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PROJECTED DEMANDS AND SUPPLIES OF WATER UNDER ALTERNATIVE ENERGY AND AGRICULTURAL DEVELOPMENT SCENARIOS IN THE GREEN RIVER DRAINAGE OF WYOMING

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INTRODUCTION

The Green River drainage in Wyoming contains large deposits of oil shale, tar sands, crude oil, coal and natural gas that are used to produce refined petroleum products, natural and synthetic gas and electrical power. Agriculture is the predominant consumer of water in the area, accounting for over 90 percent of the total depletions. With new energy projects and the associated growth of population and affluence, the demand for water is expected to increase. Future anticipated energy development and production in the energy rich areas of the 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 through adopting water conserving practices and by substituting other factors 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.

In economic terms, conservation is defined as the care and preservation of natural resources in such a way as to prolong and make for their most effective use (Sloan and Zurcher, 1970). 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. The adoption of water conservation measures may decrease the supply of water and/or change the timing of supplies to the downstream users due to reduced return flows and/or 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 determining benefits to water conservation measures. Water conservation practices, in response to increases in the price of water such as improvements to water conveyance and application systems, could reduce water diversions in irrigated agriculture. These practices are likely to increase irrigation efficiency, but at the same time reduce return flows. In the energy sector, the demand for water can be reduced by conservation measures such as, the use of waste or brackish water in energy development projects, alternative methods of mining and dry or hybrid cooling towers in power generation. Other water conservation practices (not available to the private sector) include reduction of water evaporation from reservoirs and the consumption of water by phreatophytes along canals and river banks. In the long run, substitution of capital 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; Franklin, 1982; Hyatt, 1970; and State of Wyoming, 1977b). Water management programs may be instigated by individual water users when water quantity and/or water quality problems, such as increased salinity or competition for the same water supply, are relatively isolated and can be effectively solved. When water use problems cannot be effectively solved on an individual basis, such as may be the case in the Green River Basin, the public sector may act to achieve a balance. In most cases, government management policies have been an imposition of regulations. For example, in the Upper Colorado Basin, the government policy on salinity is a standard administered by the Environmental Protection Agency (EPA). Salinity does not impose much damage to water users in the Upper Basin. Significant damages are imposed on water users in the Lower Basin in the form of crop damage, decreased soil productivity, high treatment costs, pipe corrosion and greater use of detergents and chemicals.

An agreement between the Upper Basin States and the EPA in 1974, requires salinity be maintained at or below 1972 levels. Anticipated energy development in Wyoming and other upper basin states of the Colorado River Basin could affect the salinity standards imposed by the EPA. For example, surface mining operations for coal, oil-shale and tar sands will expose new geologic materials to the atmosphere and could contribute additional salt to surface and subsurface runoff. Also, additional withdrawals of surface water to meet expanding energy needs will increase the salt concentration of remaining river flows.

The appropriation of presently unused water for increased energy production in the Green River Basin of Wyoming could increase the salinity for downstream users. In 1976, the EPA imposed salinity standards 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 these salinity regulations. The primary problem addressed by the model is the choice of alternative public investments in water conservation and salinity control given the salinity regulations on the Colorado River.

Public policy alternatives investigated were the investment in water conservation programs such as evaporation suppression, phreatophyte control for dilution purposes, investments in sprinkler irrigation systems and the lining of irrigation canals.

Water utilization is altered by changes in the value of water and the cost of resources. For example, new technologies have allowed irrigators to use water more efficiently. While crop yields per unit of water can generally be increased through investments in water management practices and greater use of substitute and complimentary inputs, for example, fertilizer, 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 use of water in the agriculture and energy producing sectors. 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 losses due to phreatophytes and reservoir evaporation. For each alternative method, it is important to consider both the quantity and the cost of conserving water, i.e., the supply functions. Water quality constraints also are considered.

It is important to specify financing of the particular conservation or water management practice. Financing of the water conservation and water quality projects is assumed to be from public and/or private 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 could accrue to both the individual farmer and downstream users, the investment could be shared by both the private and government sector. Government incentives in the form of tax exemptions or low cost loans may facilitate private investment expenditures on water conservation practices as part of the cost is covered by the public. In this study, sprinkler irrigation systems and canal linings were financed by the private sector.

There is a large choice of technical alternatives from which the agricultural and energy sectors can choose to achieve the economically efficient level of water conservation. It is the purpose of this study to determine the cost and impact on income of alternative water conservation policies in the Green River Basin.

Objectives of the Study

This project focuses on the substitution of capital for water within and between the agricultural and energy sectors of the Green River drainage basin economy in Wyoming. The substitution process is analyzed both with the imposition of a salinity regulation and without the regulation. This study compares alternative courses of action to achieve economic growth in the basin.

A question that is often raised is the extent that water conservation measures may be applied to irrigated agriculture and to the energy sector without reducing agricultural output. For example, given a fixed water supply, how might farmers and energy managers substitute other factors of production for water so that the agricultural base is maintained in the face of increasing water demands? 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 stock energy resources are physically or economically depleted. The major objectives of this study are:

1. Develop a suitable methodology to analyze the economics of alternative structural and non-structural water use technologies in agriculture and energy;
2. Estimate, over time, the costs of alternative water conserving practices that may be implemented in response to growing demands for water;
3. Evaluate alternative economic policies that provide incentives for adoption of optimum techniques of water use over time; and
4. Develop a model that is applicable to any water basin in Wyoming.

The specific objectives of this study are:

1. To identify the need for water conservation measures as well as water saving techniques employed by different sectors of the economy in response to increased water demands;
2. To determine the cost of public sector investments in water conservation measures given a salinity regulation; and
3. To examine the welfare cost of public policies aimed at changing water use in the energy and agricultural sector.

Methodology

A mathematical programming model was developed to maximize net income for the agriculture and energy sectors of the Green River Basin. The model also measured the impacts caused by the adoption of alternative water conservation technology. Different levels of water use were determined by altering water conservation measures in the sectors. The water conservation measures that maximize net sectoral income with the lowest cost to society 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. Current 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.

Expansion of municipal water demand to meet energy growth is included in the energy sector.

Study Area

The study area is the Green River drainage basin located in Wyoming (see Figure 1). The Green River begins in the northern end of the basin in the Wind River Range of Wyoming and passes into eastern Utah at the southern end of the basin through Flaming Gorge Reservoir. 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 geographical and physical features of the Green River Basin are summarized in Table 1.

Table 1. Major Geographical and Physical Features of the Green River Drainage in Wyoming.

Rivers	Communities	Physical Features	Political Units
Green	Green River	Wind River Range	Carbon County
Big Sandy	Rock Springs	Red Desert	Fremont County
Hams Fork	Kemmerer	Flaming Gorge	Lincoln County
Henry's Fork	Eden	Fontenelle Reservoir	Sublette County
Savery Creek	Farson		Sweetwater County
	Big Piney		Teton County
	Pinedale		Uinta County

The Green River Basin in Wyoming is both one of the fastest growing energy areas and a water-use area, so an economic analysis of alternative water conservation technologies may be quite fruitful.

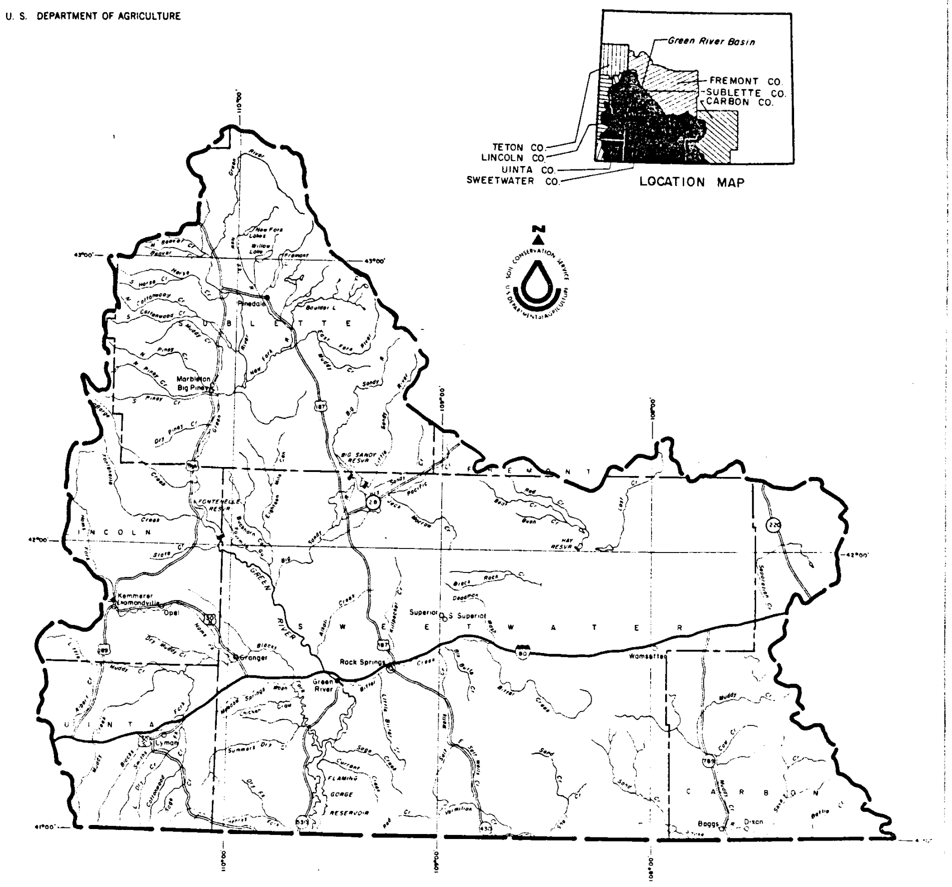

FIGURE 1
GREEN RIVER BASIN
UINTA, SWEETWATER, CARBON, LINCOLN,
SUBLETTE, FREMONT, AND TETON COUNTIES, WYOMING

JUNE 1973
10 0 10 20 30 40 MILES
SCALE 1:1,500,000

Source: Wyoming State Engineer

Potential Water Conservation Practices

The water required for production of energy units and the consumptive use in agriculture is more or less constant. One of the major problems associated with development in the Green River Basin is the large "losses" of water occurring from reservoir evaporation and evapotranspiration from phreatophytes. Investments in water conservation practices to reduce these "losses" is investigated in this report. The overall level of conservation practices are given below.

Phreatophytes, 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 that 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 17 western states, it is estimated that phreatophytes consume 25 million acre-feet annually (Robinson, 1958). To dramatically illustrate the water used by phreatophyte, for every 10 acre-feet of water used in agriculture, eight 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 to 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. Total evaporation estimates range from 5,000 to 100,000 acre-feet annually for all of the major reservoirs and wetlands in the Green River Basin. It is estimated at Flaming Gorge Reservoir alone, fresh water evaporates at a seasonal rate of 69,481 acre-feet (Hughes et al., 1974). Most evaporation estimates in the Green River Basin excluding Flaming Gorge are slightly over 25,000 acre-feet annually.

Total water diverted by agriculture can be reduced by shifting to less water intensive crops, better maintenance of current irrigation distribution systems, or capital-intensive water distribution systems, i.e., lined canals, pipelines, sprinkler systems, etc. Capital substitution is thought to be a major source of water conservation by water policy planners. However, as indicated by Frickel (1980), increased conveyance efficiency through capital substitution does not necessarily imply reduced water diversions. 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 to the point where his marginal benefits are equal to his marginal costs. In such an adjustment process, the farmer will likely reduce return flows thereby decreasing downstream flows. Since water rights of downstream users are in part based upon seepage, only the water not available for further beneficial use will be regarded as a loss. There could also be legal complications associated with such water conservation practices. 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.

Clawson (1977, p.5) states, "The west will use its limited water supply and its limited area of first class cropland more intensively in the decades ahead." His conclusion is based on the premise that irrigated agriculture has been encouraged to use water, because of a water rights system which makes water transfers difficult and extensive subsidization of irrigation water costs. Clawson further concludes, "Irrigation use of water will come under increasing pressure to yield value products as great as might be achieved with the same water elsewhere." This implies that the efficient use of irrigation water may be necessary to maintain agricultural production in an area.

The inequality of the marginal benefits of water between upstream and downstream may cause inefficient water allocations in a basin. Take for example the situation where the upstream user of water has higher costs and lower revenues due to the inability to substitute other factors for water in order to maintain or increase the supply of water to the downstream user. This substitution of other factors for water is not an economic improvement for the upstream user. However, if the compensation paid to the upstream user for his higher cost is less than the downstream users improved net revenue position, then the reduced water use would be a potential improvement for the basin. Thus, it is important to determine the overall effects of alternative water conservation measures in a region. Water policy planners must be aware of the potential for added returns.

Technology is also available to decrease water consumption in energy production. For example, Abbey (1979) discusses several options available to electric power generation plants to reduce water use. 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 less than 100 acre-feet per year per 1,000 MW; and the hybrid cooling system, which combines dry and wet tower cooling and reduces water requirements to l,000-5,000 acre-feet per year per 1,000 MW. The costs of water reductions by a dry or a hybrid cooling system are 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 per year compared to a wet cooling system; for a 40 percent wet system, cost is estimated at $870 per acre-foot per year 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 opposed to dry cooling in power generation, it can be concluded that water availability will have a small effect on the price of electricity.

Even though water rights can be transferred among water uses, social and legal difficulties associated with water ownership and transfers must be resolved for optimal utilization to occur. Most western states follow the doctrine of prior appropriations in appropriating waters within the state. This doctrine states "first in time, first in right" which means the right of the first users of water in the state proceeds the rights of future users of water. Under Wyoming 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) the proposed use will not impair existing rights, (c) the proposed used is physically feasible, and (d) the proposed use will not adversely affect the environment and welfare of the public. In Wyoming, a water right is generally regarded as being tied to the land and therefore cannot be sold independent of the land. However, agricultural water rights can be transferred to other uses by filing a petition which must be approved by the state engineer. In Utah, a water right is independent of the land. The sale or transfer of water rights is a means by which water can be allocated within or between agricultural and energy producing sectors.

These potential water conservation practices are 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 Green River Basin.

WATER RESOURCES

Development of energy resources in Wyoming is going to require substantial amounts of water. As to whether additional supplies of water are available to sustain anticipated energy development and its associated economic activities has spurned several water inventory studies. Studies that include the Green River Basin are the annual reports by the Upper Colorado River Commission, U.S. Department of the Interior (1974), the U.S. Water Resources Council (1971), and the State of Wyoming (1977). The 1977 report by Wyoming concluded that from 340,000 to 580,000 acre-feet of water per year is available to meet future needs in the Green River Basin. This is also consistent with other water inventory reports for the Upper Colorado River Basin, notably, Narayanan et al. (1979) and Hyatt et al. (1970).

The actual flow of the Colorado River is less than the flow estimated for the Colorado River Compact made between Wyoming, Colorado, New Mexico, Utah, Arizona, Nevada and California on November 24, 1922. Article III of the Colorado River Compact apportioned in perpetuity the exclusive beneficial consumptive use of 7,500,000 acre-feet of water per year to the Upper and Lower Basin states. Under Article III of the Upper Colorado River Basin Compact signed on October 11, 1948, Wyoming's share is 14 percent or 1,043,000 acre-feet of water per year after Arizona's entitlement of 50,000 acre-feet. However, this estimated flow of the Colorado River was overly optimistic. The Upper Colorado River Commission estimates the annual virgin flow is 14,000,000 acre-feet. To meet the obligations of 7,500,000 acre-feet per year to the Lower Basin states, an additional 750,000 acre-feet delivery to Mexico under Section III of the Mexican Treaty signed on February 3, 1944 and Arizona's entitlement, Wyoming's share of water under the Upper Colorado River Basin Compact would be 798,000 acre-feet.

Under Article III of the Colorado River Compact, all reallocation of water due to an overestimation of flow is to be shared by the Upper Basin states. This tends to be a greater burden on Wyoming and the other states to meet their obligations in water short years,

Since the water available for allocation established under the Colorado River Compact is insufficient to meet the compact allocations, the Upper Basin states, which includes Wyoming, have less than their share of the annual consumptive use of 7,500,000 acre-feet allocated in the compact. As indicated by the State of Wyoming's 1977 report, Narayanan et al. (1979), Upper Colorado River Commission and the U.S. Bureau of Reclamation, considerably less water is available for consumptive use in the Green River Basin of Wyoming. The Upper Colorado River Basin Commission keeps fairly accurate data on the "virgin" or natural flows of the Colorado River and thus, the allotments to each state.

The base figure used in this study is the U.S. Water Resources Council's long term discharge of 14,994,200 acre-feet per year for the Colorado River. Wyoming's share would be 864,000 acre-feet per year after evaporation losses are accounted for. With 1975 depletions in Wyoming amounting to 409,200 acre-feet, additional water available to meet Wyoming's future needs is 454,800 acre-feet on an annual basis.

Water Use Practices in Agriculture

Irrigation is the largest consumptive use of water in the Green River Basin. Over 250,000 acre-feet of water are consumed annually by irrigation (State of Wyoming, 1977b). This accounts for over 90 percent of the total depletions in the basin. Due to the arid climate, irrigation is an essential component of crop production. Over 336,000 acres of land were under irrigation in 1975. Most of the cropland is in pasture, hay and small grains. There is a potential for increased yields on 205,000 acres by better and more intensified management (State of Wyoming, 1977b). Increased cultivation on an additional 115,000 acres is also probable. Whether or not it is economically viable will be analyzed.

Alternative technological practices to increase irrigation efficiency include reducing seepage from conveyance system, reservoir evaporation and evapotranspiration by phreatophytes, i.e., deep rooted plants that do not contribute to the beneficial use of water and deep percolation. Water losses attributable to phreatophytes and weeds are estimated to be 25-60 percent of the water used in agriculture (Horton & Campbell, 1974; Isrealson and Hansen, 1967). It is estimated that the conveyance systems, including seepage in unlined canals, for irrigation 15-60 percent of the diversions are returned (Isrealson and Hansen, 1967). Since water rights of downstream users are based in part upon seepage and return flows, only the water not available for further beneficial use will be regarded as a loss in this study.

Several alternatives to improve the efficiency of conveyance, i.e., reduce conveyance losses, are available and are examined in the literature. Aerial spraying of phreatophytes is effective, but causes some crop damage. Treatment of canal banks with ground rigs, clearing, mowing and channalization are other alternatives. Canal lining with concrete, clay or rocks or delivering water through pipes are other high-efficiency conveyance means but are relatively more expensive (Isrealson and Hansen, 1967; Cummings and Gisser, 1977). Adoption of these alternatives can save water lost through deep seepage or evapotranspired by weeds and phreatophytes and as a result is not available to downstream users.

Changes in water application methods can also reduce the demand for water. It is estimated that 30-50 percent of the water applied is consumptively used by crops under flood irrigation, 70-80 percent for sprinkler irrigation and upwards to 95 percent for trickle systems. However, under high wind conditions, sprinkler systems may be less efficient. In analyzing cost-effectiveness of saving water through alternative irrigation systems, the suitability of irrigation methods to terrain and crops grown received careful consideration. The efficiency of water use under alternative irrigation practices and associated costs can be estimated from available data (Narayanan, Padungchai and Bishop, 1979; Franklin, 1982; and Olson, 1977 (a), (b)).

Water Use in Energy

Coal mining, steam electric power generation plants, oil and gas industries and trona mining are the major industrial users of water in the basin. Currently, 10 percent of the water depletions are accounted for by these industries (State of Wyoming, 1977b).

Projected energy development in coal, oil and gas, trona, uranium and oil shale by 2000 will bring about large increases in the consumptive use of water. Upwards of five to eight fold increases in consumptive use by the energy sector may be needed to meet all projected developments.

Although projections of water use in the energy sector are available, these are based on specific assumptions about the techniques of production. For example, in a coal fired steam electric plant, the water demand can vary from 2000 AF/yr/l000 MW to 15,000 AF/yr/l000 MW, depending on the kind of cooling system used (Hu, Pavlenco and Englesson, 1978). The costs become higher as the associated cooling system requires less water. Water quality considerations and the price of water will decide the optimal technology required for water use in energy production. With the value of water estimated at about $10-20 per acre-foot in agriculture, the energy sector is expected to use high water-consuming technologies. Private irrigation decisions will not necessarily bring about an optimal total basin-wide management strategy, therefore, the appropriate economic policy will have to be considered. This study incorporates alternative water demands and their associated costs to present the economically efficient alternative for the basin and compares it with alternative courses of action to achieve a balanced and viable economic growth in the basin.

Other Water Uses

Reservoir evaporation depletions, fish and wildlife, recreation, municipal and domestic consumption, exports and other depletions such as Wyoming's share of the Colorado River Storage Project (CRSP) evaporation, combine to account for approximately 120,000 acre-feet per year--less than 30 percent of the total consumptive use in the Green River Basin. Any increase in energy production will also tend to increase municipal water demand. Yet any salvage of water through reduction of reservoir evaporation or phreatophyte transpiration will decrease the basin's overall depletion thereby allowing for more water for other beneficial uses.

Water Quality Issues

Of major importance with any development of Colorado River Compact Water is the need to meet PL 92-500 and PL 95-217. The Colorado River Basin Salinity Control Act (PL 93-320) authorized the Secretary of the Interior to construct several projects for the improvement, enhancement and/or protection of water quality in the Colorado River. One important project to Wyoming is the Big Sandy River Unit. It is a project to reduce salt loading of the Big Sandy River and the Green River. The Big Sandy River discharges an estimated 180,000 tons of dissolved solids annually into the Green River (U.S. Dept. of the Interior, 1976). The Big Sandy River Unit as proposed consists of a number of wells drilled along a 15 mile reach of the river that contributes 110,000 tons of salt annually to the Big Sandy River. The project will reduce salt loading by approximately 80,000 tons of salt per year with an estimated total cost of 32 million dollars. Approximately 6,000 acre-feet of water is pumped in the above option to improve water quality and as such is regarded as a consumptive use of water in the Green River drainage.[1/]

The Colorado River Basin Salinity Control Act is the major reason for the construction of the Big Sandy River Unit. Without point source control measures, the salinity concentration will exceed the 879 mg/l criteria established by PL 92-500. This report analyzes the contribution of Wyoming's Green River drainage basin to salinity in the Lower Colorado River Basin.

[1/] Chevron Oil Company has signed an agreement to use this water with water from Fontenelle Reservoir in a fertilizer plant outside of Rock Springs. It is estimated that 10 to 11 thousand acre-feet of water can be salvaged. This report does not look into that option. Additional information since January 1983 indicates that Chevron Oil will not likely participate in the project without Federal funding. As of August 1983, there are no plans to build a fertilizer plant nor use water from the Green River.

ECONOMIC ANALYSIS

Alternative water conservation measures in irrigated agriculture and energy development will have a variety of economic, social and environmental impacts on the Green River Basin. The impacts of non-energy surface water development, i.e., reservoir construction, pipelines, etc., will tend to be outweighed by the impacts associated with energy development; for example, 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 a shift in recreation use/opportunities depending on the type and extent of development. Any development of surface-water supplies in the Green River Basin will have to take into consideration the existing legal and political agreements pertaining to water rights, preservation of endangered species and river compacts between states.

Under the water rights system within the state, it is possible for water to be transferred from the agricultural sector to the energy sector. Given an efficient agricultural sector, as water is transferred away from agriculture 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 in terms of income 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 should 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, 1979), the gain in income in the energy sector would be 10 to 100 times greater than the loss in agricultural income. This will also be true in

Wyoming. Thus, the transfer of water from agriculture to energy is anticipated in accordance to the state's water rights system.

Within the Green River Basin, agriculture accounts for the major portion of surface water depletions. Of the estimated 500,000 acre-feet of water diverted for irrigation each year, 250,000 acre-feet are consumptively used by crops. Water not consumed by crops or phreatophytes is returned to the stream by surface return flow and seepage or percolates into aquifers. Consumptive use by crops is a function of soil moisture, soil salinity, type and density of crop and climate. Both water depletions due to the evapotranspiration process and return flows due to seepage-from canals and over-irrigation increase salinity downstream.

Better on-farm irrigation water management would generally result in increased yields and reduced variable costs, but higher capital cost to the irrigator. Some important considerations with increased irrigation efficiency are changes in soil salinity and crop production, timing and quantity of downstream flows and salinity concentrations downstream. All of these factors need to be considered in determining whether or not and which irrigation conservation practice should be implemented.

Major deposits of coal, oil, natural gas, oil shale, trona and tar sand are located in the Green River Basin. Currently, 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 expansion of steam electric power generating plants are planned for most areas of the basin.

Water quantity and environmental concerns, both air and water pollution, must be addressed by any energy development plans. Adoption of water conservation measures can minimize water pollution in some areas at additional costs, but may increase water quality problems downstream. Both economic feasibility and environmental impacts will determine the development of these resources.

Model Formulation

The general nature of the management model used to evaluate the impacts of water conservation practices and salinity options in the Green River Basin is presented and the potential uses of the model explainedin this report. A formal mathematical statement of the management model is given in Appendix A.

The empirical model is a linear programming model which maximizes net sector income for the agricultural and energy sectors by allocating water within and between the two sectors of the economy. Net sector income is gross income less the cost of production, but does not include the cost of water or land. Different levels of water allocations are determined by including various water conservation measures in the two sectors. The water conservation measures that maximize net sector income with the lowest cost of salinity control to the basin determine the allocation of water. Lying at the heart of the model is the choice of the amount of water in agriculture and energy and the level of technology for water distribution and use (sprinkler, lined canals, type of cooling technology, etc.). The model maximizes net farm income and net energy income subject to various constraints. The constraints are irrigated acres, crops, crop rotation, water intensity or application levels, the irrigation distribution technology, salinity, water availability, energy use, water technology, labor, raw materials and capital equipment.

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, the sector is conserving water. 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 so the maximum amount of net income is generated from the water used. Net farm income does not include the cost of water, however, all capital expense for improved technology is deducted from the returns to the farm sector. Thus, capital costs of investment decrease the total returns but are "affordable" to private irrigators. 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 factors of production are substituted for water in irrigated agriculture, then water use can be reduced.

Water conservation in the energy sector also is 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, coal gasification, oil shale development, etc.

It should 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 water consumption is less in the former than in the latter.

The model maximizes net sector income (agriculture and energy), subject to constraints imposed in the agricultural and energy sector and additional costs incurred by the public sector for measures to control salinity, evaporation and phreatophytes. The adoption of these projects will, in effect, reduce salinity and the demand for non-agricultural and non-energy water use. These costs are subtracted from net sector income as the costs of these projects are borne by the state. Any water conservation policy or program adopted benefits the users and is thereby assumed to be a cost subtracted from the net sector income.

In an imperfectly competitive market where restrictions are placed on the use or the transfer of water from one sector to another sector, as in Wyoming, the economic efficient allocation of water may not result. However, the linear program used for this study will still achieve an efficient allocation of water for the given constraints imposed on water in the Green River Basin. The choice of constraints affects the results of the model in terms of net income, costs of salinity control and other costs. These results can be used to calculate sector, state and regional impacts.

Scenarios

To measure the agricultural sectors output, energy sectors output and water use associated with alternative water conservation measures, six scenarios are analyzed in this study. The initial scenario determines the optimal allocation of water between sectors under current conditions. Municipal and industrial and other uses are allocated their use of water prior to the allocation by agriculture and energy. As the demand for water increases, it is possible to determine the appropriate water conservation practices policy-makers should implement in order to increase the economic welfare of the basin. The value of the objective function in each scenario is compared with the initial scenario to determine the impacts of each policy.

Scenario I

Scenario I maximizes net sector income maintaining the level of water quality specified by EPA standards in 1974. This scenario allows for government regulation and investment in water conservation practices.

Investments in water conservation technologies decreases the amount of water demanded for the same level energy production. Energy producers will have an incentive to adopt water conserving practices if the increased marginal value of water exceeds the additional cost of the conservation practice. This is also true in the agricultural sector. The investment in 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 likely the adoption and therefore the investment in water conservation practices. This scenario is used as a base example of current procedure and practice.

Scenario II

For Scenario II, the model maximizes net sector income subject to the previous constraints. The level of water quality is not restricted and thus a salinity control cost is imposed on Wyoming for increase salinity downstream that may exceed the salinity standard. The salinity control cost is $133.94 for each additional salt ton exceeding the EPA standard. This change is associated with increased damages downstream for pollution control (Andersen and Kleinman, 1978) and is charged to Wyoming. The analysis determines if the salinity control cost is large enough to warrant an increase in the level of capital investment in irrigation practices or in water conservation practices. The damages are subtracted from net sector returns to the basin as a cost per mg. per liter of reducing salinity downstream. It is assumed throughout this study that any on-farm capital investment will be made by the private sector. The private sector, in particular the irrigator, will not be expected to pay for any public investment in salinity control. In fact, it is quite clear the irrigator will not be able to pay back any investment given historical records of the Bureau of Reclamation. However, private and public investment in salinity control is allowed to take place. 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 regardless of the level of salinity and given impacts to downstream users.

Scenario III

Under Scenario III, the level of public investment in water conservation projects and in salinity control projects is zero. Additional costs of meeting the EPA salinity standard are suffered by farmers. This scenario results in an improvement of efficiency in the water distribution system from the point of diversion to the point of discharge on the farm. In this scenario, farmers make capital improvement investments in order to conserve water. This scenario allows for private investment, if needed to maintain the agricultural base of the economy under conditions of tight fiscal control by federal and state governments. The comparison of Scenario I 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 the impact of salinity control costs on Wyoming and private investment in conservation as the salinity standard is relaxed. The salinity control cost is the same as for Scenario II. Private but not public investment in salinity control is allowed to take place.

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

Scenario V

The fifth scenario increases the net agricultural returns in the year 2000 by approximately 24 percent. This is an associated growth of 1.2 percent per year. The EPA standard is adhered to and both private and public investment is allowed. The growth in the agricultural sector is analyzed to assess the impacts agricultural growth has in the basin.

Scenario VI

The last scenario also increases net agricultural returns by 24 percent and salinity control investment is allowed in the private and public sectors. However, the salinity standard is relaxed and the salinity control cost is imposed on the basin for increased salinity damages to downstream users.

The last two scenarios achieve the results that would be obtained if the "family farm" policy and rational agricultural growth is firmly maintained. The relaxation of the salinity standard is to measure the impacts on Wyoming.

DATA DEVELOPMENT

Numerous sources were used to obtain the agricultural and energy sector's production coefficients, water resource availability, water quality, consumptive use and economic data. The majority of the data were taken from three publications: Franklin (1982); Narayanan, Franklin and Bishop (1982); and Narayanan, Padungchai and Bishop (1979).

Water Resources

The virgin flow of the Green River and its tributaries is derived by using hydrologic data obtained from Franklin (1982), Narayanan et al. (1979) and State of Wyoming (1977). Wyoming's share of water with the flow of the Colorado River at 14.9 million acre-feet is 937,000 million acre-feet. However, subtracting off Colorado River Storage Project evaporation losses and current levels of depletions of municipal, industrial, export, wildlife and other uses, the current supply of water available for the agricultural and energy sector is estimated to be 770,000 acre-feet annually. By 2000, the state's available annual supply for the agricultural and energy sector is estimated to be 542,000 acre-feet. The water available for consumptive use in the model is derived by subtracting current and future consumptive water use from annual flow.

The salinity concentration level associated with the tributaries and the Green River is a weighted average of salt and water flow of the Green River Basin. The estimated salt loading and flow of water is obtained from Padungchai (1980).

Table 2 gives Wyoming's share of the Colorado River water, present and projected consumptive use and available supply of water. Table 3 shows the planned Big Sandy River salinity control project and its effect on salt loads, the cost and consumptive use of water.

Table 2. Available Water for Agricultural and Energy Development with the Effect of Big Sandy River Salinity Control Unit.

		Wyoming 14.0%	Current Consumptive Use[a/]	Current Net Available	Projected Consumptive Use in 2000[a/]	Projected Net Available in 2000
		(AF x 10^3)				
Average annual flow of Colorado River	14,994					
Lower Basin share	8,300[b/]					
Upper Basin share	6,694	937				
Main Stem evaporation	520	73				
Net Upper Basin share	6,174	864	94	770	322	542

Source: Franklin (1982); and Narayanan, Padungchai and Bishop (1979).

[a/] Current and projected consumptive use is the sum of non-irrigation and non-energy uses, i.e., municipal, industrial, export, wildlife, project evaporation, etc.

[b/] Lower Basin Share = 7.5 MAF, Mexico = 0.75 MAF, and Arizona = 0.05 MAF.

Table 3. Big Sandy River Unit Salinity Control Project Estimated Effect.

Project	Estimated Salt Reduction (tons/year)	Estimated cost ($ millions)	Water Loss (acre-feet)
Big Sandy River Desalting Project	80,000	32	6,000

Source: Narayanan, Padungchai and Bishop (1979).

Agricultural Activities

Seven irrigated crops were selected for the study area. They are alfalfa (full and partial irrigation), hay, barley, wheat, oats, nurse crops and pasture. Annual prices and crop yields were obtained from Wyoming Agricultural Statistics over the last seven years while production costs were obtained from Olson (1977a and 1977b). Ten percent higher yields were used for sprinkler irrigations based on Frickel (1980), Franklin (1978) and Cummings et al. (1977). These three reports indicated yields increased as application uniformity improved.

Total irrigated land is approximately 274,000 acres of which about 186,000 acres is irrigated hay. An additional 59,070 acres of land has the potential for irrigation by the year 2000. Table 4 gives the crop yield, consumptive use, irrigated acres and net returns for flood and sprinkler irrigation by crop for the Green River Basin. Sprinkler investment costs are subtracted from the objective function.

Energy Activities

Production in the energy sector is divided into natural energy mined and final energy produced. The natural energy output include underground and strip mined coal, petroleum, natural gas and crude oil from oil shale. The final energy outputs are converted from natural energy outputs. These include electricity from coal fired electric generation plants, synthetic natural gas from coal gasification facilities and refined oil products.

The prices and costs of producing coal, crude oil and natural gas at the well head, shale oil and refined products from crude oil were reported in Padungchai (1980), Narayanan et al. (1979), and Keith et al. (1978). Specific details on the actual development of the prices received and operating costs are given in the above sources. The average price of electricity was obtained from Narayanan et al. (1979). Cost data for alternative cooling technologies were obtained from Hu, Pavlenco and Englesson (1978); and U.S. EPA (1979). Cost information for various oil shale and coal gasification developments was obtained from Probstein and Gold (1978) and Keefer and McQuivey (1979).

Table 4. Estimated Annual Crop Yields, Consumptive Use, Net Returns per Irrigated Acre for Flood and Sprinkler Irrigated Acres.

	Alfalfa		Nurse					
	Full	Partial	Crop	Barley	Wheat	Oats	Hay	Pasture
	(ton)	(ton)	(bu.)	(bu.)	(bu.)	(bu.)	(ton)	(AUM)
Annual flood irrigated yield	2	1.25	55	55	32.1	60	1.5	2
Annual sprinkler irrigated yield	2.2	1.375	60.5	60.5	35.31	66.0	1.65	2.2
	- - - - - - - - - - - - - -(acre feet) - - - - - - - - - - - -							
Consumptive use per acre for flood irrigation	2.1	1.1	1.6	1.2	1.67	1.6	1.6	1.3
Consumptive use per acre for sprinkler irrigation	2.31	1.21	1.76	1.32	1.837	1.76	1.76	1.43
	- - - - - - - - - - - - - - -(dollars/acre) - - - - - - - - - - -							
Net returns per flood irrigated acre	42.58	15.06	34.87	34.87	19.98	2.88	24.69	9.00
Net returns per sprinkler irrigated acre	46.84	16.57	68.61	68.61	14.63	3.17	27.16	9.90
	- - - - - - - - - - - - - - - -(acres)- - - - - - - - - - - - -							
Current irrigated acres	62,317		19,767		3,550	2,383	185,867	85

Source: Franklin (1982).

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

The current and future planned energy production capacities for natural energy output and final outputs were obtained from Narayanan et al. (1979), Padungchai (1980), Franklin (1982) and State of Wyoming (1981).

The net returns, current and future energy production capacities for the energy activities are given in Table 5.

Table 5. Net Returns and Capacities for Selected Energy Production Activities.

Energy Activity	Net Returns (Dollars/Unit)	Production Capacities 1980	2000
Underground coal (ton)	$ 0.96	0	58,000,000 tons
Strip coal (tons)	0.96	15,130,000 tons	47,800,000 tons
Petroleum (bbl)	3.93	18,750,000 bbl	11,573,500 bbl
Natural gas (mcf)	0.21	203,204,000 mcf	136,437,000 mcf
Refined oil (bbl)	13.84	1,200 bpd	1,200 bpd
Coal gasification (mcf)	0.14	0	250 mmcfd
Oil shale		0	100,000 bpd
- surface retort (bbl)	3.92		
- insitu retort (bbl)	2.92		
Electricity-coal fired (Mwh)		2,743 MW	2,743 MW
- 100% wet evap. cooling	9.04		
- 40% wet evap. cooling	4.96		
- 10% wet evap. cooling	3.00		
- 100% dry cooling	1.50		

Source: Padungchai (1980); Narayanan et al. (1979); Keefer and McQuivey (1979); U.S. EPA (1979); Hu, Pavlenco and Englesson (1978); Keith et al. (1978); Probstein and Gold (1978); and the State of Wyoming (1981).

When the natural energy products are converted to final energy outputs, energy losses occur during the conversion process. Energy conversion process efficiencies were obtained from Keith et al. (1978) and Narayanan et al. (1979).

The consumptive use of water in the conversion process were obtained from Narayanan et al. (1979), Keefer and McQuivey (1979), U.S. EPA (1979), Colorado Department of Natural Resources (1979), Hu et al. (1978), Keith et al. (1978) and Probstein and Gold (1978). Estimates of water requirements for energy production are given in Table 6.

Non-Agricultural and Non-Energy Activities

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

Table 6. 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	
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	

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 (1979).

The costs per acre of canal clearing of phreatophytes by mechanical clearing and spraying of phreatophytes and reservoir evaporation suppression were derived and updated from Hughes, Richardson and Franckiewicz (1974 and 1975); Culler (1970); Kearl and Brannan (1967); Bowser (1952); and Koogler (1952). These are given in Table 7. The cost of these activities are included in the profit function associated with either the agricultural or energy profits.

Estimates of water salvaged by phreatophyte control 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), Robinson (1958) and U.S. Water Resources Council (1971). The estimates of evaporation water that can be salvaged by various methods were derived in Hughes et al. (1974 and 1975). Table 7 gives the estimates of water salvaged by evaporation suppression and phreatophyte control.

Table 7. Estimated Cost and Water Salvaged from Alternative Methods.

	Reservoir Evaporation Suppression		Phreatophyte Suppression			
	Monomolecular Film	Destratification	Sparse Growth Spraying	Dense Growth Spraying	Mechanical Clearing	Canal Lining
cost[a] ($/AF)	9.20	10.00	10.00	35.00	20.00	1968.75[b]
Total potential water salvaged (AF/Yr)	1,312	1,500	5,000	1,500	5,000	24,000

Source: Hughes et al. (1974 and 1975), Horton and Campbell (1974), Culler (1970), Kearl and Brannan (1967), Robinson (1958), Blaney (1952), Bowson (1952), Cramer (1952), Koogler (1952), Robinson (1952), Turner and Skibitzke (1952) and U.S. Water Resources Council (1971).

[a] Annual cost.

[b] Canal lining costs are annual costs in dollars per acre.

MODEL RESULTS, DISCUSSION AND CONCLUSIONS

The mathematical model estimates the economic impacts of agricultural and energy development and the optional allocation of water given alternative water conservation technologies in the Green River Basin for the years 1980 and 2000. The year 1980 represents a base year for production and prices and thus a basis for comparison with the impacts of future development.

The salinity standard established by the EPA in 1974 at Imperial Dam is first held constant and then relaxed to investigate the impact of salinity control on private and public investment and development within the Green River Basin in Wyoming.

In 1980 under the assumptions of Scenario I, maximum net return to the agricultural and energy sectors in the Green River basin is $348 million. The net return for the agricultural sectors is $5 million and for the energy sector $343 million. Total public investment is $12,070 for evaporation suppression. Private investment in canal lining and sprinklers is not economically justified. Consumptive use is 313,984 acre-feet in agricultural and 30,187 acre-feet in energy.

For Scenario II, which is different from Scenario I in that the salinity standard is relaxed and a cost is imposed on Wyoming for increased salinity downstream, the results are the same as for Scenario I. Since the level of public investment in evaporation suppression is maintained for 1980 conditions, this implies the cost to Wyoming of evaporation suppression as a means to reduce salinity concentration is less than the cost of damages imposed by increased salinity downstream. The cost of evaporation suppression is $9.20 per acre-foot, far less than the salinity damage cost of $133.94 per ton per acre-foot.

Investments in phreatophyte and evaporation controls are not publicly financed in Scenario III and IV. As a result, net agricultural returns are reduced by $12,780 from $5 million and the level of net energy production and returns are not affected. Again, salinity concentration downstream is not allowed to exceed the standard imposed by the EPA.

The same linear programming model was used to determine the net income to agriculture and energy in the basin for various agricultural and energy development in the year 2000. For Scenarios I and II, net basin returns for agriculture total $4.8 million and for energy $533 million or a total or $537.8 million. Total consumptive use of water is over 380,000 acre-feet of which over 80 percent is used by agriculture. As in 1980, Wyoming does not consumptively use all of its allotted Colorado River water. Approximately 160,000 acre-feet are still available for use. The salinity concentration with the additional development does not exceed the EPA standard imposed at Lee's Ferry.

As the public investment of $12,070 in evaporation suppression is eliminated, overall salinity is not affected but net agricultural returns decrease by $12,000.

Table 8 summarizes the results of the linear programming model for Scenario I and II. In Scenarios III and IV, net returns for agriculture and the basin consumptive use and irrigated acres are slightly less while public investment is zero.

Comparison of the two policy alternatives, i.e., positive vs. zero public investment funding, indicates in 1980 and 2000 that with a $12,070 public investment in evaporation suppression agricultural net returns are larger by $12,780. Since energy production is at maximum level, no further increases are forthcoming, all additional water is allocated to agriculture.

Table 8. Model Results for Maximizing Net Sector Returns for Agriculture and Energy in 1980 and 2000 as Estimated by the Mathematical Model for Scenario's I and II.

	Agriculture		Energy		Basin	
	1980	2000	1980	2000	1980	2000
Net returns ($000)	5,000.7	4,760.4	343,002.7	533,008.9	347,947.5	537,773.2
Water consumptive use (AF)	313,894	305,214	30,187	75,622	344,081	380,837
Irrigated acres	194,974	190,185				
Public investment cost					12,070	12,070

Thus, private individuals and farmers tend to reap the entire benefits of the evaporation suppression investment, i.e., agricultural returns increase by the exact amount of evaporation suppression cost.

The damage charge to Wyoming in 2000 from the relaxation of the EPA salinity standard is zero. This is because the amount of water actually diverted in the Green River Basin alone is not large enough to increase the salinity concentration of Colorado River water. It is recognized that development in other Upper Basin states could affect the quantity and therefore the quality of water at Lee's Ferry, thus an environmental charge would be imposed on Wyoming and the other states.

By the year 2000, net agricultural returns are reduced by $240,254 (5 percent) and 4,789 acres (2.5 percent) are taken out of production. Net energy returns are $190.0 million larger (55 percent). As water use expands with growth in the energy sectors, streamflow is reduced causing an increase in salinity concentration. Increased salinity concentration could result in damage costs being imposed on Wyoming. Since damage costs are greater than net returns to agriculture, agricultural production is reduced to meet salinity standards.

A question arises as to what are the conditions under which the continued viability of irrigated agriculture in the Green River Basin might be possible with salinity controls and energy development. "The continued viability of irrigated agriculture" refers to the conditions where irrigated agriculture returns remain at least constant in year 2000. It is assumed for planning purposes that in 2000 the net value of agricultural products will increase by approximately 24 percent to 6.2 million over 1980.2/

2/ This implies that prices received will increase faster than prices paid which is a heroic assumption to say the least. Yet this is one possible method to force the linear program to achieve a growth in the agricultural sector in order to analyze the impacts given agricultural growth in the basin.

The next section discusses impacts with a growing and maintained agricultural base. Conclusions are also presented with regards to public and private investment alternatives to enhance development in southwestern Wyoming.

Impacts of Agricultural Growth

As the previous section indicates, if growth in the Green River Basin by the year 2000 is correctly forecast, salinity and water availability are not constraints to development. However, private on-farm investment is too costly to undertake and public evaporation and phreatophyte control investment is minimal.

The trade-off between increased agricultural profits and the cost in terms of reduced energy production and salinity damage costs are given in Table 9. The analysis includes the impacts on net basin income and net energy income under public funding of evaporation and phreatophyte control measures. Table 9 is the summary of costs associated with increased agricultural returns given the alternative of relaxing or maintaining the EPA salinity standard.

If the salinity standard is relaxed by the year 2000 and irrigated agriculture expands, the analysis indicates agricultural returns increase by $1,439,400 over 1980 levels and net energy returns are not affected. Public investment increases by $65,000 ($15,000 in reservoir destratification and $50,000 in phreatophyte control) to $77,100. This is a cost of $9.87 per acre-foot for salvaging 7,812 acre-feet of water. The cost imposed on the state for damages associated with a salinity concentration that is 1.2 percent over the standard is $1,566,900. The net returns to the basin are reduced by $192,400 as agricultural expansion takes place and the salinity standard is relaxed.

If the EPA salinity standard were maintained at the Colorado River compact point, Lee's Ferry, then increased net returns of $1,439,600 to

Table 9. Net Basin Returns, Net Agricultural Returns, Net Energy Returns, Public Investment Expenditures and Salinity Damage Cost in 2000 as Net Agricultural Returns Increase (Thousands of Dollars).

	With Increased Salinity Concentration (Relax the EPA Standard)			Without Increased Salinity Concentration		
	Initial Solution[a]	Solution with Max Net Ag Returns	Change	**Initial Solution**[b]	Solution with Max Net Ag Returns	Change
Net basin returns	$537,773.2	$537,580.8	$-192.4	537,773.2	242,294.9	-295,478.3
Net ag. returns	4,760.4	6,200.0	1,439.6	4,760.4	6,200.0	1,439.6
Net energy returns	533,008.9	533,008.9	0	533,008.9	238,704.4	-294,304.5
Public investment	12.1	77.1	65.0	12.1	2,612.1	2,600.0
(Big Sandy River) (salinity control)	(0)	(0)	(0)	(0)	(2,400.0)	(2,400.0)
(evaporation suppression)	(12.1)	(12.1)	(0)	(12.1)	(12.1)	(0)
(reservoir mixing)	(0)	(15.0)	(15.0)	(0)	(15.0)	(15.0)
(phreatophyte control)	(0)	(50.0)	(50.0)	(0)	(185.0)	(185.0)
Salinity control cost	0	1,5669[c]	1,566.9	0	0	0

[a] Results of Scenario II.

[b] Results of Scenario I.

[c] Increased salinity concentration over the EPA standard by 1.2 percent.

agriculture would result in net energy returns being reduced by $294 million and public investment increasing by $2.6 million when compared to Scenario I (the analysis of maximizing agricultural and energy returns with the salinity standard). The total public investment of $2,612,070 includes an annualized cost (over 30 years) of $2.4 million for the construction and implementation of the Big Sandy River Salinity Control Unit to reduced salt loading of the Green River. The remaining investment of $212,007 in evaporation and phreatophyte control salvages 8,812 acre-feet for a cost of $24.07 per acre-foot. The net cost is estimated to be $295.5 million. This is almost entirely from the energy sector. Thus, if agriculture has the first right to water on the Green River drainage and the rights are not readily transferable, it is conceivable for the development of energy resources to be severely restrictive.

A question that must be asked is, "what is the appropriate policy?" If the EPA salinity standard must be maintained and energy development occurs, is a cost of $295 million a reasonable policy choice to expand agricultural production and returns by $1.4 million? The appropriate answer is dependent on the position the policy managers of the state wish to take with respect to agricultural growth or energy production. Note the comparison of Scenario I from 1980 to 2000 without agricultural growth resulted in approximately $240,000 or five percent decrease in the agricultural sector.

By reducing the assumption of a 24 percent growth in the agricultural sector, a modest eight percent increase in net farm income, $400,000 in 2000 over 1980, does not reduce net energy income, but does reduce basin wide net returns by $727,791 or less than 0.2 percent. Total public investment is increased by $1,367,000 by phreatophyte control and construction of the Big Sandy River Salinity Control Unit ($1.2 million or approximately one-half size of a completed unit). Thus, even a small annual growth of 0.4 percent in net agricultural returns over 20 years will result in a net cost of over $727,000 in 2000 given that net agricultural returns increases only by $400,000.

In all scenarios, the increase in agricultural returns is less than the cost imposed on the state because of salinity damages. Severance funds will also be less because of reduced production in the energy sector.

Concluding Remarks

The results of the model suggest that if water is easily transferable, development of energy resources along with their municipal impacts could be accomplished with limited public investment, loss in net farm income or increases in salinity. Wyoming will not completely "use" its entitlement to Colorado River water. If, however, water is not freely transferable and agricultural returns increase by 25 percent, the net cost to the state is estimated to be a minimum of $1.5 million in salinity damages. Salinity concentration is a major constraint to development in the Upper Colorado River Basin. If agricultural growth is to take place, given the EPA ruling in 1974 salinity levels, public investment must take place and some trade-off of water between energy and agriculture must be incorporated. Without public investment and water transfer to energy, the implications could be of a larger magnitude because of reduced development of energy resources.

As increases in the salt concentration occur downstream, the imposition of an additional cost borne by Wyoming decreases the opportunity to increase profits. For example, the increased salinity control cost could be $1.57 million and increased agricultural profits are $1.44 million. Irrigators will not be willing to pay for the increased salinity cost. Additional cost in public investment expenditures by the state is a concern that has to be considered.

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 also is needed to determine the availability and cost of credit for agriculture, energy and other sectors for water investment projects. Enhancements to this study would be to gain additional information as to the actual consumptive use of water in agriculture, energy and municipalities. Additional data on actual irrigated acreage, projected energy development, population growth and air quality would make this study more useful to policy planners of the state of Wyoming.

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APPENDIX A

Mathematical Formulation of the Management Model

The purpose of this appendix is to present a formal mathematical Description of the linear program model described in Section III, Economic Analysis. The notation used in the following description is described in Table A.1.

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

$$\text{Max } Z = N_A + N_E - \Sigma^{G}_{g=1} b_g Q_g - dQ_W$$

(net sector income)

where $N_A = TR_A - TC_A - \Sigma^{S}_{s=1} b_s Q_s$

(net agricultural income)

$N_E = TR_E - TC_E$

(net energy income)

$TR_A = \Sigma_i \Sigma_j \Sigma_k P_i A_{ijk} Y_{ijk}$ $\quad i = 1,\dots,I$; $j = 1,\dots,J$; $k = 1,\dots,K$

(total agricultural revenue)

$TC_A = \Sigma_i \Sigma_j \Sigma_k [C_{ijk} A_{ijk} + C_w W_{ijk} A_{ijk}]$ $\quad i = 1,\dots,I$; $j = 1,\dots,J$; $k = 1,\dots,K$

(total agricultural cost)

$TR_E = \Sigma_e P_e Q_e$ $\quad e = 1,\dots,E$

(total energy income)

$TC_E = \Sigma_e \Sigma_m \Sigma_n C_{emn} Q_{emn} - C^T_e$ $\quad e = 1,\dots,E$; $m = 1,\dots,M$; $n = 1,\dots,N$

(total energy cost)

subject to the following constraints:

$$\Sigma_i\Sigma_j\Sigma_k A_{ijk} \le A_p$$

(irrigated acreage)

$i = 1,\ldots,I$
$j = 1,\ldots,J$
$k = 1,\ldots,K$

$$\Sigma_i\Sigma_j\Sigma_k\Sigma_e\Sigma_m\Sigma_n a_i A_{ijk} + w_{emn} Q_e \le W$$

(consumptive use)

$i = 1,\ldots,I$
$j = 1,\ldots,J$
$k = 1,\ldots,K$
$e = 1,\ldots,E$
$m = 1,\ldots,M$
$n = 1,\ldots,N$

$$L \le A_p - \bar{L}$$

(potential level of lined canals)

$$s \le A_p - \bar{s}$$

(potential acreage of sprinklers)

$$W + \Sigma_I w_g Q_g \ge 0$$

$g = 1,\ldots,G$

(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).

Table A.1. Model Notation

A	agriculture
E	energy
i	type of crop $i = 1,2,\ldots,I$
j	water application level $j = 1,2,\ldots,J$
k	irrigation distribution technology $k = 1,2,\ldots,K$
e	energy use (coal, oil shale, 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 $n = 1,2,\dots,N$
s	private water conservation measure such as a sprinkler irrigation and canal lining $s = 1,2,\dots,5$
g	public water investment measure such as phreatophyte control, evaporation control and salinity control projects $g = 1,2,\dots,G$
b_g	cost of public investment technology g
Q_g	quantity of public investment technology g
d	cost of salinity concentration over the EPA standard
Q_w	quantity of salinity exceeding the EPA standard
b_s	cost of water conservation measure s
Q_s	quantity of water conservation measure s in subbasin r
P_i	price less the return to water to grow the ith crop per acre
A_{ijk}	ith crop acreage using water application j and irrigation conveyance k
Y_{ijk}	yield or productivity of per acre of crop i, application j, and distribution k
C_{ijk}	cost of production using input prices of fertilizer, seed, feed, land labor, and farm machinery for crop i, water application j, and distribution k
C_w	cost of water per acre-foot
w_{ijk}	water application per acre for the ith crop, jth application, and kth distribution system in acre-feet
P_e	price less return to water of each energy use e
Q_e	quantity produced for each energy use e
C_{emn}	cost of energy use e using water technology m and other factors of production n
Q_{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
C^T_e	cost of transporting energy resources out of the region
A_p	Potential irrigated acreage
A_i	consumptive use requirement per acre of crop i

w_{emn}	water required to produce one unit of energy use e using water technology m and factors n
W	water allocation level
$\bar{L}$	level of existing lined canals
L	potential level of new lined canals
$\bar{S}$	acres of existing sprinklers
S	potential acres of new sprinklers
W_g	water salvaged by public water conservation investment g
CAP_e	capacity of energy use e