclear power electric generation		
- wet tower cooling	17.0123-19.3946 AF/yr/MW	
- 40% wet tower cooling	6.1457- 7.4022 AF/yr/MW	
- 10% wet tower cooling	1.4900- 1.8571 AF/yr/MW	
- dry tower cooling	0 AF/yr/MW	

Source: Narayanan, et. al. 1979; Keith et. al., 1978; U.S. EPA, 1979; Hu, et. al., 1978; Probstein and Gold, 1978; and Colorado Department of Natural Resources, 1979a.

TABLE 14

CAPACITIES OF ENERGY FACILITIES BY SUBBASIN

A Steam-Electric Power Generation Facilities

Subbasin	Production in MW 1974	1985	2000
1	1267.7	3540	3540
2	163.2	1950	2250
3	635.0	2263.6	3508.6
4	--	--	--
5	--	--	--
6	34.5	34.5	34.5
7	328.7	4878.7	4878.7
8	--	1500	1500

B Nuclear Power Generation Facility (year 2000 only)

Subbasin	Production in MW
3	13,000

TABLE 14 (CONTINUED)

C. Oil Refineries (in operation)

Subbasin	Production in Barrels per Day (bpd)
1	2,300 bpd
3	7,500 bpd
5	5,400 bpd
7	22,020 bpd

D Oil Shale Facilities

Subbasin	Production in Thousands of bpd	
	1985	2000
1	0	100
2	145	218.5
3	75	125
5	80	137

E Tar Sand Facilities (year 2000 only)

Subbasin	Production in bpd
3	10,000 bpd
6	10,000 bpd
8	10,000 bpd

TABLE 14 (CONTINUED)

F Coal Gasification Facilities (year 2000 only)

Subbasin	Production in MMcfd
1	250 MMcfd
7	1,785 MMcfd

G Coal Production (thousands of tons)

	1974 Production		1985 Production		2000 Production	
Subbasin	Underground	Strip	Underground	Strip	Underground	Strip
1	103	4,088	200	23,900	58,000	47,800
2	266	3,385	9,800	18,100	114,600	36,200
3	5,492	--	21,600	500	43,200	14,900
4	1,265	--	5,700	--	11,400	3,900
5	845	23	3,250	23	6,500	2,300
6	--	107	200	107	200	500
7	10	7,873	10	76,550	40	540
8	--	--	26,400	1,000	53,200	3,000
Total	7,981	15,476	67,160	120,180	287,142	109,140

TABLE 14 (CONTINUED)

H Crude Oil and Natural Gas Production (1976)

Subbasin	Crude Oil (bbls)	Natural Gas (mcf)
1	11,573,508	136,936,838
2	22,593,645	52,173,144
3	26,125,238.48	32,214,359
4	--	--
5	3,284	3,934,786
6	409,993.44	9,333,731
7	4,370,837	394,540,789
8	12,240,033.45	9,469,415
Total	77,316,539.37	638,103,617

Sources: Narayanan, et. al., 1979, and Padungchai, 1980.

Non-Agricultural and Non-Energy Activities

The non-agricultural and non-energy activities are comprised of reservoir evaporation suppression by monomolecular film and destratification activities, phreatophyte control by spraying and mechanical clearing, and canal clearing and maintenance.

Objective function coefficients. The costs per acre of canal clearing of phreatophytes, the costs per acre foot of mechanical clearing and spraying of phreatophytes, and reservoir evaporation suppression were derived from Hughes, Richardson and Franckiewicz (1974 and 1975), Culler (1970), Kearl and Brannan (1967), Bowser (1952), and Koogler (1952) and given in Table 15. The cost of these activities are included in the profit function, but not in specific association with either the agricultural or energy profits.

The water consumptive use coefficients. Estimates of water consumptive use by phreatophytes were obtained from a Symposium on Phreatophytes sponsored by the American Geophysical Union and reported in Transactions (1952) these include Blaney (p. 61-66), Bowser (p. 72-74), Cramer (p. 77-80), Koogler (p. 74-77), Robinson (p. 57-61), and Turner and Skibitzke (p. 66-72). Additional estimates were obtained from Horton and Campbell (1974), Culler (1970), and Robinson (1958). The estimates of evaporation water that can be salvaged or non-evaporated by various methods were derived in Hughes et. al. (1974 and 1975). Table 16 gives the estimates of water salvaged by evaporation suppression and phreatophyte control.

TABLE 15

ESTIMATE COST OF WATER SALVAGE ALTERNATIVES

	Reservoir Suppression		Phreatophyte Suppression			
Subbasin	Monomolecular Film ($/AF)	Destratification ($/AF)	Sparse Growth Spraying ($/AF)	Dense Growth Spraying ($/AF)	Mechanical Clearing ($/AF)	Canal Lining ($/Acre)
1	9.20	10.00	10.00	35.00	20.00	1968.75
2	9.20		12.50	35.00	20.00	1968.75
3	9.20	5.00	9.25	22.50	15.00	1968.75
4	9.20	5.50	15.00	35.00	23.00	1968.75
5	9.20		12.50	25.00	17.50	1968.75
6	9.20		15.00	35.00	20.00	1968.75
7	9.20	3.00	9.20	20.00	15.00	1968.75
8	9.20	2.00	20.00	35.00	23.00	1968.75

Source: Hughes, et. al., 1974 and 1975; Culler, 1970; Kearl and Brannan, 1967; Bowser, 1952; and Koogler, 1952.

TABLE 16

ESTIMATES OF WATER SALVAGE FROM ALTERNATIVE METHODS (AF/YR)

Subbasin	Reservoir Suppression		Phreatophyte Suppression			
	Monomolecular Film	Destratification	Sparse Growth Spraying	Dense Growth Spraying	Mechanical Clearing	Canal Lining
1	1,312	1,500	5,000	1,500	5,000	24,000
2	1,165	0	5,000	2,000	5,000	23,400
3	5,723	8,395	12,000	28,000	15,000	66,000
4	1,117	6,800	5,000	2,000	2,000	53,200
5	1,117	0	5,000	10,000	10,000	109,000
6	256	0	5,000	2,000	5,000	5,200
7	3,236	5,250	15,000	5,000	15,000	18,300
8	1,965	140,200	2,000	3,000	2,000	16,400

Source: Hughes, et. al., 1974 and 1975; Horton and Campbell, 1974; Culler, 1970; Robinson, 1958; Blaney, 1952; Bowser, 1952; Cramer, 1952; Koogler, 1952; Robinson, 1952; and Turner and Skibitzke, 1952.

CHAPTER V

MODEL RESULTS

The mathematical program predicted the economic impacts of agricultural and energy development and the optimal allocation of water given alternative water conservation technologies in The Upper Colorado River Basin for the years 1974, 1985, and 2000. Three levels of available water supply are analyzed for the study. Case 1 incorporates 14.9 MAF annual flow, Case 2 incorporates 13.8 MAF annual flow, and summer flow is the remaining case. The year 1974 is used as the base year for production and prices for comparison of the future impacts of development.

Case 1, 14.9 MAF Annual Flow

With the annual flow of the Colorado River based on an optimistic view of the available water supply, 14.9 MAF, the following results are obtained.

1974 Model Results

Table 17 compares the predicted model results with the actual production level for agriculture farm products. The predicted level of water consumptive use for agriculture and energy production, by subbasin, are given in Table 18. As shown in Table 17, the predicted levels of agricultural production in alfalfa hay, pasture and other hays, and potatoes are within five percent of the actual acres in production. Alfalfa, pasture and potatoes have a discrepancy of 2.8, 0.0, and 1.7 percents, respectively. The predicted levels of water

TABLE 17

PREDICTED AND ACTUAL CROP PRODUCTION IN 1974 (ACRES)

Crop	Actual Production	Model Prediction	Deviation
Alfalfa hay	276,851	284,662	+7,811
Pasture and other hays	748,029	748,029	0
Small grains*	67,380	79,958	+12,578
Corn grain	18,635	14,760	-3,875
Corn silage	30,053	13,592	-16,461
Potatoes	3,093	3,040	-53
TOTAL	1,144,041	1,144,041	0

*Small grains include barley, wheat, oats, rye, and sorghum for all purposes.

TABLE 18

CONSUMPTIVE USE OF AGRICULTURAL AND ENERGY PRODUCTION BY SUBBASIN IN 1974 AS PREDICTED BY THE MODEL (1,000 ACRE FEET)

Subbasin	Agriculture	Energy	Total
1	474.5	13.58	488.08
2	144.0	3.53	147.53
3	310.8	10.64	321.44
4	206.9	.44	207.34
5	342.9	.56	343.46
6	233.0	.36	233.36
7	206.4	5.88	212.28
8	66.9	.65	67.55
TOTAL	1,985.4 [1)]	35.62 [1)]	2,020.98 [1)]

[1)] The numbers do not add up due to rounding.

consumptive use, approximately 2.02 million acre feet, shown in Table 18, are to be used as a base for which to compare the water consumptive use in future years under alternative scenarios and water availabilities. Other studies have estimated the total consumptive use of water for agriculture at 2.161 MAF and 0.55 MAF for energy production (Narayanan and Bishop, 1979), 19.85 MAF for agriculture and .041 MAF for energy (Padungchai, 1980), and Abbey (1979) estimated the energy sector consumes .067 MAF. Thus, the estimates predicted by this study compare favorably with estimates of the other studies.

The salinity standard established by the Environmental Protection Agency in 1974 at Imperial Dam is maintained for the base year. For future years, the standard is held constant or relaxed to predict the impact salinity has on water conservation measures within the Upper Colorado River Basin under alternative public and private investment strategies. The model predicted for the base year that 8.339 million tons of salt and 12.075 million acre feet of water are delivered to the Lower Basin for an average of .69 tons of salt per acre foot. The historical flow of water at the compact point, Lee's Ferry, is 10,346 million acre feet on the average and 7.856 million tons of salt according to water quality records with an average of .759 tons of salt per acre foot. Padungchai (1980), estimated a flow of 12.069 million acre feet and 8.46 million tons of salt passed Lee's Ferry for an average of .70 tons of salt per acre foot.

1985 Model Results

By 1985, an additional 223,440 acres are projected to be irrigated. (Table 9). In addition to the agricultural sector, the energy sector

will increase from expansion of existing capacities for some facilities to several new energy facilities such as oil shale development on the order of 300,000 barrels per day. The linear program model predicted the optimum level of water allocation and the appropriate adoption of water conservation measures based on the new projected levels of agriculture and energy development.

Under the assumptions of Scenario I, the agricultural and energy activities are optimized subject to the available water, water conservation technologies, and no salinity standard established by the EPA. The estimated net return to agriculture is $134.086 million and for energy development the net return is $2,500.23 million (Table 19). This is an increase of $1,677.7 million over 1974 ($24.2 million increase for agriculture and $1,653.8 million for energy). The predicted products of the agricultural sector and the comparison to 1974 is given in Table 20. The water consumptive use associated with the increases in the agricultural and energy activities is 648,200 acre feet more than the 1974 level. The associated water consumptive use by subbasin and the comparison to 1974 is given in Table 21. The consumptive use of water by state is given in Table 22.

A private investment of 2,725 acres of sprinkler irrigated land in East Central Utah, West Central Colorado and Southwestern Utah at a total investment cost of $182,575 is adopted to maximize profits in the basin. No conservation practice was adopted. Since the level of salt concentration downstream was allowed to increase over the EPA level, the salinity control projects are not constructed.

The electricity sector used 100 percent wet tower cooling and the oil shale sector composed of surface mining in subbasin 2, Northwestern

TABLE 19

ESTIMATED NET RETURNS TO AGRICULTURE
AND ENERGY IN 1985. (MILLIONS OF DOLLARS).

Sector	Net Returns	Change from 1974
Agriculture	134.086	24.2
Energy	1,500.23	1,653.8
TOTAL	2,634.13	1,677.7

TABLE 20

PRODUCTION OF IRRIGATED LAND IN 1985 BY SUBBASIN. (ACRES)

Sub-basin	Alfalfa	Pasture	Small Grains	Corn Grains	Corn Silage	Potato	Total	Change from 1974
1	39,161	277,231	23,789			4	340,185	0
2	30,676	70,516	6,908			14	108,114	14,400
3	71,506	95,047	16,468		8,938	11	191,970	25,240
4	34,036	82,969	6,807	4,255			128,067	11,300
5	71,801	102,925	14,360	8,975		108	198,170	9,000
6	76,526	38,053	15,305		9,566	2613	142,063	45,500
7	116,624	66,633	25,979	14,578		178	223,992	118,000
8	14,097	14,655	4,293		1,762	112	34,920	0
TOTAL	454,428	748,029	113,911	27,808	20,266	3040	1,367,481	223,440
Change from 1974	169,766	0	33,954	13,048	6,673	0	223,440	

TABLE 21

ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE AND ENERGY IN 1985 BY SUBBASIN (1,000 ACRE FEET).

Subbasin	Agriculture	Energy	Total	Change from 1974
1	474.5	39.2	513.7	25.6
2	158.6	51.1	209.7	62.2
3	360.3	47.3	407.6	86.2
4	228.9	1.96	230.86	23.5
5	360.4	15.3	375.7	32.3
6	351.1	.4	351.5	118.1
7	427.3	61.1	488.4	276.1
8	67.0	24.8	91.7	24.2
TOTAL	2,427.9	241.3	2,669.2	648.2

TABLE 22

ESTIMATED WATER CONSUMPTIVE USE BY STATE IN 1985 (1,000 ACRE FEET).

State	Total Allotment	Total Consumption	Unallocated Water
Wyoming	720	513.7	306.3
Colorado*	2,801	1,585.3	1,215.7
Utah	1,112	499.4	612.6
TOTAL	4,633	2,598.4	2,134.6

* New Mexico's share is included in Colorado's share.

Colorado, and underground mining in subbasins 3 and 5, Northeastern Utah and Central Colorado. These technologies are based on profits and not on water consumption. Over 8,365,700 tons of salt or approximately 0.776 tons of salt per acre foot were indicated at Lee's Ferry, compared to the historical level of 0.76 tons of salt per acre foot.

When the level of salinity concentration is not allowed to increase over the EPA standard and public investment in conservation and salinity control projects are encouraged, i.e. Scenario II, the net return to the Upper Basin decreases by $9.4 million dollars with a decrease of over $900,000 in the agricultural sector over the initial 1985 solution. The net returns to the energy sector do not change. This model predicts a $5.89 million investment in canal lining (2.683 miles) and sprinkler irrigation (9,083 acres). The investment in phreatophyte and evaporation control measures and salinity control projects totals $2.6 million and salvages 224,000 acre feet of water at an average annualized cost of $11.60 per acre foot. The total cost of public investment is $8.489 million. The Paradox Valley Evaporation Ponds Project is the only Colorado River salinity control project to come on line.

Table 23 shows the agricultural and energy consumptive use of water given investment in the public sectors and the deviation of consumptive use over the initial 1985 solution.

When the salinity constraint is relaxed, the model indicates that the salt level not water is the major constraint to development in the Upper Colorado River Basin. The outflow to the lower basin increases by 350,000 acre feet to 11.13 MAF; the concentration of salt is .70 tons per acre foot, a decrease of 9.7 percent over Scenario I.

When public investment for evaporation and phreatophyte control projects and salinity control projects are not allowed, i.e. Scenario III, the net return to the Upper Basin decreases by over $13.3 million from the initial solution. The net return to the energy sector does not change but the net agricultural income decreases by $5.9 million. There is an increase of 2,983 miles of lined canals and 23,453 acres of sprinkler irrigated land at an investment of $7.44 million. This is 300 more miles of lined canals, 14,000 more sprinkler irrigated acres, and $1.05 million less public investment when compared to the solution given positive public investment. It should be noted that public investment is assumed in the agricultural sector, thus, the irrigator is subsidized by $7.44 million. If the irrigators were required to pay for the investment, it would not take place. The energy sector did not adjust its water conservation technology in any industry.

Table 24 shows the agricultural sector's consumptive use of water given zero investment in evaporation, phreatophyte, and salinity control projects.

If only the salinity control projects and agricultural investments are allowed to be funded, the total net return to the basin decreases by $11.4 million over Scenario I (as opposed to $13.3 million decrease above. The only salinity control project that comes on line is the Paradox Valley evaporation pond project at a cost of $1,638,000. When compared to Scenario II, there is an additional $2.0 million loss in the two sectors, agriculture and energy.

Where the level of salt concentration can increase so that the damages downstream attributed to the higher salt load are compensated by a damage cost reducing profits to the Upper Basin, Scenario IV, the total

TABLE 23

ESTIMATED WATER CONSUMPTIVE USE IN SCENARIO II IN AGRICULTURE AND ENERGY IN 1985 WITH THE MAGNITUDE OF REDUCTION AS COMPARED TO SCENARIO I (1,000 ACRE FEET).

Subbasin	Agriculture	Energy	Total	Deviation
1	474.5	39.2	513.7	0
2	158.1	51.1	209.2	-.5
3	360.3	47.3	407.6	0
4	228.5	1.96	230.46	-.4
5	290.5	15.3	305.8	-69.9
6	351.1	.4	351.5	0
7	427.3	61.1	488.4	0
8	67.0	24.8	91.8	0
TOTAL	2,357.4	241.3	2,598.7	-70.5

TABLE 24

ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE UNDER CONDITIONS OF GOVERNMENT REGULATIONS AND ZERO PUBLIC INVESTMENT IN 1985 AS COMPARED TO SCENARIO I (1,000 ACRE FEET).

Subbasin	Agriculture	Change
1	435.3	-39.2
2	158.1	-.5
3	360.3	0
4	199.0	-29.9
5	292.8	67.6
6	351.1	0
7	310.6	-116.7
8	67.0	0
TOTAL	2,174.2	-253.7

profits increase by $500,000 over the solution under the maintenance of a salinity regulation, Scenario II. The net returns to agriculture and energy do not change. The increase in salt concentration is 2.63 percent. The damage is estimated to be $3.5 million. The agricultural consumptive use of water in Scenario IV is the same as Scenario II. (See Table 23).

The cost of salinity control projects and water conservation projects total $4.476 million, salvaging over 229,000 acre feet of water, at an annualized cost of $19.51 per acre foot. The water conservation measures include 708 miles of canal lining, 9,083 acres of sprinkler irrigation, spraying and clearing of phreatophytes along river beds and floodplains, evaporation suppression by monomolecular layers and reservoir destratification.

With no public investment in evaporation, phreatophyte, and salinity control projects and compensate increases in salt load downstream, Scenario V, the salt load increases downstream by 6.5 percent over the EPA level with a total compensation of approximately $8.66 million. Net basin profits decrease by $11.6 million over Scenario I and $2.7 million over Scenario IV. The net returns to agriculture and energy do not change. The public sector is assumed to pay the compensation since irrigators will not be able to pay the damages.

Table 25 summarizes the cost and water salvage potential of various conservation measures and salinity control measures adopted under four scenarios in 1985 for 14.9 MAF annual flow.

The most efficient allocation of water is Scenario IV, which includes damage estimates due to increased salinity downstream. As Table 25 indicates, the cost per acre foot of water conservation is

TABLE 25

COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 1985 UNDER CONDITONS OF 14.9 MAF ANNUAL FLOWS. (COST IN THOUSANDS OF DOLLARS)

Technology/ Project	Scenario II Salvage	Scenario II Cost	Scenario III Salvage	Scenario III Cost	Scenario IV Salvage	Scenario IV Cost	Scenario V Salvage	Scenario V Cost
Agriculture								
Canal Lining	62,309	5,281.8 (2,683 miles)	65,821	5,872.8 (2,983 miles)	23,400	1,393.9 (708 miles)	23,400	1,393.9 (708 miles)
Sprinkler Irr.		608. (9,083 acres)		1,570.7 (28,453 acres)		608.5 (9,083 acres)		608.5 (9,083 acres)
Energy								
Other Sectors								
Res. Evap. Suppression	15,891	146.2			15,891	146.2		
Res. Destratification	162,145	390.5			162,145	390.5		
Spraying	42,000	242.0			32,000	299.0		
Mech. Clearing								
Salinity Control								
Paradox Valley	-4,000	1,638.0			-4,000	1,638.0		
TOTAL (Cost/AF)	278,345 ($30.50/AF)	8,489.0	65,821 ($113.09/AF)	7,443.5	229,436 ($19.51/AF)	4,476.1	23,400 ($85.57/AF)	2,002.4

$19.51 and the level of increased salt concentration is 2.6 percent over government regulations.

The market solution with externalities is Scenario I.

2000 Model Results

The same linear program was used to determine the net income to the basin for various agricultural and energy development under several alternative water conservation measures. An additional 9,360 irrigated acres are projected over 1985 (Table 9). In addition to the agricultural sector, the energy sector will expand to include new energy facilities such as tar sand development nuclear generation, and coal gasification, and the expansion of several existing facilities such as electricity generation and oil shale production.

The net farm income of the region is predicted to be $134.4 million, a slight increase over Scenario I in 1985 due to increased irrigated acreage, and the net energy income is predicted to be $4,471.9 million, an increase of 80% over 1985. The predicted results to the agricultural sector increases alfalfa production in 7,064 acres, small grains on 1,412 acres, corn for grain on 344 acres, and 534 acres of corn silage. The acreage increases occur in Northeastern and East Central Utah and Central Colorado. The water consumptive use associated with the increases in the agricultural and energy activities is approximately 3,130,000 acre feet or 500,000 acre feet more than the free market solution (Scenario I) in 1985. The associated water consumptive use by subbasin is given in Table 26. The consumptive use of water by state is given in Table 27. The comparison of Table 22 and 27 indicates that agricultural and energy consumptive use has increased by 28,300 acre feet in Wyoming, 199,200

TABLE 26

ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE AND ENERGY IN 2000 BY SUBBASIN (1,000 ACRE FEET)

Subbasin	Agriculture	Energy	Total
1	451.6	90.4	542.0
2	158.1	106.1	264.2
3	368.7	332.4	701.1
4	228.5	4.7	233.2
5	367.6	26.8	294.4
6	354.6	.7	355.3
7	427.3	109.9	537.2
8	67.0	34.7	101.7
TOTAL	2,424.2	705.7	3,129.9

TABLE 27

ESTIMATED WATER CONSUMPTIVE USE BY STATE IN 2000 (1,000 ACRE FEET)

State	Total Allotment	Total Consumption	Unallocated Water
Wyoming	542.0	542.0	0
Colorado*	2,171.0	1,785.1	931.9
Utah	1,100.0	802.8	297.2
TOTAL	4,359.0	3,029.9	1,229.1

* New Mexico's share is included in Colorado's share.

acre feet in Colorado and New Mexico, and 303,400 acre feet in Utah over 1985.

No water conservation technology was adopted. Over 8 million tons of salt was allowed to pass to the lower basin. The outflow is approximately 10,049,000 acre feet. The model predicted 0.80 tons of salt per acre foot, an increase of 5.3 percent for the free market solution.

The energy sector used 100 percent wet tower cooling for nuclear power generation and fossil fuel generation; surface mining of oil shale in Northwestern Colorado and underground mining for shale in Southwestern Wyoming, Northeastern Utah and Central Colorado; surface retorting of tar sands for oil in Northeastern Utah, Central Utah and Colorado, and Southwestern Utah; and the lurgi method of coal gasification in Wyoming and Utah. The energy sector impacts are the same in all Scenarios in 2000.

The net returns to the upper basin decreases by $13.35 million as a salinity standard is imposed. The net returns to agriculture decrease by $4.2 million. Salt loading is decreased and the Colorado River outflow to the lower basin increases by 500,000 acre feet. The public investment in water conservation projects total $9.1 million, of which $5.9 million is for lining 2,983 miles of canals, $631,900 is for 9,432 acres in sprinkler irrigation, $536,700 is for evaporation suppression and $424,000 is for phreatophyte spraying. The public investment in salinity control is $1.6 million for the Paradox Valley evaporation ponds. Over 281,000 acre feet could be salvaged, thus reducing the salt load downstream.

The net returns to the basin decrease an additional $4.7 million under conditions of zero appropriations for public investment in water

evaporation, phreatophyte and salinity control projects. The total investment increases by $3,703,100 (41 percent) to $12.806 million. Over 147,000 acre feet of salvaged water is possible. The salinity regulation is the greater deterent to development. Over 5,600 miles of canals need to be lined and 24,351 acres of crops are to be sprinkler irrigated. Table 28 shows the agricultural consumptive use of water given zero public investment in evaporation, salinity and phreatophyte control projects and a government salinity regulation. When compared to no salinity regulation (Scenario I) the table shows a 237.0 acre feet decrease in consumptive use.

If the salinity control projects are funded, the total net return to the basin decreases by $15.7 million over Scenario I (as compared to a $18 million decrease without salinity control funding). The only salinity control project to be funded will be the Paradox Valley unit and the number of miles of canals that will be lined will decrease by 2,000 miles.

Net sector returns decrease by $12.2 million as a damage cost is imposed on the upper basin in the form of compensation to the lower basin for increased salt concentration over the EPA level set in 1974. The total increase in salt concentration is 5.03 percent with an associated damage cost estimated to be over $6.7 million. The agricultural consumptive use of water is estimated at 2.35 million acre feet.

The total cost of water conservation projects and salinity control projects is over $4.49 million, salvaging 229,000 acre feet of water at $19.61 per acre foot. The water conservation measures include 708 miles of canal lining; 9,432 sprinkler irrigated acres; over $536,000 of reser-

TABLE 28

ESTIMATED WATER CONSUMPTIVE USE IN AGRICULTURE UNDER CONDITIONS OF A SALINITY REGULATION AND ZERO CONSERVATION INVESTIGATION IN 2000 WITH THE MAGNITUDE OF CHANGE AS COMPARED TO NO SALINITY REGULATION (1000 ACRE FEET)

Subbasin	Agriculture	Change
1	453.3	-16.3
2	158.1	0
3	368.7	0
4	195.5	-33.0
5	297.4	-70.2
6	354.6	0
7	310.6	-116.7
8	67.0	0
TOTAL	2,187.2	-237.0

voir evaporation suppression; $299,000 in phreatophyte control; and $1.6 million dollar salinity control investment in the Paradox Valley unit.

The net returns to the basin decrease an additional $1.2 million and a total compensation of $11.9 million is charged to the upper basin for increasing the salt concentration by 8.86 percent as funds for reservoir evaporation suppression, phreatophyte control and salinity control projects are eliminated. The elimination of the $2.5 million of public investment increases the salinity level of the Colorado River from 5.03 percent to 8.86 percent, with an associated increase of $5.2 million in damage cost.

Table 29 summarizes the cost and water salvage potential of various conservation measures and salinity control projects under four scenarios in 2000 for 14.9 MAF annual flow.

Scenario IV is the most efficient allocation of water given public investment. The cost of water conservation per acre foot of water salvage is $19.61 with associated damage costs of $6.7 million.

Case 2, 13.8 MAF Annual Flow

The following results are obtained when the annual flow of the Colorado River is adjusted to 13.8 MAF based on the 1922-1974 average virgin flow at Lee's Ferry.

The 1974 model results of Case 2 compares closely with the 1974 results of 14.9 MAF annual flow. The consumptive use of water in agriculture totaled 2.02 MAF and in energy totaled 35,600 acre feet, for a total consumptive use of 2,055 MAF. The excess of water allotment to each state ranged From 155,000 acre feet in Wyoming to 1.3 million in Colorado and New Mexico. The outflow of the Colorado River is 10.85 MAF

TABLE 29

COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 2000 UNDER CONDITIONS OF 14.9 MAF FLOW. (COST IN THOUSANDS OF DOLLARS)

Technology/ Project	Scenario II Salvage	Scenario II Cost	Scenario III Salvage	Scenario III Cost	Scenario IV Salvage	Scenario IV Cost	Scenario V Salvage	Scenario V Cost
Agriculture								
Canal Lining	65,821	5,872.8 (2,983 mi)	147,003	11,115.0 (5,646 mi)	23,400	1,393.9 (708 mi)	23,400	1,393.9 (708 mi)
Sprinkler Irr.		631.9 (9,432 acres)		1,691.5 (24,351 acres)		631.9 (9,432 acres)		631.9 (9,432 acres)
Energy								
Other Sectors								
Reservoir Evap. Suppression	15,891	146.2			15,891	146.2		
Reservoir De-stratification	162,145	390.5			162,145	390.5		
Spraying	42,000	424.0			32,000	299.0		
Mech. Spraying								
Salinity Control								
Paradox Valley	-4,000	1,638.0			-4,000	1,638.0		
TOTAL	281,857	9,103.4	147,003	12,806.5	229,436	4,499.5	23,400	2,025.8
(Cost/AF)	($32.30/AF)		($87.11/AF)		($19.61/AF)		($86.57/AF)	

with an associated salt flow of 8.37 million tons for an average of .772 tons of salt per acre foot.

For 1985, the share of water to each state for Case 2 is given in Table 5. For every scenario, the consumptive of water by state is less than the allocated levels for each state. The excess water in Wyoming ranges from 39,305 acre feet for Scenario I to 78,500 acre feet in Scenario V; for Colorado and New Mexico, 393,037 acre feet for Scenario I to 611,066 acre feet in Scenario III; and 337,636 acre feet in all scenarios for Utah. An additional 223,400 acres of potentially irrigable land the expansion of the energy sector in electricity production and oil shale production is indicated.

The optimum level of water conservation technology under agricultural and energy development is predicted under the following five scenarios. The associated level of energy production is the same in all scenarios. Each energy development process, i.e., electricity, coal production, crude oil production, refined oil production, oil shale production, etc., is being produced at full capacity. Wet tower cooling is used for electricity production, underground mining is used for shale in subbasins 3 and 5, and surface mining is used for shale in subbasin 2.

Table 30 summarizes the investment cost and the total water salvaged in four alternative scenarios in 1985 for 13.8 MAF flow. As the most efficient allocation of water, Scenario IV with positive public investment and regulation, the cost of water conservation per acre foot of water salvaged is $19.51 with the associated damage cost of $7.11 million. Scenario I, which indicates the free market solution, has a value of agriculture $900,000 more than Scenario IV and total net returns of $12.4 million more.

TABLE 30

COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS 1985 UNDER CONDITIONS OF 13.8 MAF FLOW. (COST IN THOUSANDS OF DOLLARS)

Technology/ Project	Scenario II		Scenario III		Scenario IV		Scenario V	
	Salvage	Cost	Salvage	Cost	Salvage	Cost	Salvage	Cost
Agriculture								
Canal Lining	65,821	5,872.8 (2,983 mi)	139,402	10,624.1 (5,396 mi)	23,400	1,393.9 (708 mi)	23,400	1,393.9 (708 mi)
Sprinkler Irr.		607.9 (9,074 acre)		1,569.0 (23,419 acre)		608.5 (9,083 acre)		608.5 (9,083 acre)
Energy								
Other Sectors								
Res. Evap. Suppression	15,891	146.2			15,891	146.2		
Res. Destratification	162,145	390.5			162,145	390.5		
Spraying	42,000	424.0			32,000	299.0		
Mech. Clearing								
Salinity Control								
Paradox Valley	-4,000	1,638.0			-4,000	1,638.0		
TOTAL	284,857	9,079.4	139,402	12,193.1	229,436	4,476.1	23,400	2,002.4
(Cost/AF)	($31.87/AF)		($87.47/AF)		($19.51/AF)		($85.57/AF)	

The results predicted by the model for the free market solution are the same under 14.9 and 13.8 MAF annual flow of the Colorado River. The difference between the two is over 1.2 MAF less outflow to the Lower Basin, increasing the salt concentration to .87 tons per acre foot.

In Scenario II, the consumptive use of water in agriculture remains about the same as under 14.9 MAF except for subbasin 7. Consumptive use decreases by 115,000 acre feet caused by lining 1,541 miles of canals, thus increasing the return flow to the basin to maintain the salinity standard. Scenario III indicates the decrease in public investment of $2.6 million in salinity, evaporation and phreatophyte control increases investment in canal lining and sprinkler irrigation by $5.7 million. The average cost of water salvage increases from $31.87 to $87.47.

The level of salt concentrations increase by 5.3 percent increasing downstream damage cost to $7.11 million and public investment totals $4.476 million to salvaging 229,436 acre feet of water in Scenario IV. In Scenario V, the salt concentration increases downstream by 9.3 percent, resulting in $12.5 million in damage cost to the Upper Basin and increases investment in canal lining and sprinklers to $2.002 million.

A comparison of Table 30 to Table 25 indicates that the total cost of public investment expenditures for water conservation in 1985 is roughly the same under 14.9 MAF annual flow and 13.8 MAF annual flow of the Colorado River given each assumption for the various Scenarios.

In 2000, the number of potentially irrigable land increases by 9,360 acres and the energy sectors capacity of existing and new development expand as indicated above. In all scenarios, the energy sectors production is the same given 13.8 MAF and 14.9 MAF annual flow.

Given the total allocated water in each state, Wyoming consumptively uses its entitlement and Utah consumes all except 22,000 acre feet. The net returns to the agricultural sector is $10.6 million less than the results under 14.9 MAF flows. The total public investment in each Scenario are approximately the same in Case 2 as in Case 1 (see Table 29). The major difference between the two cases is the increased salt loads downstream and the reduced outflows. Table 31 shows the percent change in salt concentration downstream from Lee's Ferry over the government regulation and the outflow to the Lower Basin in each scenario for Case 1, 14.9 MAF annual stream flow, and Case 2, 13.8 MAF annual stream flow. As Table 31 indicates, given the policy of no government regulation on salinity, as the Colorado River's stream flow decreases, the salinity concentration increases downstream over the EPA regulation level established in 1974. Also, the outflow downstream decreases by an average of 1,027,200 acre feet with no government regulation and by an average of 1,037,950 acre feet with government regulation.

Case 3, Summer Flow

The following results are predicted when the model is adjusted to a six-month period of summer stream flows of the Colorado River and its tributaries. Annual stream flows of 13.8 MAF, state water allocations based on 13.8 MAF, and half of the energy output is produced in a six-month period is assumed.

The energy production levels are one-half the production levels, capacities, net returns, and consumptive use of water as described earlier for 1974 model results under Case 1 and 2 of

TABLE 31

PERCENT CHANGE IN SALT CONCENTRATION AND THE COLORADO RIVER OUTFLOW AT LEE'S UNDER CONDITIONS OF 14.9 and 13.8 MAF ANNUAL STREAM FLOW GIVEN ALTERNATIVE LEVELS OF GOVERNMENT POLICY IN 2000.

Scenario		Percent Change in Salt Concentration 14.9 MAF	Percent Change in Salt Concentration 13.8 MAF	Outflow of Colorado River at (AF) 14.9 MAF
I	NR* NCI NSI	11.98	12.27	10,049,100
II	R CI SI	0	0	10,514,700
III	R NCI NSI	0	0	10,433,200
IV	NR CI SI	5.03	5.01	10,352,100
V	NR NCI NSI	8,86	9.06	10,146,000

* R - Salinity Regulation; NR - No Salinity Regulation, CI - Public Conservation Investmen NCI - No Public Conservation Investment; SI - Salinity Control Investment; NSI - No Sali Control Investment. Note: Scenarios IV and V include a damage cost charged to the Uppe Basin due to increased salinity levels downstream.

14.9 MAF and 13.8 MAF stream flow. The agricultural sector expands as indicated in earlier sections. For Scenarios IV and V, which do not impose a salinity standard but a damage cost for increased salinity salt downstream, the level of concentration over the EPA level does not increase downstream. The results of the analysis for Scenarios IV and V are the same as the assumptions for Scenarios II and III respectively.

In 1985, for all scenarios, the states, allotments of Colorado River water is not totally used. Wyoming consumptively uses 513,700 acre feet of its allotted 553,000. Colorado and New Mexico have an excess of 463,000 acre feet of their allotted 2,049,000 acre feet, and Utah 500,000 consumption is 337,000 acre feet less than its allotment.

In 2000, Wyoming consumptively uses its entire allotment of 375,000 acre feet of Colorado River water for the annual period and Utah consumptively uses all of its 825,000 acre feet allotment, except for 22,356 acre feet. Colorado and New Mexico has over 250,000 acre feet in excess of their consumptive use. The net agricultural consumptive use of water in Wyoming is 190,000 acre feet less than consumptively used in 1985 for all policy alternatives in 2000.

Table 32 summarizes the cost, salvage and average cost per acre foot of water salvage for the various government policy alternatives in 1985 under summer flow assumptions.

The results given under the assumption of government investment in conservation technology and salinity control projects and damage costs attributed to the Upper Basin for increased salinity concentra-

TABLE 32

COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 1985 UNDER CONDITIONS OF SUMMER FLOW. (COST IN THOUSANDS OF DOLLARS)

Technology/ Project	Scenario II		Scenario III		Scenario IV		Scenario V	
	Salvage	Cost	Salvage	Cost	Salvage	Cost	Salvage	Cost
Agriculture								
Canal Lining			64,738	5,684.8 (2,888 mi)			64,738	5,684.8 (2,888 mi)
Sprinkler Irr.		498.8 (7,445 acre)		607.9 (9,074 acre)		498.8 (7,445 acre)		607.9 (9,074 acre)
Energy								
Other Sectors								
Res. Evap. Suppression	15,891	146.2			15,891	146.2		
Res. Destratification	160,645	375.5			160,645	375.5		
Spraying	27,000	249.0			27,000	249.0		
Mech. Spraying								
Salinity Control								
Paradox Valley	-4,000	1,638.0			-4,000	1,638.0		
TOTAL	199,536 ($14.57/AF)	2,907.5	64,738 ($97.20/AF)	6,292.7	199,536 ($14.57/AF)	2,907.5	64,738 ($97.20/AF)	6,292.7

tion downstream is the same as the results under the imposition of a salinity standard. This is due to the fact that the level of salt concentration downstream has not increased over EPA standards set in 1974. During the six-month summer period, the majority of stream flows, ranging from 49 to 87 percent with an average of 70 percent of annual stream flow based on U.S.G.S. stream gauging records occurred. An average of 60 percent of salinity concentration occur during the same six-month summer period. Thus, the salt load is not increased over government regulation levels. This also holds when public funds are eliminated. The salinity concentration downstream does not increase.

A comparison of Table 32 to Tables 25 and 30 indicate the relative differences in water conservation cost per acre foot salvage in each scenario. In all scenarios except Scenario V, the public investment level is less and thus the cost per acre foot salvaged is less.

Table 33 summarizes the cost and water salvaged under the alternative policy scenarios in each sector of the economy for the summer flow assumption in 2000. By comparing Table 33 to Table 29, it can be shown that total public water conservation investment is less under summer flow assumptions for all scenarios except Scenario V, as were the results in 1985.

TABLE 33

COST OF WATER CONSERVATION TECHNOLOGY AND SALINITY CONTROL PROJECTS AND THE WATER SALVAGED UNDER FOUR ALTERNATIVE SCENARIOS IN 2000 UNDER CONDITIONS OF SUMMER FLOW. (COST IN THOUSANDS OF DOLLARS)

Technology/ Project	Scenario II Salvage	Scenario II Cost	Scenario III Salvage	Scenario III Cost	Scenario IV Salvage	Scenario IV Cost	Scenario V Salvage	Scenario V Cost
Agriculture								
Canal Lining			59,926	4,886.4 (2,482 miles)			59,926	4,886.4 (2,482 miles)
Sprinkler Irr.		7.2 (108 acres)		631.9 (9,432 acres)		7.2 (108 acres)		631.9 (9,432 acres)
Energy								
Other Sectors								
Res. Evap. Suppression	9,316	85.7			9,316	85.7		
Res. Destratification	160,645	375.5			160,645	375.5		
Spraying	8,403	77.3			8,403	77.3		
Mech. Spraying								
Salinity Control								
Paradox Valley	-4,000	1,638.0			-4,000	1,638.0		
TOTAL (Cost/AF)	174,365 ($12.52/AF)	2,183.7	59,926 ($92.09/AF)	5,518.3	174,365 ($12.52/AF)	2,183.7	59,926 ($92.09/AF)	5,518.3

CHAPTER VI

DISCUSSION

The purpose of this study was to determine the welfare cost of alternative government policies, i.e., regulation and investment policies, on the allocation of water in the Upper Colorado River Basin. This chapter analyzes the various public policies and the trade off associated with increasing agricultural profits.

Public Policy Analysis

If the assumption is made that the appropriate government policy is a salinity regulation on stream flows and public investment in water conservation and salinity control projects, then public investment will total $8,489,000 in 1985 given an assumption of 14.9 MAF annual stream flow. Public investment in the non-agricultural sector will total $2,598,700 and in the agricultural sector will total $5,890,300. In 2000, total public agricultural investment increases by $614,400 and public investment in the non-agricultural sector stays the same. The cost of salvaging one acre foot of water increases from $30.50 to $32.30. See Table 34 for the public investment expenditures for 14.9 MAF flow. Net agricultural returns decline by $3 million in 2000 due to cropping pattern changes.

If water conservation projects such as evaporation and phreatophyte control in the non-agricultural sector and salinity control projects are not funded, the investment in canal lining and sprinkler irrigation systems total $7,443,500 in 1985 and $12,806,500 in 2000.

The comparison of the two policy alternatives, positive or zero public investment in the non-agricultural sector in water conservation

and salinity control projects, indicates in 1985 that investment in the agricultural sector is $1,553,200 greater without assistance in the non-agricultural sector for dilution purposes. Total public investment is $1,045,500 less without non-agricultural investment. The $1,045,500 added investment increases net farm income by $4.97 million since the dilution of Colorado River water is not undertaken by the agricultural sector but by evaporation suppression, phreatophyte control, and the Paradox Valley evaporation ponds. Net basin income is $3.926 million more with the additional investment.

In 2000, total investment is $3,757,100 more without investment in the non-agricultural sector. Agricultural investment is $6,504,700 with non-agricultural investment and is $12,806,500 without the assistance. The $3,757,100 total less investment results in overall net farm income increase by $1,013,000 and net basin income increase by $4.6 million.

If the appropriate government policy is to relax the salinity regulation and charge the Upper Basin States a damage cost for increased downstream, a comparison of the government policy to invest or not in water conservation and salinity control projects is given below. Investment in the agricultural sector totals $2,002,400 and investment in the non-agricultural sector totals $2,473,700 in 1985. Net agricultural returns total $133.171 million. By 2000, the agricultural investment increases $23,400 and net returns to agriculture increase by $321,000 due to additional irrigated acreage. If the government policy is to not fund non-agricultural water conservation and salinity control projects, the total agricultural investment remains the same in 1985 and 2000 as above, $2,002,400 and $2,025,800, respectively. The average cost of water salvaged per acre foot increases about four and one half

times from $19.51 to $85.57 in 1985 and from $19.61 to $86.57 in 2000, in the comparison of funding non-agricultural water conservation projects. However, in 1985 damage cost to the Upper Basin in increased salinity concentration downstream increases from $3.5 million with non-agricultural investment to $8.66 million without investment. In 2000, the damage cost totals $6.7 million with investment and $11.86 million without the non-agricultural investment. This indicates that the $2.47 million investment in non-agricultural, i.e., evaporation suppression and phreatophyte control, water conservation and salinity control projects can reduce damages to downstream users on the order of $5.16 million in 1985 and 2000. Table 34 has these comparisons.

The results indicate that the net returns to the basin and agriculture are the highest under the assumption of no regulation on salinity levels, positive public investment, and a damage cost charged to the Upper Basin on increased salinity concentration downstream. Analysis of Bureau of Reclamation projects in the western states indicates that partial repayment and in some cases, full repayment of the public investment will be required. However, with very few exceptions, the success of the repayment schemes are nil. It would not be expected for the irrigators to pay back any investment under taken by the public sector. Any investment in salinity control will not be expected by the private sector.

The analysis is the same for a lower stream flow, e.g., 13.8 MAF annual flow, as for 14.9 MAF annual flow. The only major difference is an additional $4.749 million increase in agricultural investment required in 1985 under the assumption of a salinity regulation and no funding of non-agricultural water conservation projects. Table 35 shows

TABLE 34

PUBLIC INVESTMENT EXPENDITURES IN 1985 AND 2000 UNDER ALTERNATIVE PUBLIC POLICIES FOR 14.9 MAF ANNUAL FLOW (THOUSANDS OF DOLLARS).

		1985		2000	
Scenario		Investment Expenditure	Salinity Damage Cost	Investment Expenditure	Salinity Damage Cost
II	Public	$8,489.0		$ 9,103.4	
	Ag.	5,890.3		6,504.7	
	Non-Ag.	2,598.7		2,598.7	
	($/AF)	30.50		32.30	
III	Public	7,443.5		12,806.5	
	Ag.	7,443.5		12,806.5	
	Non-Ag.	0		0	
	($/AF)	113.09		87.11	
IV	Public	4,476.1	$3,500.0	4,499.5	$ 6,700.0
	Ag.	2,002.4		2,025.8	
	Non-Ag.	2,473.7		2,473.7	
	($/AF)	19.51		19.61	
V	Public	2,002.4	8,660.0	2,025.8	11,860.0
	Ag.	2,002.4		2,025.8	
	Non-Ag.	0		0	
	($/AF)	85.57		86.57	

Note: Scenario II and III include a government salinity regulation and Scenario's IV and V do not.

TABLE 35

PUBLIC INVESTMENT EXPENDITURES IN 1985 AND 2000 UNDER ALTERNATIVE PUBLIC POLICIES FOR 13.8 MAF ANNUAL FLOW (THOUSANDS OF DOLLARS).

		1985		2000	
Scenario		Investment Expenditure	Salinity Damage Cost	Investment Expenditure	Salinity Damage Cost
II	Public	$ 9,079.4		$ 9,103.4	
	Ag.	6,480.7		6,504.7	
	Non-Ag.	2,598.7		2,598.7	
	($/AF)	31.87		32.30	
III	Public	12,193.1		12,806.5	
	Ag.	12,193.1		12,806.5	
	Non-Ag.	0		0	
	($/AF)	87.47		87.11	
IV	Public	4,476.1	$ 7,100.0	4,499.5	$ 6,700.0
	Ag.	2,002.4		2,025.8	
	Non-Ag.	2,473.7		2,473.7	
	($/AF)	19.51		19.61	
V	Public	2,002.4	12,500.0	2,025.8	12,100.0
	Ag.	2,002.4		2,025.8	
	Non-Ag.	0		0	
	($/AF)	85.57		86.57	

Note: Scenario II and III include a government salinity regulation and Scenario's IV and V do not.

the cost of the alternative policies in 1985 and 2000 given 13.8 MAF flow. Net agricultural returns and basin returns remain about the same. The relation of the salinity standard imposes salinity damage costs of $3,500,000 in 1985 and $6,700,000 in 2000 with non-agricultural water conservation investment. Without the $2,473,700 investment in the non-agricultural sector, then the damage costs increases by $5.4 million in 1985 and 2000.

In 2000, public investment of $2.2 million will achieve the same results except that private investment is $500,000 to $700,000 less.

The free market solution, i.e., no regulations, incentives, or subsidies to influence the decision-making process, has total net returns to agriculture 1 to 6 million dollars and total net returns to the basin 10 to 18 million dollars more than any other policy alternative when comparing years, 1985 to 2000, flows, 14.9 MAF, 13.8 MAF and summer, and policy alternatives, investment in the non-agricultural sector or not and salinity damage cost. However, the salinity concentration downstream increases between 9.5 and 12.5 percent over the 1974 EPA standard. Also, the streamflow past Lee's Ferry is approximately 350,000 to 465,000 acre feet less due to a higher application and consumptive use of water in agriculture. Thus, downstream damages in the form of reduced return flow, reduced stream flow, and increased salinity are not adjusted.

Trade-Off Analysis

The trade-off between increased agricultural profits and the charge in public investment is analyzed given the following assumptions:

1. Annual stream flows are approximated for 14.9 MAF,
2. Positive public investment in salinity control projects,

3. Government regulations on salinity concentration will be maintained, and

4. The potential irrigated acreage expands by 233,440 acres in 1985 and by 9,360 acres in 2000.

The analysis includes positive or zero public water conservation investment in evaporation suppression and phreatophyte control, the impacts on net basin income and net agricultural income, and the level of public investment. The maximum level of net agricultural returns is $134.086 million in 1985 and $134.442 million in 2000 for the free market solution.

Table 36 is the summary of public investment costs in 1985 and 2000 under the alternative public policy choices of positive and zero funding of evaporation and phreatophyte water conservation projects. As the public funding for water conservation projects is eliminated, the analysis indicates an associated rise in agricultural investment and an increase in welfare loss to the basin.

If public policy, in 1985, is to fund water conservation investment in both the agricultural and non-agricultural sectors in order to expand the agricultural net returns by $915,000, to the free market level of maximum net returns, then investment increases by $1,685,000 for 25,000 acres of additional sprinkler irrigation technologies. There is an approximate $500,000 decrease investment in lining 250 miles of canals due to switching to sprinkler systems and the associated crop net returns with sprinkler irrigation. Net basin returns decrease by $281,000. The public investment in evaporation suppression and phreatophyte control is unchanged. Total agricultural investment increases by $1.2 million to $7.268 million and non-agricultural

TABLE 36

NET BASIN RETURNS, NET AGRICULTURAL RETURNS, AND PUBLIC INVESTMENT EXPENDITURES IN 1985 AND 2000 AS NET AGRICULTURAL RETURNS INCREASE (MILLIONS OF DOLLARS).

	1985 With Non-Ag Public Investment			1985 Without Non-Ag Public Investment		
	Initial Solution	Max Net Ag Returns	Change (dollars)	Initial Solution	Max Net Ag Returns	Change (dollars)
Net Basin Returns	$2,624.726	$2,624.445	-$ 281,000	$2,622.29	$2,622.29	-$ 450,000
Net Ag Returns	133.171	134.086	915,000	130.816	134.086	3,270,000
Non-Ag. Investment	2.599	2.599	0	1.638	1.638	0
Ag. Investment	6.073	7.268	1,195,000	6.664	10.384	3,720,000
(canals)	(5.282)	(4.792)	(-490,000)	(5.873)	(7.313)	(1,440,000)
(sprinklers)	(.791)	(2.476)	(1,685,000)	(.791)	(3.071)	(2,280,000)

	2000 With Non-Ag Public Investment			2000 Without Non-Ag Public Investment		
	Initial Solution	Max Net Ag Returns	Change (dollars)	Initial Solution	Max Net Ag Returns	Change (dollars)
Net Basin Returns	$4,592.779	$4,592.210	-$ 569,000	$4,590.44	$4,589.70	-$ 740,000
Net Ag. Returns	130.196	134.442	4,246,000	129.183	134.442	5,259,000
Non-Ag. Investment	2.599	3.199	600,000	1.638	1.638	0
Ag. Investment	6.687	10.905	4,218,000	8.975	14.972	5,997,000
(canals)	(5.873)	(7.722)	(1,849,000)	(7.161)	(11.789)	(4,628,000)
(sprinklers	(.814)	(3.183)	(2,369,000)	(1.814)	(1.813)	(1,369,000)

Note: Public Investment in salinity control projects is allowed to take place, thus resulting in the $1,638,000 figure in Non-Ag Investment.

investment is unchanged at $2.6 million, of which $1.638 million is for the Paradox Valley salinity control project.

The impacts associated with the expansion of net agricultural returns are net basin returns decrease by $281,000, net agricultural returns increases by $915,000 agricultural investment increases by $1.2 million, and non-agricultural investment is unchanged.

When public policy is to not fund non-agricultural conservation projects and net agricultural returns increases by $3.27 million, total agricultural investment increases by $3.72 million. Net basin returns decreases by $450,000.

Initially, net basin returns total $2,622.74 million, net agricultural returns total $130.816 million, and agricultural investment totals $6.664 million, of which $791,000 is investment in sprinkler irrigation systems and $5.87 million is investment in canal lining. An increase of $1.183 million in net agricultural returns causes a $113,000 decrease in net basin returns and a $1.297 million increase in agricultural investment for 14,360 additional acres of sprinkler irrigation technology and 170 additional miles of canals lined. To increase net agricultural returns by another $1.0 million to $133.0 million reduces net basin returns by $153,000 to $2,622.47 million and increases canal lining investment by $1.133 million in lining 474 miles of canals.

The welfare loss to the basin is $183,000 as agricultural investment increases by $1,270,000 to increase net returns to agriculture by $1.086 million. Over 19,670 additional acres of agricultural land is sprinkler irrigated. A decrease of approximately 24 miles of canals are lined. Additional increases in agricultural profits results in a trade-off between sprinkler irrigation incentives and canal lining incentives.

The impacts associated with the expansion of net agricultural returns by $3.27 million are net basin returns decrease by $449,000 and agricultural investment increases by $3,720,071 of which $1,540,219 is in canal lining and $2,279,852 is in sprinkler irrigation.

In 2000, given public investment in the non-agricultural sector, net basin returns total $4,592.779 million, agricultural returns total $130.196 million, agricultural investment totals $6.69 million, and non-agricultural investment totals $2.6 million. An increase of $804,000 in net agricultural returns causes a $59,000 decrease to the basin and a $866,000 increase in investment for canal lining. To increase net returns to agriculture by an additional $1.0 million to $132.0 million reduces net returns to the basin by an additional $120,000 to $4,592.6 million and increases agricultural investment by $517,700 and non-agriculture investment by $600,000 through chemical spraying and the mechanical clearing of streambanks of phreatophytes.

Net basin returns decreases by $150,000 and agricultural investment in increases by $1.15 million in canal lining to increase net returns to agriculture by another $1.0 million. In order to increase net agricultural profits, total investment expenditures plus the decreased net basin profits is the increase in total agricultural profits. Since the non-agricultural sector is totally funded for all water conservation projects, the increase in agricultural profits comes about from investment in sprinkler irrigation or canal lining by a larger amount than is returned. Net energy returns are unaffected by increases in agricultural profits.

The analysis given zero public investment in non-agricultural water conservation projects causes overall private investment expenditures to

be greater than the increase in net returns to agriculture. Net basin returns decreases causing a welfare loss to the Upper Colorado River Basin. The welfare loss is the difference between the increased agricultural returns and the increased cost of water conservation measures. As net agricultural returns increases by $1.817 million to $131.0 million, agricultural investment in canal lining increases by $2,011,520 to a total of $9,172,188. The welfare loss to the basin is $190,000. An additional $1.0 million increase in net agricultural returns causes an increase in canal lining by $1,152,812 and a welfare loss of $152,812.

In all cases, the increase in net agricultural returns is less than the cost of agricultural investment to implement the increased returns. In 2000, welfare loss to the basin is $569,000 with public investment and $740,000 without public investment. Increased agricultural profits are generated by decreased basin profits and increased public investment in agriculture and evaporation/phreatophyte control. The salinity level downstream is unaffected, thus, no additional costs due to lower basin damages are taken in consideration.

Concluding Remarks

In 1985, public investment in water conservation programs will necessitate agricultural investment by $1.195 million, however without public investment in water conservation programs, agricultural investment will have to increase by $3.72 million. In 2000, the range for agricultural investment is $4.218 million with public investment to $5.977 million without public investment in water conservation projects. Thus, even without public investment, the public policy framework must include large investments in the agricultural sector for farmers and

irrigation districts to increase agricultural profits. The welfare loss will range upwards to $740,000 without public investment in 2000. Therefore, the argument to maintain the family farm and to increase family farm profits could promote increased debts to the farm where the profits the farm receives could not pay off the investments needed.

The results of the model also suggests that while some trade-off exists between agriculture and public investment, the salinity concentration of the Colorado River is the major constraint to development. If energy development and agricultural growth is to take place given the Environmental Protection agency ruling in 1974 to meet minimum salinity levels, public investment in water conservation and salinity control projects must take place. Without public investment in agricultural water conservation projects, agricultural growth will not take place and will not compete with the energy sector for water. The cost to net agricultural sector is $5.887 million in 1985 and $5.259 million in 2000 under 14.9 MAF annual flow.

As increases in the salt concentration occurs downstream, the imposition of an addition cost borne by the Upper Basin decreases the opportunity to increase profits. For example, the increased concentration costs could range from $3.5 million to over $12 million depending on the year and the level of public investment in the agricultural and non-agricultural sectors. The increases in agricultural profits, however, is minimal, ranging from zero increase to over $3.4 million, again depending on the year and the level of public funding. Irrigators will not be willing to pay for the increase damage cost at all. In most cases, public assistance in canal lining and sprinkler irrigation will seem to be most fitting.

A final result is that electrical power generation, oil shale production, tar sand production, and coal gasification is maintained at the highest net income to the producer regardless of the level of water consumption.

A limitation of this study and thus a recommendation for further research is the restriction of the transferability of water. To restrict the transfer of water between sectors and states could prevent an optimal allocation of output. Further research is also needed to determine the availability and cost of credit for agriculture, energy, and other sectors for water conservation projects.

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