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The Effects on Agriculture in Utah of Water Transfers to Oil Shale Development

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DEPARTMENT OF ECONOMICS

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ABSTRACT

In Part I the institutional factors affecting water distribution in the Upper Colorado River Basin in general and specifically the Uintah Basin are presented. The historical development of the appropriation doctrine of water allocation is outlined and Utah water policy is examined. These institutional factors are analyzed in light of the prototype oil shale development in the Uintah Basin and potential impact on the area's agricultural sector. Oil shale water estimates are compared with Uintah Basin water availability and examined with regard to population projections and municipal water use. Lastly, Utah water policy and the appropriation doctrine are viewed as restraints to efficient water transfers.

In Part II irrigation water is treated as a random variable. Its actual quantity is not known ahead of time. If transfers of water to oil shale production affect the variability of water used in agriculture then there will be impacts in agriculture even if the farmers receive the same average quantity of water as originally. These impacts are analyzed in the context of the expected utility maximization hypothesis, i.e., the farmers are hypothesized to maximize expected utility. The measure of an increase in variability is the "mean preserving spread." The analyses seek to determine the impact upon expected (average) real income (utility), expected profits (net farm income), purchased inputs, the price of water, and the price of land. The analyses are conducted for both the case where the farmers are risk neutral and the case where they are risk averse.

PREFACE

The so-called energy crisis produced renewed interest in national self-sufficiency in energy production, a new look at "unconventional" energy sources such as oil shale, tar sands, and coal gasification and liquefaction, and a spate of governmental initiatives to encourage development.

The northeast section of Utah (the Uintah Basin) is a part of the rich oil shale belt, and with the government leasing of two prototype sites on the White River known as U_a and U_b, it was believed by many people that oil shale development was imminent. Studies were made of the water needs of an oil shale industry and agricultural producers became threatened because they are the big users of water in the area.

This study assesses the water situation in the Uintah Basin and explores the likely effects of development of the prototype lease sites on agriculture. The study consists of two parts: (1) An analysis of the current water demand-supply situation in the area and the projected impact of oil shale development with particular emphasis on agriculture, and (2) an analysis of the effects on farm production decisions of increasing the variability of water deliveries resulting from water transfers. The first part deals generally with the quantities of water available for agricultural production while the second deals with issues that arise when the variability of those quantities is increased even if the annual quantity of irrigation water available is unaffected.

This study was financed by a grant from the Office of Water Research and Technology under its Title I Allotment Program. Gardner and Tew were responsible for Part I dealing with the current demand supply situation and Lyon wrote Part II on the effects of increasing the variability of water supplies to irrigators.

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PART I

THE IMPACTS OF THE PROTOTYPE OIL SHALE DEVELOPMENT ON AGRICULTURAL AND MUNICIPAL WATER SUPPLIES

INTRODUCTION

It has often been alleged that the development of the arid western United States has been limited by the lack of water. The amount of that resource available has dictated agricultural production and the location of settlements.

Recent years have witnessed large price increases in energy, and the nation is searching for new forms that are economically feasible and environmentally acceptable. As a result, much attention is being focused on the development of alternatives to liquid petroleum.

Oil shale is one of the most abundant but undeveloped forms of energy in the United States. High grade deposits, located within the Green River formation of Utah, Colorado, and Wyoming (Upper Colorado River Basin), contain the equivalent of 600 billion barrels of oil. Exploitation of this resource would offer a significant supplement to U.S. supplies of liquid petroleum. Studies of the feasibility of oil shale indicate that the availability of large quantities of water will play a key role in determining to what extent an oil shale industry can become a reality.

It is apparent that the legal right to utilize water will be perhaps the most important factor in the consideration of water for energy in the Upper Colorado River Basin. From available data it is obvious that present water availability exceeds that which is presently utilized in the basin. However, it is also apparent that this quantity of water is in turn exceeded by present rights granted by most states in the area. The obvious conclusion is that many appropriative rights granted to private parties are not being fully utilized. Nonetheless, these rights remain as charges against the future availability of water in the oil shale rich areas. How state water control agencies reconcile current water administration policies with the need for energy water will determine to a large extent if oil shale operations will become a reality.

Since the bulk of existing water rights in the Upper Colorado River Basin is associated with agriculture, there has been some concern that increased energy water demands will have a detrimental impact on the area's agriculture. In attempting to assess the impact of oil shale development upon existing agricultural water supplies, this report will focus upon three principal areas of investigation:

1. To examine the current Utah water policies, laws, regulations, as well as other factors which are affecting the development of the state's water resources. Much of the legislation governing water use and development in Utah also incorporates aspects of broader, regional policies, such as the Colorado River Compact and the Upper Colorado River Compact. Therefore, water policies will be investigated from a multi-state or regional viewpoint as well as from the vantage point of Utah's own water policies. Primary emphasis will be placed upon the legislation and problems dealing with the Upper Colorado River Basin.

2. To examine the oil shale development firms, the mining and retorting processes, and the associated water requirements. Likely alternatives for obtaining water for oil shale will also be studied.

3. To evaluate the impact of oil shale development on agriculture. The geographic area of study will be the Uintah Basin in general and the Ashley Valley-Vernal City area specifically. Population impacts in the Uintah Basin, water sources for the basin and Ashley Valley, and the restraints which exist regarding oil shale's use of agricultural water will be examined.

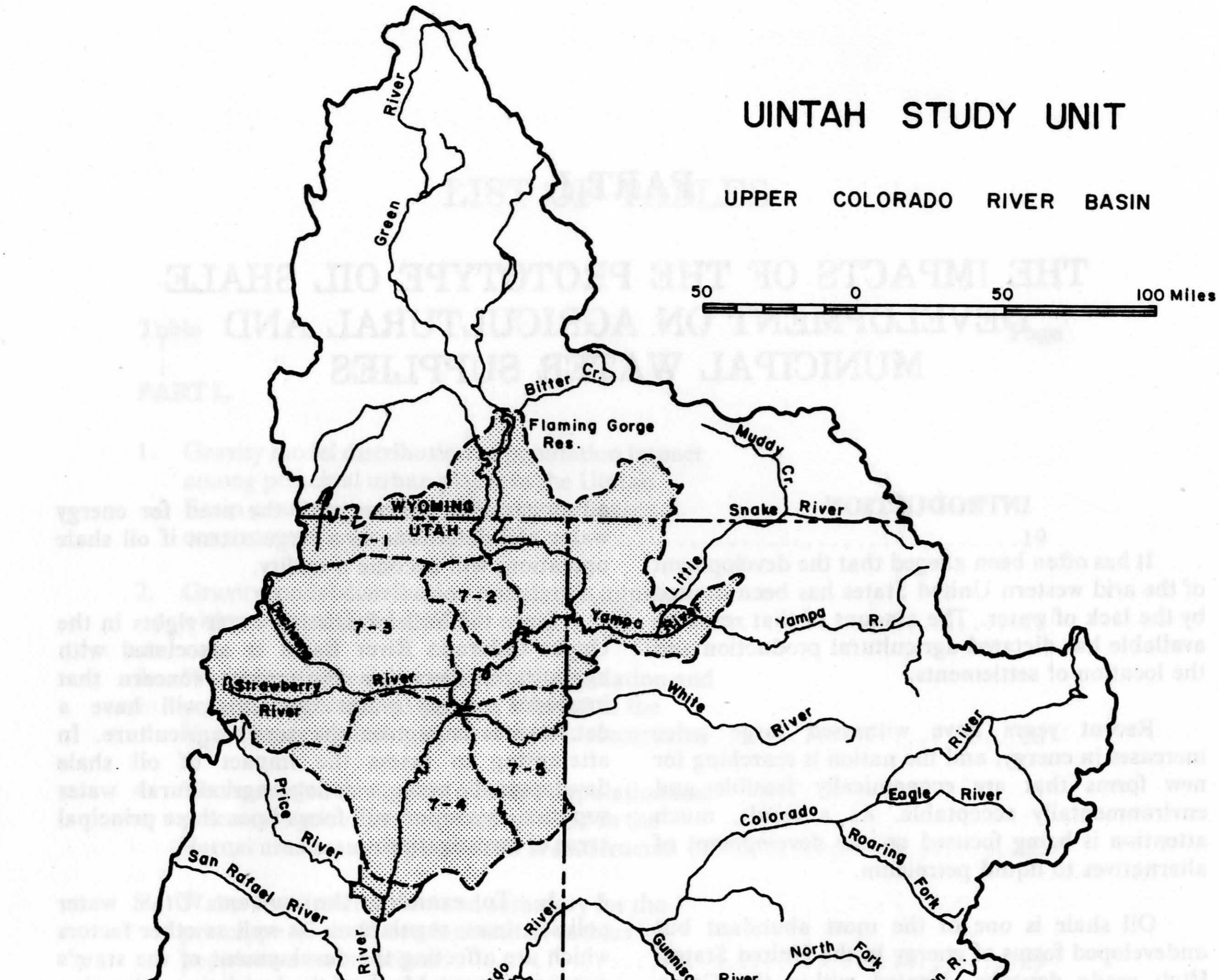

UINTAH STUDY UNIT
UPPER COLORADO RIVER BASIN
50
0
50
100 Miles
Green
River
Bitter Cr.
Flaming Gorge Res.
Muddy Cr.
WYOMING
UTAH
Snake River
7-1
7-2
7-3
7-4
7-5
Little Snake
Yampa
Yampa R.
Strawberry River
River
White
White River
Price River
Colorado
Eagle River
Roaring Fork
San Rafael River
Gunnison River
North Fork
Gunnison R.
Blue Mesa Res.
Colorado River
Green River
Dirty Devil
Fremont River
Escalante R.
Paria R.
Lake Powell
San Juan River
San Juan R.
Navajo Res.
UTAH
COLORADO
ARIZONA
NEW MEXICO

Figure 1.

The study presumes that oil shale development will reach only the prototype stage of development in the near future. This represents a capacity of approximately 100,000 barrels/day.

FACTORS AFFECTING CURRENT STATE WATER POLICY

Introduction

The very nature of the prior appropriation doctrine is one of extensive institutional involvement in the allocation of water. The scarcity of water throughout the west has prompted the enactment of several major interstate and international compacts.

Nowhere is this situation more apparent than with the Colorado River, quite possibly the most regulated waterway in the world. The legislation, compacts, treaties, and other agreements which govern the Colorado River system are known collectively as the "Law of the River."

It is obvious, therefore, that allocation of Utah's water resources will be done within this institutional framework. Energy development will have to compete with other demands for the state's valuable water resources.

The purpose of this section is to explore the regulations of the Colorado River system, explain the appropriate doctrine as it relates to the State of Utah, identify the competing demands for water within the state, and present the current factors and proposals affecting the development of a state-wide water policy.

The Colorado River System

The cornerstone of the body of law regulating the Colorado River is the Colorado River Compact of 1922. The parties involved are the federal government, the states of Utah, Colorado, Arizona, New Mexico, Wyoming, Nevada, and California. The primary purpose of the compact is to distribute the United States entitlement of flow of the river equally between the upper basin states (Utah, Colorado, Wyoming, and New Mexico) and the lower basin states (Arizona, California, and Nevada). Based upon pre-1920 data, the compact established the total flow of the river available for distribution among the upper and lower basin states at 15 million acre feet (maf). The major provision of the compact is one requiring the upper basin states to deliver a minimum of 75 maf to the lower basin states in any consecutive 10-year period. The Mexican Water Treaty of 1944 guarantees Mexico an annual quantity of 1,500,000 acre feet of water from any and all sources (USDI, 1974).

While the 1922 compact regulates the river as to the allotment between the upper and lower basins, it does not divide the water between the individual states of each area. The Upper Basin Compact of 1948 (USDI, 1974) allocates the water to the four participating states of the upper basin on a percentage basis in the following manner (USDI, 1974):

Colorado	51.7%
Utah	23.0%
New Mexico	11.25%
Wyoming	14.0%

(Note: Arizona is guaranteed an annual flow of 50,000 acre feet from the upper basin allotment.)

A major problem with the original Colorado River Compact and the subsequent Upper Basin Compact is that information upon which the initial river flow was calculated was greatly overestimated and the later Mexican Treaty obligations had not been defined. Later years have shown that the river's total flow at Lee Ferry is closer to 13.3 maf than the original estimate of 15 maf (USDI, 1974). Therefore, the upper basin's entitlement is approximately 5.8 maf after fulfilling the lower basin's flow requirements, which are still held at 75 maf in any given 10-year period. However, it is the variability of the flow which has required the upper basin states to develop considerable storage capacity in order to reduce the effect of variability. (This was the motivating force behind the Colorado River Storage Project which included Glen Canyon Dam and Flaming Gorge Dam.)

Based upon the more accurate estimate of the total river flow (Noble, 1974), the percentage division of the upper basin's allotment entitles the four states to the following amounts of water:

Colorado	2,976,000 af
Utah	1,322,000 af
Wyoming	805,000 af
New Mexico	627,000 af

It should be noted, however, that the above data are based upon Bureau of Reclamation estimates. The State of Utah generally takes a more liberal view with regards to its entitlement, and places the figure around 1.4 maf. It is that estimate which will be utilized in this study. Also, the Colorado River proper does not flow through Utah for any great distance. Nonetheless, 15 percent of the virgin flow of the river at Lee Ferry does originate in Utah (Lawrence and Saunders, 1975).

Before outlining Utah's current and projected uses of the state's Colorado River allotment, mention should be made of the appropriative doctrine, which underpins all water-related development, and the statutory manner in which water rights are obtained.

Historical

The early water users in the west were generally miners and farmers who often trespassed upon the public domain to divert water from streams to the point of use. Because of the lack of courts and established local procedure regarding the use of water, these early inhabitants developed their own local customs. They were usually related to the same rules which governed mining districts and claims.

When water-use conflicts did reach the courts, the decisions tended to reflect these local characteristics rather than the traditional riparian views. The development of the west was dependent upon successful farming and mining and these activities were dependent upon water. Therefore, the courts and the Congress, recognizing the importance of such development, allowed water to be withdrawn by anyone who could put it to a beneficial use in accordance with the laws and customs of the respective states. Thus the law of prior appropriation was born.

The essentials of the concept are that water rights are acquired through the diverting of water from a natural watercourse and applying it to a beneficial use. This water right has a priority date which reflects the date that action was first taken to utilize the water. This priority establishes a relationship between a particular water right and all other water users on the stream. Those rights superior (earlier) are guaranteed their water supply before the needs of those inferior (later) can be met.

The appropriation doctrine in Utah developed in slightly different fashion than those areas where water rules were related to mining claims. The Mormon pioneers were the first Anglo-Saxons to practice irrigation on an extensive scale in the United States. Their colonization patterns involved the establishment of many small communities generally separated from each other by miles of desert and mountains and as a result were largely self-contained. The development of a cooperative-type irrigation system under church control was usually one of the first activities of any new settlement.

The Mormon Church contemplated the colonization of the Great Basin in such a way as to maximize the use of the area's scarce water resources. This use would be applied to all land that could be reached by the water—not just those areas contiguous to the surface water channels.

The church took possession of the region and supervised the allotments of parcels of land to settlers. These early rights were recognized by the Mormon State of Deseret and the Territory of Utah pending issuance of formal land titles by the United States. It was also established that those who had first made beneficial use of water should be entitled to continued use in preference to those who came later. This fundamental principle was to be later sanctioned by the legislature and the courts (Dewsnup and Jensen, 1973).

These early methods were terminated with statehood when the legislature provided that an appropriation could only be obtained through filing an application with the State Engineer. (Note: Those who owned rights prior to 1903 but had not yet perfected those rights in terms of putting the water to beneficial use were given a reasonable amount of time to do so. Of course, those who had claim to water based upon pre-1903 action still held title to the water.)

This 1903 statute was revised and reenacted in 1905 and again in 1919. The 1919 law is the basis of the present enactment contained in the Utah Code Annotated (1953).

The Utah Appropriation statute contains the following declaration: "All waters in this state, whether above or under the ground are hereby declared to be the property of the public, subject to all existing rights to the use thereof." (73-1-1) "Rights to the use of the unappropriated public waters in this state may be acquired only as provided in this title " (73-3-1) (Hutchins, 1965).

The current laws, therefore, declare that the state has the right to control the diversion and distribution of the public waters within its boundaries. The control of the diversion and distribution of such public waters are vested in the State Engineer, subject to judicial review and to the constitutional provision recognizing and confirming existing rights to the use of waters for useful and beneficial purposes (Dewsnup and Jensen, 1973). The statutes clearly make it the duty of the state to appropriate the water in a manner that will be in the best interests of the public.

This statutory procedure is now the exclusive method of appropriating water. Applications to appropriate are filed in the office of the State Engineer, and unappropriated water may be acquired for any recognized beneficial use. Subject to compliance with the statutory procedure for perfecting a water right, an application has priority as of the date it was filed in the State Engineer's office (Dewsnup and Jensen, 1973).

The laws state that it is the duty of the State Engineer to approve an application that meets the filing requirements if: (a) there is unappropriated water in the proposed source; (b) the proposed use will not impair existing rights or interfere with more beneficial use of the water; (c) the proposed plan is physically and economically feasible and not detrimental to the public welfare; and (d) the applicant has the financial ability to complete the proposed works and has applied for the appropriation in good faith and not for speculation or monopoly. However, if the State Engineer has reason to believe that more beneficial use of the water for irrigation, domestic, stockwatering, power, mining, or manufacturing purposes will be interfered with or the public welfare will be adversely affected, he must withhold approval or rejection pending an investigation (Hutchins, 1965).

Once an application is approved, the applicant is given a specific time in which to place the water to beneficial use and submit written proof of appropriation. An applicant may be granted additional time for completing construction of the works and applying the water to beneficial use upon a showing of diligence or reasonable cause for delay (The Utah Code Annotated, 1953, Sec. 73-3-12). If an application lapses for failure of the applicant to comply with the provisions of the act, the State Engineer may, upon showing of reasonable cause, reinstate the application. However, the priority date of the application must be altered to reflect the date of reinstatement (The Utah Code Annotated, 1953, Sec. 73-3-18).

Once the water is placed to beneficial use, the applicant submits proof of his actions and is issued a certificate of appropriation, which is filed in the State Engineer's office. Domestic purposes, stockwater, irrigation, municipal power, manufacturing, fish culture, and the use of navigable water for the recovery of salt and the minerals have all been classified as beneficial use of state waters.

A certificate of appropriation constitutes prima facie evidence of the water right. The right consists not only in the amount of the appropriation but also in the priority. It also extends to quality as well as quantity. A water right is considered as a species of real property and is protected as such. It is a usufructuary right, meaning the right to divert from the source of supply. Lastly, a water right in Utah is separate and distinct from the land upon which it is used. However, if a deed transferring land does not specify otherwise, the water right passes with title to the land (The Utah Code Annotated, 1953, Sec. 73-1-11).

Current water uses

Utilizing the administrative mechanism just outlined, Utah is currently depleting the Colorado River by 825,000 acre feet annually (Hansen, 1975). Approximately 90 percent of the current diversions are related to agriculture, with 5 percent for municipal and industrial purposes, and 5 percent for managed wetlands. Of the municipal and industrial uses, about 7,800 acre feet are utilized in the production of thermal power (Lawrence and Saunders, 1975).

Although it would appear that nearly 600,000 acre feet are still available for the state to allocate, the current situation is one of strong competition for the remaining water. The following pages will discuss the problems facing Utah in allocating the state's remaining Colorado River allotment among the most likely water users.

Over-appropriation

A common statement made regarding the Colorado River is that it is over-appropriated. As was previously mentioned, Utah currently utilizes 825,000 acre feet of the state's entitlement, leaving some 600,000 acre feet available. According to state officials this amount is sufficient to meet the forseeable domestic demand of the state (Lawrence and Saunders, 1975). Problems arise, however, if additional quantities will be demanded for agriculture and energy development.

The State Engineer has approved filings totaling just under 600,000 acre feet from the remaining amount of the state's allotment. These filings, if proved, could by themselves exhaust the entire entitlement (Hansen, 1975). The majority of this remaining water is covered by an approved application, in the name of the Bureau of Reclamation, for the Central Utah Project. That flow which remains is associated with approved applications in the lower reaches of the basin and along major tributaries of the Colorado River.

It is obvious, therefore, that Utah is currently utilizing or has commitments for using the entire 1.4 maf to which the state is entitled.

Indian water rights

The Supreme Court, in 1908, held that when Indian reservations were established, sufficient water to supply all Indian lands was also reserved.

The **Winters Doctrine** interpretation discussed below, has made the Indians an important element in any plans to develop Utah's remaining water.

The case of **Winters vs. United States** is generally thought to be the real beginning of the reservation doctrine, an item which will be discussed at greater length later in this section. The essential point of the Winters decision is that waters set aside as belonging to the Indian reservations are superior to other subsequent appropriators who obtained their rights under state law, even though the Indians had not yet placed their waters to a beneficial use (Hansen, 1975). The justification for the Winters decision is not clear. Some viewpoints, however, reflect the idea that the motive behind the action was to provide the Indians with the potential of rebuilding their lives after the westward migration had destroyed their previous livelihood (Hansen, 1975).

One major problem with rights as defined under the **Winters Doctrine** is quantifying those rights. If all the land belonging to the Indians were to be assessed as arable, the water requirements would more than exhaust the remaining Colorado River allotment in Utah. Furthermore, negotiations with Indian representatives have seen these water demands continually reevaluated upward.

A second problem area is a legal one; whether the **Winters Doctrine** intended the reserved water to be utilized for other than agricultural-related purposes. There has been no definitive answer to the question by the courts as yet and so the issue will remain moot until resolved.

The Indians have been involved in most recent water developments in the Colorado River Basin. Specifically, they have been guaranteed water in the new Central Utah Project (CUP). In 1965, a contract was executed between the United States (Bureau of Reclamation and Bureau of Indian Affairs), the Ute Indian Tribe, and the Central Utah Water Conservancy District, in which the non-Indian parties recognized 36,450 acres of Indian lands as being served or to be served from the Duchesne River. For their part, the Indians agreed to defer development of 15,242 acres of non-irrigated land (USBR, 1973). This particular agreement related only to the Bonneville Unit of the CUP, however. Similar deferrals should be executed for the Upalco and Uintah Units of the CUP totaling 13,876 acres. Thus, the Ute Indians would defer irrigation to a total of 29,118 acres of land (USBR, 1973).

The key point in these actions is that the water use has been deferred, not abandoned. The agreement provides that Indian water supplies may be converted to uses other than agricultural, with the understanding that the total water to be used by the Indians will not exceed the equivalent of 4.0 acre-feet per acre for the acreage from which the water is converted (USBR, 1973).

Since the execution of these agreements there have been considerable delays in the full development of the Central Utah Project. Congress has failed to appropriate funds and inflation has forced alterations in original plans. These delays have led to a general dissatisfaction by the Indians with the proposed development of their water rights, resulting in suits being filed to halt construction of the CUP until the Indian rights are guaranteed.

At the present time 129,201 acres of Ute and Ouray Reservation land are claimed and determined to be arable under the **Winters Doctrine**. If a water requirement of 3 acre-feet per acre is assumed, the Ute tribe's rights to undeveloped Upper Colorado River Basin water would be 387,000 acre feet per year (Lewis, 1975). Thus, the Indians will be a major component in any future plans to develop the state's remaining water.

Salinity

Salinity problems arise because all water developments produce increases in salinity concentration. Public law 92-500 (Federal Pollution Act Amendments of 1972) implies that salinity levels should be maintained at or below 1972 levels (Lawrence and Saunders, 1975). There are essentially two ways of preventing salt buildup: take out the salt, or restrict further water use. Desalinization is costly, and restricting further water use would essentially mean a moratorium on any development. Extensive work is being done on the salinity problem of the Colorado River. Nonetheless, any development on the river cannot proceed without consideration of the salt problem.

Federal water rights—the reservation doctrine

The reservation doctrine is based on the premise that since all of the land now occupied by the western states once belonged to the federal government, the western states did not acquire title to the public lands once they were admitted to the union. Therefore, the federal government still retains ownership of these federally-retained lands. These claims extend to the right to dispose of and regulate the public lands and waters in accordance with the Property Clause of the Constitution (Hansen, 1975).

In answer to those who claim that the federal government relinquished control of these water rights with the Act of 1866, 1870, and the Desert Land Act of 1877, the federal government claims that control was only deferred to the western states, but ownership remained in the hands of the federal government (Hansen, 1975). Therefore, when the government reserved a part of the public domain for its own purposes, it also reserved sufficient water to facilitate these purposes.

The beginning of the reservation doctrine is generally associated with the **Winters Doctrine** mentioned earlier in conjunction with Indian rights. However, subsequent cases indicate that the reservation doctrine may also apply to other water withdrawals.

The key problem with water rights claimed under the reservation doctrine is again one of no clearly defined amounts or purposes.The possibility of conflict between states and the federal government is always present since the watershed on which most of the streams and rivers originate in Utah and the other western states is federal land.

Efforts have been made in Congress to quantify the amount of water which would be classified as belonging to the federal government under the reservation doctrine. Until such time as the law is clarified there will always exist the possibility that presently allocated water would be subject to potential federal demands.

Potential water uses—agriculture

The portion of the Upper Colorado River Basin located in Utah contains over one million acres of arable land. The 1965 Upper Colorado Region Framework Study sponsored by the Water Resources Council indicated that 307,600 acres were under irrigation. Of this portion, 125,000 acres did not receive full irrigation requirements. (A full amount is defined by the study as water sufficient to satisfy consumptive use as calculated by the Blaney-Criddle method.) (Lawrence and Saunders, 1975.)

The majority of the area's agricultural water rights are located along the Duchesne River in the Uintah Basin. Beef, grade A dairying, and sheep are the main enterprises. The principal crops are related to the livestock industry, and in order of greatest acreage are alfalfa, pasture, barley, corn, silage, wheat, and oats. Livestock grazing is permitted on National Forest lands and the grazing districts of the Bureau of Land Management. The growing season is too short for most cash crops and precipitation is inadequate for dry farming (Skogerboe and Austin, 1967).

Until very recently it appeared that agriculture would be the only major water user in the Colorado River system in Utah. To utilize the state's full allotment vast exports of water to the Bonneville Basin were contemplated. Potential new water uses, especially those related to energy, have permanently altered that view.

It is the view in the State Engineer's office that there are only two possibilities open to agriculture, since it is the use which will find it most difficult competing on the open market for sufficient water. First, the possibility exists that increases in demand for agricultural products will cause food prices to rise giving farmers sufficient incentive and purchasing power to compete with other demands for water on the open market. Second, a public desire to preserve agriculture could prompt action by the state legislature, to prevent the transfer of water from agriculture to other uses (Hansen, 1975). Such an action would maintain the agricultural base and would essentially prohibit agricultural water rights from being allocated in the free market.

At the present time agricultural producers seem to be ambivalent about such an action. Many are concerned that water will not continue to be available for agricultural production. At the same time, however, farmers also see the possibility of selling their water rights at a high price to some industrial operation and using the income for retirement or for investment in some other business. Consequently they do not wish to see public action which would preclude this possibility.

Although new inbasin irrigation could conceivably consume vast amounts of water, committed agricultural water, which in this case means the Bonneville, Uintah, Upalco, and Jensen units of the Central Utah Project, will provide only about 108,000 acre feet for agriculture (Lawrence and Saunders, 1975).

Energy

Energy related water uses are generally associated with four principal activities: oil shale, thermal-electric power generation, conventional coal mining, and coal gasification and liquefaction. Because of the nature of the energy shortage and the slow development of solar and nuclear power plants, the use of coal and other fossil fuels is approaching a crash status. In light of this situation the coal and oil shale reserves of Eastern Utah are of particular importance.

The water requirements for coal mining are small, and often sufficient water is developed in the mine itself to meet mining needs. Electric generating plants consume about 15,000 acre feet of water annually per 1,000 megawatts of capacity. The majority of the water is used for cooling purposes. At the moment only about 7,800 acre feet annually are being used for thermal power generation, but at least four large thermal plants are in various stages of development. The associated water requirements would be about 120,000 acre feet annually to supply an additional 8,000 megawatts of capacity (Lawrence and Saunders, 1975).

The water requirements, methods of delivery, and uses of water for oil shale will be discussed in depth in a later chapter. Basically, the projected water needs for a 100,000 bls/day operation and a support community of 8,000 people are estimated at 36,000 acre feet annually (Lawrence and Saunders, 1975).

Water for coal gasification and liquefaction is estimated at 15,000 acre feet per year for a 250 M cu ft/day operation (USDI, 1974). At the moment the number of plants and their size is speculative, although the amount of the state's coal deposits indicates that the industry will be important to Utah's energy development plans.

A problem, however, with all such experimental operations is that no large commercial plants have been attempted and the water estimates may be subject to considerable error.

Wildlife and recreation

Besides the water demands for agriculture, energy, and industry, there is considerable pressure to maintain streamflows for fishery, recreational, and aesthetic purposes. Some federal legislation including the Wilderness Act, Wild Horse and Burro Act and recently the Endangered Species Act, if interpreted literally, could stop all development for any purposes along many energy-related waterways. Section 7 of the Endangered Species Act reads, speaking of federal involvement in any way, "...the actions shall not jeopardize the continued existence of such endangered species and threatened species or result in the destruction or modification of habitat of such species which is determined by the Secretary, after consultation as appropriate with the affected States, to be critical" (Phelps, 1975, p. 76). As an example of the potential implications of these environmental statutes, Utah's and Colorado's oil shale tracts may be inhabited by five endangered species of mammals and fish. The federal involvement in the management of these tracts in leasing and developing them could eliminate any action which would alter in any way the natural habitat of these species. In effect, the action would eliminate development.

Environmental agitation for the preservation of the natural environment of the Upper Colorado River Basin has had considerable impact. Recent political developments in the State of Colorado, for example, have delayed some energy development projects in that state. Finally there are some proposals to designate many of the energy-related waterways in Utah as wilderness areas. Such action would completely eliminate development along those rivers.

Future water policy

It should be obvious from the preceding pages, that the formulation of a state water policy which reflects current water needs is of paramount importance. Historically, the state, as represented by the Board of Water Resources and the State Engineer, has supported and encouraged any water development which did not injure other water users. The guiding principle was first in filing, first in right. This policy, however, has resulted in the potential overallocation of virtually all of Utah's streams and rivers. The problem is particularly acute in the Upper Colorado River Basin. It is now apparent that the problem is no longer one of getting the water developed, but of choosing between competing and often conflicting uses.

The administrative problems in dealing with the vast number of competing and conflicting water filings have resulted in the Governor formally declaring a moratorium on all water allocations in the state. In reality such a situation has existed for some time, especially in regards to the state's Colorado River water. As an example of the magnitude of the problem, energy filings totaling 1.2 maf are on file for the Upper Colorado River Basin alone (Hansen, 1975). This amount is nearly equal to the state's entire Colorado River allotment.

The job of developing a comprehensive water policy will most likely incorporate two primary concepts: attempting to obtain maximum usage of presently approved water rights and formulating a sound criteria for the allocation of presently non-allocated water. In both cases legislative attempts have been made to clarify the problems. It is apparent, however, that the courts will eventually occupy a major role in delineating specific guidelines.

Diligence

It has been previously mentioned that approved filings for the Upper Colorado River Basin will exhaust the state's entitlement if all those filings are fully developed. Delays in the full utilization of such approved filings have brought up the possibility that sufficient action may never be taken to fully develop these rights.

Historically, extensions of time for full development have been granted as a matter of course. Delays of 50 years are not uncommon. The law states that "reasonable and due diligence" will be shown in fully utilizing approved allocations. Obviously, this statement is subject to wide interpretation. In the past if marginal effort was shown in proving up on a right an extension would be granted. The critical water situation, however, dictates that such latitude may not be in the best interests of current priorities.

The legislature attempted to come to grips with the problem when on May 13, 1975, it passed S.B. 290 which amended Section 73-3-12 of the Utah Code. The act gives to the State Engineer the power to strictly limit extensions of time and requires proof as to the necessity of such extensions. If proof of "reasonable and due diligence" is not shown, the State Engineer, following hearings, is empowered to lapse the filings, thus returning the water to the state for future allocation.

It is difficult to assess the impact of the statute without allowing time for the administrative process to function. Nonetheless, a number of filings, by some estimates up to 100,000 acre feet will be lapsed.

Forfeiture

A second area of concern regarding already allocated water is the issue of abandonment and forfeiture. In this situation, water which has already been allocated and developed is not being utilized. The law specifically mentions the time necessary to define abandonment and forfeiture. Nonetheless, they are primarily judicial decisions and technically difficult to define. Often only a portion of a water right would be subject to such action and this situation complicates the process. Such efforts could, however, provide the state with some new water to allocate to other potential uses.

Priority

The state has seldom departed from the policy of first in filing, first in right, as the guideline for allocating water. This process was adequate when the majority of filings were for the same purposes, namely agriculture. In light of the altered energy picture and continued municipal demands, the question naturally arises whether the use of the filing date as the sole criterion for allocating water is in the best interest of the public.

There are currently on file with the State Engineer literally hundreds of filings, the majority of which are dated after 1950. These filings are for a number of purposes, including energy-related uses. How to deal with these filings will be a major issue in any water policy.

The situation was highlighted in the last legislative session, when a piece of legislation (S.B. 291) was introduced. The bill represented a radical departure from the traditional allocation practices. In essence it would have empowered the State Engineer to decide, without respect to filing date, which filings are most important to the public welfare and, therefore, should be approved. It appears that the primary purpose of the bill was to legislate a ranking of priorities to guide future water allocations. Such a legislative clarification would obviously be easier and faster to obtain than a judicial decision, although that latter route will likely be explored. Although the bill was defeated, it underscores the need in the minds of some people to view future allocation of water in terms of the apparent reality in increased scarcity.

It appears that the current feeling among the governing officials of the Board of Water Resources and the Governor is that water should be developed, allocated, and managed by a basin-wide entity, similar in scope to a conservancy district. Ideally, and particularly in urbanized areas, water allocations should be patterned after public utilities: anyone can sign up for water delivery, water is priced to cover supply cost, and shortages are shared equally (Lawrence and Saunders, 1975).

As a general policy, public entities seldom participate in water development projects without actually holding title to the water. Since the economic feasibility of such large undertakings is a function of size, the operations naturally require the allocations of significant amounts of water. This situation has some interesting ramifications. If large amounts of water are allocated to the state to develop and distribute to individual users, the state will soon occupy the role of water-broker. Individual water rights will be difficult to obtain, and the traditional role of State Engineer may be altered. Obviously then, the state's own water filings will be a significant element in defining a water policy.

In those areas where the Board of Water Resources is able to obtain rights or already holds them, it has been petitioned by other potential users to relinquish parts of those rights. In most cases the Board will attempt to reach some type of arrangement for granting a firm agreement for use of the water in place of the actual water right. Such might well be the case with energy demands.

In summary, it appears that definitive action must be taken to reconcile the state's present water allocations with future water demands. Utah is currently utilizing only a part of the state's Colorado River allotment, yet on the books is very nearly over-allocated. Efforts to eliminate abandoned, stale, and inactive water rights could provide some additional water to meet foreseeable demands. The quantification of Indian and federal government rights would also provide a realistic yardstick to evaluate the current water resources available to the state. These rights should not continue to be hypothetically dealt with. Lastly, the formulation of meaningful criteria to evaluate the vast number of unapproved filings would allow the state to make progress with that situation.

OIL SHALE TECHNOLOGY: WATER NEEDS AND SOURCES

The extraction of oil from oil shale is not new. The Indians of the Upper Colorado River Basin often amazed settlers by showing them examples of the area's burning rocks. In more contemporary times, the extraction of a liquid fuel from shale has been attempted in various ways. None of these previous attempts, however, has approached the magnitude now being contemplated for the oil shale industry in Utah and Colorado.

Utah's oil shale deposits are located in the Uintah Basin and those deposits with the greatest percentage of oil per ton of shale are in eastern Utah near the Colorado state line. Some estimates indicate that 300 billion barrels of oil are contained in these shale reserves (Utah Division of Water Resources, 1975).

The lands which contain oil shale deposits are owned by the federal government, by the State of Utah, and by private individuals and corporations, and comprise thousands of acres. Ten years ago the State of Utah filed an application to the Bureau of Land Management for In Lieu Selection Rights on 156,000 acres of federal land. It is expected that title to these lands will pass to the state thereby placing ownership of a substantial amount of these oil shale lands under Utah's ownership.

In an effort to determine the feasibility of shale oil as an alternative to liquid petroleum, the Department of the Interior, in 1974, invited bids and awarded leases for prototype oil shale development on tracts which are known as U_a and U_b, located adjacent to the White River. Under the agreements of the lease the consortium of Phillips Petroleum Company, Sun Oil Company, and Sohio Petroleum Corporation, is required to make bonus payments over a five-year period to the Department of the Interior totaling $120,704,000 (Utah Division of Water Resources, 1975).

Because of the high costs involved in the development of these prototype tracts, no single company seemingly has the resources to finance the operation independently. Rather, the approach has been to form consortia composed of a number of firms, generally major oil firms, to provide the development expertise and necessary capital and technology. As an example of the tremendous costs involved, one company has estimated that $200,000,000 will have to be spent before the first drop of shale oil is produced in Utah (Utah Division of Water Resources, 1975).

The following pages present a brief description of these consortia, the technology that will most likely be utilized in mining and retorting oil shale, some of the associated water requirements, possibilities for obtaining this water, and some of the problems that are to be expected.

The development firms—Colony Development Operation

Colony Development Operation, a joint venture of Atlantic Richfield Company, Shell Oil Company, Ashland Oil Inc., and Oil Shale Corp. has operated a pilot plant to recover oil from shale since 1971 in Colorado. It was thought that the Colony group would be the first group to operate a commercial plant. Their timetable had called for commercial operation to begin near Rifle, Colorado, by 1978. The rising cost of oil shale production coupled with an altered political climate in Colorado which is oriented toward environmental demands, however, forced the Colony organization to indefinitely suspend its project last year.

At the heart of the Colony operation is the retorting method developed by the organization known as Tosco II. Research on the Tosco II method was conducted at the Denver Research Institute for 10 years (1956-66) and under Colony sponsorship a 24 ton/day pilot plant in Colorado has been utilized.

The Tosco process involves the feeding of minus 1/2 inch crushed shale particles into a horizontal rotating retort, where it is heated by mixing with small hot ceramic balls. Shale oil vapors are distilled off, removed, and condensed. The cooled balls and spent shale are discharged from the retort and screened to separate out the balls, which are sent to a heater, reheated, and recycled to the retort. The spent shale is cooled and discharged to compacted waste piles. It normally contains about 4 percent of carbonaceous "semi-coke" coating on the particles of spent shale, as discharged.

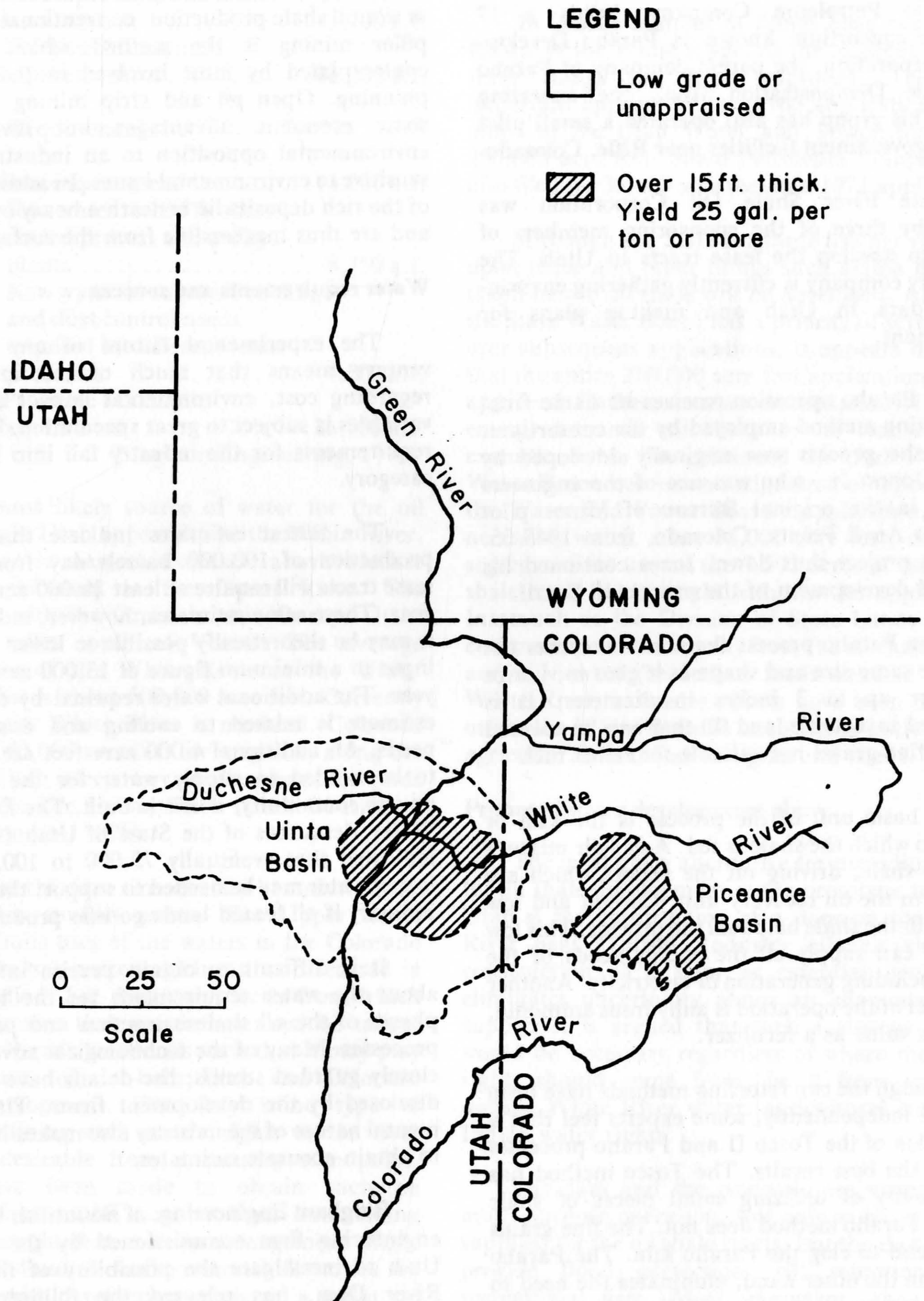

LEGEND
Low grade or unappraised
Over 15 ft. thick. Yield 25 gal. per ton or more
IDAHO
UTAH
WYOMING
COLORADO
Green River
Yampa River
Duchesne River
White River
Uinta Basin
Piceance Basin
Colorado River
UTAH
COLORADO
0 25 50
Scale

Figure 2.

Paraho Development Corporation— White River Shale Oil Corporation

Sohio Petroleum Company, heads a 17 company consortium known as Paraho Development Corporation, the parent company of Paraho Oil Shale Demonstration, Inc., the operating entity. This group has also operated a small pilot plant at government facilities near Rifle, Colorado.

White River Shale Oil Corporation was formed by three of the sponsoring members of Paraho to develop the lease tracts in Utah. The subsidiary company is currently gathering environmental data in Utah and making plans for development.

The Paraho operation receives its name from the retorting method employed by the consortium. The Paraho process was originally developed by John B. Jones, Jr., who was one of the engineers involved in the original Bureau of Mines pilot project at Anvil Points, Colorado, from 1945-55. After the project shut down, Jones continued his work and development of the process in Brazil.

In the Paraho process the material comes out about the same size and shape as it goes in, lumps which are up to 3 inches in diameter. It is compacted in a stable land fill that can be covered with the fine gravel not suitable for retort fuel.

The basic unit of the process is the kiln or retort into which the shale is fed. A gas-air mixture heats the shale, driving off the vapors which are collected in the oil recovery unit. Carbon and low BTU gas in the shale help fuel the process. This low BTU gas can supply all the energy needs of the process including generation of electricity. Another by-product of the operation is anhydrous ammonia, which has value as a fertilizer.

Although the two retorting methods have been developed independently, some experts feel that a combination of the Tosco II and Paraho processes will yield the best results. The Tosco method has the capability of utilizing small pieces of shale which the Paraho method does not. The fine grains of shale tend to clog the Paraho kiln. The Paraho method, on the other hand, eliminates the need to crush the larger chunks into small pieces required in the Tosco operation.

In light of recent progress with the Paraho process and the suspension of the Tosco/Colony operation, the Paraho process will probably be the one employed for the first prototype plants in Colorado and Utah.

Mining

Except for some very recent developments in *in situ* oil shale production, conventional room and pillar mining is the method which is being contemplated by most involved in the oil shale planning. Open pit and strip mining may have some economic advantages but invoke loud environmental opposition to an industry already sensitive to environmental issues. In addition, most of the rich deposits lie beneath a heavy overburden and are thus inaccessible from the surface.

Water requirements and sources

The experimental nature of any oil shale venture means that much of the information regarding cost, environmental impact and other variables is subject to great speculation. The water requirements for the industry fall into this same category.

The lastest estimates indicate that a daily production of 100,000 barrels/day from Utah's lease tracts will require at least 26,000 acre feet per year. These same estimates, however, indicate that it may be theoretically possible to lower the water input to a minimum figure of 13,000 acre feet per year. The additional water required by the higher estimate is related to cooling and dust control needs. An additional 4,000 acre feet are expected to be needed to supply water for the proposed on-site community, if one is built. The Division of Water Resources of the State of Utah (1975) has indicated that eventually 75,000 to 100,000 acre feet of water may be needed to support the oil shale industry if all leased lands go into production.

It is difficult to obtain precise information about the water requirements for the individual phases of the oil shale extraction and production processes. Many of the technological advances are closely guarded secrets; the details have not been disclosed by the development firms. The experimental nature of the industry also makes it difficult to obtain accurate estimates.

Bingham Engineering, of Bountiful, Utah, the engineering firm commissioned by the State of Utah to investigate the possibility of the White River Dam, has released the following water estimates for the prototype oil shale plant:

Water Requirements
for Oil Shale Lease Tracts U_a and U_b

Minimum Requirement

Process plant . . . . 9,700 a.f.

Processed shale dust control,
irrigation and other
undefined uses .... 1,600 a.f.
Seepage, evaporation and minor
losses .... 1,700 a.f.
Total Practical Minimum
Requirement ....13,000 a.f.

Maximum Requirement

Minimum requirement ....13,000 a.f.
Add: Raw water to 100% water
cooled process and utility
plants .... 8,750 a.f.
Add: Raw water to augment cooling
and dust control needs
required by different retort
processes .... 4,500 a.f.
Total Probable Maximum
Requirement ....26,250 a.f.
(Bingham Engineering, 1976)

The most likely source of water for the oil shale lands in Utah appears to be the White River, which heads in western Colorado above Meeker and is a tributary to the Green River. The confluence with the Green is near Ouray, Utah, about 26 miles south of Vernal. The average annual flow of the White River at the Utah/Colorado line is about 500,000 acre feet. Currently the use of the White River is minimal. Colorado uses about 40,000 acre feet for irrigation along the river, and Utah uses a very small amount for lands owned by the Ute Indian Tribe (Utah Division of Water Resources, 1975).

Because the river crosses state boundaries, the potential for conflict exists. The Upper Basin Compact limits uses of the waters in the Colorado River system to a percentage basis, as discussed in the last section, but does not specify from which rivers or streams that percentage must be taken. The White River's location is such that it may play an important role in both Utah and Colorado energy development. Obviously some type of compact defining each state's rights to the river would be desirable from a security standpoint. Efforts have been made to obtain such an agreement but results have not been forthcoming and it is thought that such an arrangement might take years to finalize. At the moment all parties are proceeding with development plans on a unilateral basis.

It should be pointed out, however, that Colorado will probably not be able to use a great amount of White River water and still meet its downstream flow commitments to the lower basin. Colorado is currently utilizing most of its Colorado River allotment and any new use of the White River would have to be coupled with discontinued use of other water. Thus, current water uses in that state seem to restrict use of the White River.

In Utah a number of filings have been made for use of the White River. At the moment none of these filings has been approved. The most important appears to be a 1965 application in the name of the Utah Water and Power Board for 250,000 acre feet. Sohio Petroleum Company has also filed for 36,500 acre feet in a 1972 application.

Although the State Engineer has not yet acted upon these and other filings such action must be taken before oil shale will be developed. Although the State Water Board has a priority of seven years over subsequent applications, it appears doubtful that the entire 250,000 acre feet application will be approved. Rather, some accommodation with other energy demands will have to be reached. For example, Sohio has petitioned the Utah Board of Water Resources for an assignment of a portion of the Water and Power Board's application. If the necessary water, some 36,000 acre feet, could be segregated for use on the 7,592 acres of leased oil shale land, Sohio would withdraw its application. Inasmuch as the Division of State Lands has an enormous potential royalty from the oil shale lands, and in view of the Indian lands situated on the White River, extensive efforts have been made to utilize the White River so as to satisfy both energy, agricultural, and Indian rights and needs.

Proposed water development plans

The most likely alternative for providing water for oil shale development at the prototype tracts in Utah is the construction of a dam on the White River near Watson. Industry officials view the construction of a dam as essential because it eliminates uncertainty about an adequate water supply. It is argued that such a storage project would be necessary regardless of where the water rights should come from, be it from presently unused White River water, agricultural water, or Indian water rights.

The dam and the reservoir are viewed as a multi-purpose operation. Not only would water be supplied for the oil shale tracts, but the dam would provide flood protection, silt retention, and recreational uses. Most important, the project would provide storage for irrigation water to be used on 13,000 acres of Indian lands. The Indian involvement in the project is essential since under the **Winter's Doctrine** water must be made available to all potentially irrigable acreage. Thus, the Indian Tribe could lay claim to much of the water of the White River without regard to other water uses.

Although the White River Dam appears to be the most logical and likely alternative for obtaining water for oil shale, the project would, nonetheless, be an expensive undertaking. Originally construction costs were estimated at $7,000,000, but have now escalated to $8,500,000. (Personal communication with Jay R. Bingham, Bingham Engineering and Daniel F. Lawrence, Director, Utah Division of Water Resources.) It is obvious that the financial arrangements for the project are a major obstacle in the construction of the dam.

Several financing alternatives have been proposed. One possibility is to have construction of the project handled under auspices of the Uintah Basin Conservancy District and the Central Utah Conservancy District, with the cooperation of the Ute and Ouray Indian Tribe. Ownership would remain with the state and oil shale, as well as other users, would purchase the water as it is utilized.

The exact contractual arrangements for financing the project and delivering the water have not yet been made public, but officials have indicated that some form of public financing is likely. Rather than create a new organization entity, financing would likely be carried out under the Uintah Conservancy District since it involves working with only one county. Funds would be obtained in the form of revenue bonds with the conservancy district floating the bonds to obtain better interest rates. The exact price of water for oil shale has not been decided, but discussions with state and construction officials indicate that the figure will likely fall between $25 and $35 per acre foot.

Another possibility would be to have the oil shale consortium itself build the dam. Under the terms of the lease agreements with the federal government on the prototype tracts, the consortium is entitled to investment credits in the fourth and fifth years. Thus, it may elect to build the dam itself and write the expenses off to these investment credits.

Both of these previously mentioned possibilities incorporate the idea of a significant involvement by the oil shale industry in the construction of the White River Dam. Indeed, the project's initial focus was to provide water for oil shale. However, because of the project's potential benefits for groups other than those in oil shale, especially the Ute and Ouray Indian Tribe, state officials indicate a willingness to examine the feasibility of constructing the White River Dam without oil shale's participation. In an interview with Daniel F. Lawrence, Chairman of the Utah Division of Water Resources, he indicated that if the future of oil shale were to grow more uncertain the possibility exists that the State of Utah might be asked to appropriate the money for the construction of the dam. Mr. Lawrence in essence stated that the White River Dam should be examined on its own merits without regard to the future of oil shale.

Efforts to build the White River Dam without the oil shale industry's participation appear primarily geared toward satisfying the Indian water needs. Indeed, regardless of whatever means of financing the project is decided upon, the Indian water rights will likely be heavily subsidized either by oil shale or the state. The reasons for this action are essentially political. The Ute and Ouray water rights on the White River are not part of the deferred water rights under which the Central Utah Project operates. Nonetheless, they are water rights which the Indian Tribe is entitled to develop. Efforts to satisfy these rights could have a positive effect on Indian participation with regard to the remaining units of the Central Utah Project as well as other water developments in Eastern Utah. It, therefore, appears likely that about half of the storage in the White River dam reservoir will be Indian water. Various proposals would give the Indians a third to a half equity in the reservoir. Mr. Lawrence indicated that the possibility of obtaining funding from the Four Corners Regional Council as well as other sources for the funding of the Indian involvement is being investigated. Nonetheless, much of the impact of the White River Dam will be to satisfy Indian demands to insure Indian participation in other water development projects (personal communication with Daniel F. Lawrence, Director, Utah Division of Water Resources).

In summary, no concrete proposals for the development of the White River Dam have been finalized as yet. Efforts are currently under way to complete a memorandum of understanding between all the interested parties as well as a commitment from the state, the conservancy districts and the Indians to aid in the financing of the preliminary studies to be done on the project.

The role of oil shale is still cloudy, and negotiations are currently under way by the companies to obtain extensions of time with regard to the investment schedule on which they must prove up on their leases. Tosco and Moon Lake Electric, an electric-power company with interests in developing the area's coal deposits, have also petitioned to be involved in the White River Dam project. Their water needs must also be evaluated with regard to the water capacity of the project. It also appears likely that the State Engineer's office will approve the petition to segregate a quantity of the Utah Power Board's filing for development on the White River. The original request was for the segregation of 36,000 acre feet. However, it is likely that some 53,000 acre feet will be segregated for energy-related development.

According to Jay R. Bingham Engineering, the firm contracted by the State Board of Water Resources to survey the possibilities of the dam, work is currently being completed on the environmental impact study and test drilling for the foundation is 50 percent completed.

Bingham also indicates that the dam may have to be one of the first items built for the proposed oil shale complex. Blowers necessary for the retort have to be transported to the site. The most economical method is to transport these blowers intact. Since the weight of the blowers, approximately 700 tons, exceeds the capacity of all existing bridges in the White River area, the dam would have to be constructed first to provide a means of transporting the heavy equipment. Because of this situation and if all other aspects of the planning go as scheduled, the engineering firm estimates that the construction on the dam could begin within a year and a half to two years.

The construction of the proposed White River Dam is symbolic of the major obstacle for a commercial oil shale plant; astronomical costs. It is estimated that the dam alone would cost $8,500,000 and that the total costs for the entire commercial module could approach $1.5 billion. These costs must also be viewed in light of other financial obligations besetting members of the White River consortium. Sohio Petroleum, for example, has an obligation of $1 billion for its share of the Alaska pipeline. It comes as no surprise then that the White River Oil Shale Corporation is attempting to shift some of this financial burden to other investors.

The economic feasibility of such mammoth projects is closely tied to the market price for crude oil. Exact figures are not available as to what oil price would make oil shale feasible, but it is safe to assume that the price is higher than the current free market figure for crude.

The availability of funds and the sharply rising costs of construction and equipment are also clouding oil shale's future. To offset this problem of lack of adequate venture capital, some groups such as Colony Development, have attempted to obtain long-term, low interest federal loans for their projects. They've also attempted to receive some form of guaranteed price support for petroleum to insure an adequate return from an oil shale operation. To date all such efforts have proven unsuccessful but are no doubt continuing.

Officials once felt that work on the commercial plant may begin by 1977 and that by 1980 three commercial units, two in Colorado and one in Utah, could be in operation. However, the time schedule for the entire project is currently under an indefinite holding pattern. Whether it will even be attempted is the subject of great speculation. If a prototype plant is completed, there are no present plans to extend capacity beyond a 100,000 barrel/day limit.

POPULATION IMPACTS

The information in the last section on water for oil shale indicates that the proposed White River Dam could provide water for the prototype operation without infringing upon existing agricultural water supplies. Domestic water supplies for the increased population associated with oil shale growth may present some problems, however. Although present plans indicate that some 4,000 additional acre feet will be requested to supply municipal water, there are no guarantees that all or any of the oil shale population will locate on-site. If a new town is not built existing communities will have to absorb the population growth. In that case will the communities be able to supply domestic water without affecting the agricultural sector?

It is the purpose of this section to examine the population growth associated with the proposed oil shale plant and the necessary water needed to supply this population increase.

It is important to distinguish between water "demand" and "requirement." The term "requirement" implies a fixed need for water where the quantity utilized is quite independent of the price of water. Need is related to water-using technology, to crop requirements in irrigation, or to the population using water. Demand, on the other hand, is a specialized term utilized by economists to express the relationship between quantity of water used at various relative prices of water. One measure of the degree of responsiveness of the quantity demanded to changes in the relative price of water is known as elasticity of demand.

It is generally assumed that the demand for domestic water is relatively inelastic; i.e., that there is little alteration in water consumption as a result of price changes. Empirical studies have indicated, however, that the household demand for water is indeed affected by price changes as well as other factors. For example, Gardner and Schick (1964) found the elasticity of demand for household water to be -.77. People in communities with high prices consumed less water per capita than people in communities with low prices. As among 44 northern Utah communities an increase in the price of water of 10 percent was associated with a per capita decrease in the quantity consumed of 7.7 percent. It was also discovered that uses such as lawn and garden watering were particularly responsive to rate changes. When municipal prices are high, development of other water supply sources becomes economically attractive, and people find various ways to conserve water.

This response of consumption to price may be important in establishing water use figures for such communities as Vernal, Utah, where water has generally been plentiful and cheap. Consumption figures indicate that water use for domestic purposes has been relatively high when compared with national household consumption estimates. Increases in the rates charged for water demanded by municipal consumers may make more water available for other uses.

The population increase connected with all aspects of Utah's energy resources has been an area which has attracted great public interest. Every community located near untapped energy resources anticipates the economic benefits associated with such development. The majority of these communities also seem to be anticipating some of the problems associated with this growth.

Since the plant capacity estimated for the prototype operation has continually fluctuated, it has been difficult to establish what the exact population increases will be. As recently as November, 1974, in their task force report for Project Independence prepared for the Federal Energy Administration, the Department of the Interior estimated that a 100,000 barrel/day prototype operation would involve a total oil shale population of 24,400 people by 1980. This same study also estimated that accelerated development would involve over 90,000 people by the year 2000 (USDI, 1974). Of course, these figures reflect the belief that future oil shale development would far surpass the prototype capacity of 100,000 barrels/day at some later date.

Projecting the population distribution for the oil shale population is also a difficult task. It was originally thought that a majority of the population would locate in the Ashley Valley-Vernal area with the rest being disbursed throughout the Uintah Basin. Subsequent studies, however, have indicated that Rangely, Colorado, located only 30 miles from the proposed site, would absorb a large share.

The possibility of a new town being constructed near the present town of Bonanza, Utah, would eliminate the need for the oil shale population to locate in existing communities. If such a new town is constructed, it would have to include all the necessary facilities to attract the oil shale work force.

In light of the current status of oil shale development in Utah, namely no immediate plans for expansion beyond a 100,000 barrel/day capacity, population estimates have been scaled down. In a 1975 publication, Lewis (1975) estimates that the total population increases associated with oil shale development for the Utah lease tracts will not exceed 13,780, with a final commercial operational estimate of 12,535. If plans for the unit begin in 1978, the increased population will not become a factor until the fifth year of 1983. The eighth year represents the high point in population increase.

The population figures presented by Lewis indicate that the majority of the anticipated population, assuming no new town is built, will locate in the Vernal, Utah, and Rangely, Colorado, areas. Duchesne and Roosevelt, located in Duchesne County, Utah, would also receive an increase in population, however.

The figures indicate that Vernal would anticipate a final population increase of 3,958, Rangley an increase of 5,396, and Roosevelt and Duchesne increases of 1,574 and 479 respectively. Even if the new town is not built there will still be a considerable on-site population. It is estimated that 30 percent of the construction force and 10 percent of the operations force would live at or near the construction site (Lewis, 1975).

If the new town is built, it will capture the majority of oil shale population. Lewis (1975) estimates that the town would have a final population of 10,028 with an eighth year high of 11,024. Approximately 80 percent of the oil shale population would locate in the new facility. The remaining people would locate throughout the Uintah Basin. Vernal and Rangely would capture the great majority of this non-new town population. Roosevelt and Duchesne's population increase would be negligible.

Water needs

The Board of Water Resources has stated that 4,000 acre feet will be petitioned by the White River Oil Shale Corporation to supply adequate municipal water. This amount would be in addition to 26,000 acre feet requested for industrial requirements. If a consumption rate of .25 acre feet per capita is used (this represents a rate of 225 gallons per capita per day and is the rate generally used by the Project Independence Task Force Report) there would be enough water to support a population of 16,000 people on-site. This is more than is projected in the Lewis population estimates.

Using these same water consumption estimates and population figures for the population distribution without the new town, the water "requirements" for the Vernal area can be indicated. (See Table 3.) The Vernal figures are the only ones shown since that is the only Utah area with a considerable projected population increase. The same procedure would hold true for the other areas, however. The population table indicates that there will be a population increase of 4,010 in the eighth year of development. Using the .25 acre foot per capita consumption estimate the water requirement for that population increase is approximately 1,000 acre-feet of water.

One of the primary concerns of rural communities located within the oil shale area is that this additional water will be taken from existing agricultural supplies. Although it will be shown later in this report that there are a number of potential sources of domestic water, for the sake of argument, let it be assumed that all the additional water would be withdrawn from agriculture. How much agricultural land would be affected?

Using an annual irrigation diversion figure of 3.0 acre feet/acre, in the eighth year, which is the high population year, only approximately 335 acres would need to be removed from irrigation to supply the needed increase in domestic water needs. Thus, it would appear to require the sacrifice of very little agricultural acreage to supply the water for a significant population increase. This statement ignores the fact that water quality needs for domestic uses may not be satisfied through the simple transfer of irrigation water to municipal uses. Obviously some treatment of the water would be required or an exchange arrangement reached where communities could substitute the irrigation water for high quality water. Again, it should be mentioned that this transfer situation is hypothetical and there are still other ways to obtain sufficient water without substantial direct withdrawal from agricultural sources. These other alternatives for the Vernal area will be discussed in the next section.

The new town

Obviously, if a new town is built, a great deal of the concern currently felt by existing communities about absorbing the oil shale population will be alleviated. Whether the new town will in fact be built is uncertain at present. Vernal and Rangely are located less than 40 miles from the proposed oil shale site, and highway improvements could shorten that distance, both in miles and in trip time. Even if the new town is built, however, there will still be a close association between the new town and these two communities. A second consideration is that the new town may not be of permanent duration. It may exist only for the oil shale industry and once the shale is fully exploited the need for the town may disappear. Since the shale deposits are so extensive, however, the town may last for a very long time. Whether the high cost of the construction of the new town would offset transportation costs to and from Vernal and Rangely is debatable. Much depends on how long the new town can be assumed to last and over what period the capital costs can be amortized. One thing is fairly obvious, U_a and U_b are located in a desolate desert without the natural geo-physical features that would make a new town an attractive place to live. There would have to be some real incentive to make people want to locate there.

Water sources for Duchesne and Roosevelt

The information presented in the Lewis population estimates indicates that Vernal, Utah, will capture the bulk of the oil shale population to locate in Utah. These same figures also indicate that Roosevelt and Duchesne will receive a relatively small population increase. The following section will examine in depth the sources and water needs for the Vernal, Ashley Valley area. The water sources for Roosevelt and Duchesne will be briefly outlined here.

Roosevelt, the larger of the two Duchesne County communities, obtains its domestic water from the following sources:

1. Uriah Heaps Spring—piped from the spring near Whiterocks. The spring is Indian owned and has a capacity of 1,000 gallons per minute (1614 acre feet/year). The spring was the sole source for Roosevelt culinary water until October 1975.

2. Hancock Cove Well—developed and started to use in October 1975. Capacity is placed at 1.2 cfs (864 acre feet/year).

3. Campbell Well—the rights have been cleared and development is anticipated by 1976. Preliminary estimates of capacity indicate a rate of 4.5 cfs - (3240 acre feet/year).

The system now has two 500,000 gallon storage tanks and will add a one million gallon tank with the Campbell Well. Extensive remodeling and replacement of old lines has taken place throughout the system resulting in a savings of about one-third in water used. It is estimated that the two wells will double the supply and that present commitments will be adequate for a population of 10,000 unless considerable water-using industrial development takes place. That prospect appears unlikely at present. Should additional needs arise they will most likely be met by additional wells. (Personal communication with Larry Bagley, Roosevelt City Manager, and Leon C. Michaelson, area coordinator, Cooperative Extension Service, Utah State University.)

In 1960, Duchesne City began a major water system improvement program. The program included the development of new wells, the construction of a desander/chlorinator facility, new transmission and supply lines, a reinforced concrete reservoir and an entirely new distribution system. In 1971, a new pump house, a steel storage tank, and a high-level distribution system were constructed to bring water from the lower elevations of Duchesne to the "Blue Bench" area.

The primary source of water for the community is six shallow wells located in the Murray Springs area three and a half miles north of town. Two additional wells have been recently completed in the area. It is estimated that all eight wells pumping simultaneously will produce 1,000 gals/minute, or 2.23 cubic feet per second (1614 acre feet/year).

Other potential sources of water are two springs on Rock Creek located 25 miles northwest of the town, Starvation Reservoir, located three miles from town, and the Duchesne River which passes through Duchesne City. In 1905, the federal government filed an application to appropriate 15 cfs from the Duchesne River for municipal purposes. There is some controversy over the application, however; the State Engineer's office maintains that the water rights in question are owned by the U.S. Bureau of Indian Affairs. Legal action is pending to establish ownership of the water (Valley Engineering, 1975).

Legal action to establish title to the disputed right on the Duchesne River appears imperative for the community to develop an adequate future water supply. The eight wells in the Murray Springs area are sufficient to satisfy a population of 3,300 people at present consumption levels (Valley Engineering, 1975). Improvements in storage facilities would also eliminate existing storage deficiencies.

In short, current water supplies appear adequate to satisfy the needs of the projected population increase if rights to the Duchesne River are clarified. Without that, efforts would have to be made to obtain water from Starvation Reservoir or other sources which might have an effect on agriculture if the community were to undergo substantial population increase. The population figures in this study, however, assume the increase from oil shale to be rather small.

Upalco and Uintah Units of the Central Utah Project

These two units of the Central Utah Project, if completed, would provide more than enough water to satisfy any substantial population increase. The Uintah Unit would provide 52,000 acre feet of municipal, industrial, and agricultural water to the Roosevelt area. The project also includes water for 42,000 acres of Indian land. The Upalco unit would be located near the center of Duchesne County and would provide 20,500 acre feet of new water for municipal, industrial, and agricultural purposes (Central Utah Water Conservancy District, 1975).

The future of the two units is far from certain, however. Both projects appear to have a low priority behind already promised but as yet uncompleted water projects. In their favor is the importance of satisfying Indian rights. It was mentioned in an earlier section that the Indian demands must be satisfied or further construction on the Central Utah Project faces the possibility of indefinite suspension. The development of the Upalco and Uintah Units, therefore, may be determined by what pressures can be brought to bear by the Indians and industry.

Water sources for the Vernal-Ashley Valley area

The information presented in the last section indicates that Vernal-Ashley Valley will be the area of the State of Utah to realize the greatest direct impacts from the prototype oil shale operation. Even if all the needed water for the population increase associated with a 100,000 barrel/day prototype plant were to come from agricultural supplies it would only involve an amount sufficient to irrigate some 300 acres. Nonetheless, if energy development in the area were to be undertaken on a large scale, that situation could easily change.

The purpose of this section of the report is to investigate the current water usage in the Vernal-Ashley Valley area and to examine alternative plans for obtaining water for agriculture and municipal and industrial uses.

Current water sources

There are two public water systems that currently operate within the boundaries of the Ashley Valley. These are the Maeser and Ashley Valley-Vernal systems. The supply source for both systems is the Ashley Springs, located adjacent to Ashley Creek nine miles north of Vernal.

From the Spring Box and the adjacent sedimentation and chlorination works, the water flows southward into Ashley Valley. Water lines have been laid adjacent to the roads along section boundaries. This system provides water service to most of the developed areas in the upper Ashley Valley. In the cities, the Vernal and Maeser water systems provide water service to all developed areas

Table 1. Gravity model distribution of population impact among principal urban places in the Uintah Basin assuming no new town is constructed (Lewis, 1975).

Year	Cumulative total population impact	Duchesne[a]	Roosevelt[a]	Vernal[a]	Rangely[a]	At or near site	Other parts of Uintah Basin[c]
Commercial Stage Phase I							
5	4,538	152	500	1,257	1,713	688	227
6	6,218	206	678	1,704	2,324	994	311
7	8,277	277	911	2,290	3,121	1,265	414
8	13,780	485	1,595	4,010	5,466	1,536	689
9	11,310	419	1,376	3,461	4,718	770	566
10	10,902	412	1,354	3,405	4,614	545	545
Commercial Stage Phase II							
11-15	12,535	479	1,574	3,958	5,396	501	627
16-20	12,535	479	1,574	3.958	5,396	501	627

[a]Gravity proportions for distribution of urban population

Duchesne	0.042
Roosevelt	0.138
Vernal	0.347
Rangely	0.473

[b]Basic assumption for on-site population projections:

1. 30.0 percent of the construction force would live in the construction camp at or near the site.
2. 10.0 percent of the operations force would live at or near the site.

[c]Five percent of total population impact is allocated to non-urban parts of the Uintah Basin.

Table 2. Gravity model distribution population impact with new town (Lewis, 1975).

Year	Population impact	New town[a]	Duchesne[b]	Roosevelt[b]	Vernal[b]	Rangely[b]	Other parts of Uintah Basin[c]
Commercial Stage Phase I							
5	4,538	3,630	36	119	299	408	45
6	6,218	4,974	50	163	410	559	62
7	8,277	6,622	66	217	546	744	83
8	13,780	11,024	110	361	909	1,238	138
9	11,310	9,048	90	297	746	1,016	113
10	10,902	8,722	87	286	719	980	109
Commercial Stage Phase II							
11-15	12,535	10,028	100	329	826	1,127	125
16-20	12,535	10,028	100	329	826	1,127	125

[a]Based on an 80.0 percent capture rate for the new town.

[b]Gravity proportions for distribution of urban population outside "new town:"

Duchesne	0.042
Roosevelt	0.138
Rangely	0.473

[c]Five percent of population impact outside new town is allocated to non-urban parts of the Uintah Basin.

(The sum of individual population impacts may not equal total impact (column 2) due to rounding.)

within the respective communities. These two systems are an integral part of the Ashley Valley system.

At the time the larger Ashley Valley system was developed in 1961, most of the then existing lines, including those in Maeser and Vernal, were incorporated into the system. Under terms of the agreement, Maeser Improvement District obtained a one-eighth interest in the supply aqueduct, headworks, and treatment facilities. The district is still responsible for maintaining and administering that part of the distribution system within its boundaries. The remainder of the Ashley Valley Water System is owned and maintained by Vernal City.

Table 3. Water needed to support oil shale population and potential agricultural acreage affected in the Vernal area assuming no new town is constructed.

Year	Population impact	Water[a] needed	Acreage[b] affected
Commercial Stage Phase I			
5	1,257	314.25	104.75
6	1,704	426.0	142.0
7	2,290	572.50	190.8
8	4,010	1002.5	334.2
9	3,461	865.25	288.4
10	3,405	851.25	283.75
Commercial Stage Phase II			
11-15	3,958	989.50	329.8
16-20	3.958	989.50	329.8

[a]Based on estimate of .25 acre feet per capita.

[b]Based upon estimate of 3.0 acre feet per acre.

Table 4. Water needed to support oil shale population and potential agricultural acreage affected in the Vernal area assuming new town is constructed.

Year	Population impact	Water[a] needed	Acreage[b] affected
Commercial Stage Phase I			
5	299	74.75	24.9
6	410	102.5	34.16
7	546	136.5	45.5
8	909	227.25	75.75
9	746	186.5	62.16
10	719	179.75	59.9
Commercial Stage Phase II			
11-15	826	206.5	68.83
16-20	826	206.5	68.83

[a]Based on estimate of .25 acre feet per capita.

[b]Based on estimate of 3.0 acre feet per acre.

The present population served by the Springs would include Vernal City, all of the area outside of the Vernal City limits within Ashley Valley connected to the system, the Maeser Water District area (this is the northwest corner of Ashley Valley), and the Jensen area. The following number of connections currently exist on the total system (30 November 1975 estimate, Uintah County-Vernal City Planning Commission, 1970):

1670 - Inside Vernal City
1620 - Outside Vernal City, but on the City's system
460 - Maeser District area
120 - Jensen

Maeser sets its own rates which are comparable to Vernal City's rates. For those outside of Vernal City but on its system, the rates are approximately double the rate charged inside the city.

According to the **Water and Sewer Plan for Uintah County** prepared by Despain Planning Associates in 1970, and the Vernal City records, water rights held by Vernal City for water through the line from Ashley Springs include:

1. Steinaker Reservoir storage which the city exchanged for Ashley Springs water in the amount of 1,400 acre feet divided as follows:

   a. 750 a.f.—Vernal City in its own right.
   b. 200 a.f.—Transferred to Vernal City by Naples Water Company.
   c. 150 a.f.—Transferred to Vernal City by Ashley Water Company.
   d. 300 a.f.—Transferred to Vernal City by Glines-Davis Water Company.

   The water is available on a year-round basis.

2. Ashley Central Irrigation Company Water Stock (Mutual Irrigation Company) totaling approximately 4,112.95 acre feet. This water is available year round.

3. Ashley Upper Irrigation Company Water Stock (Mutual Irrigation Company) which is equal to approximately 34.30 acre feet available year round.

4. Ashley Valley Reservoir Company Water Stock totaling approximately 503.52 acre feet available year round.

5. Diligence Rights Claim No. 1370, for 3.5 cfs (2529 acre feet/year) from Ashley Springs on a year-round basis.

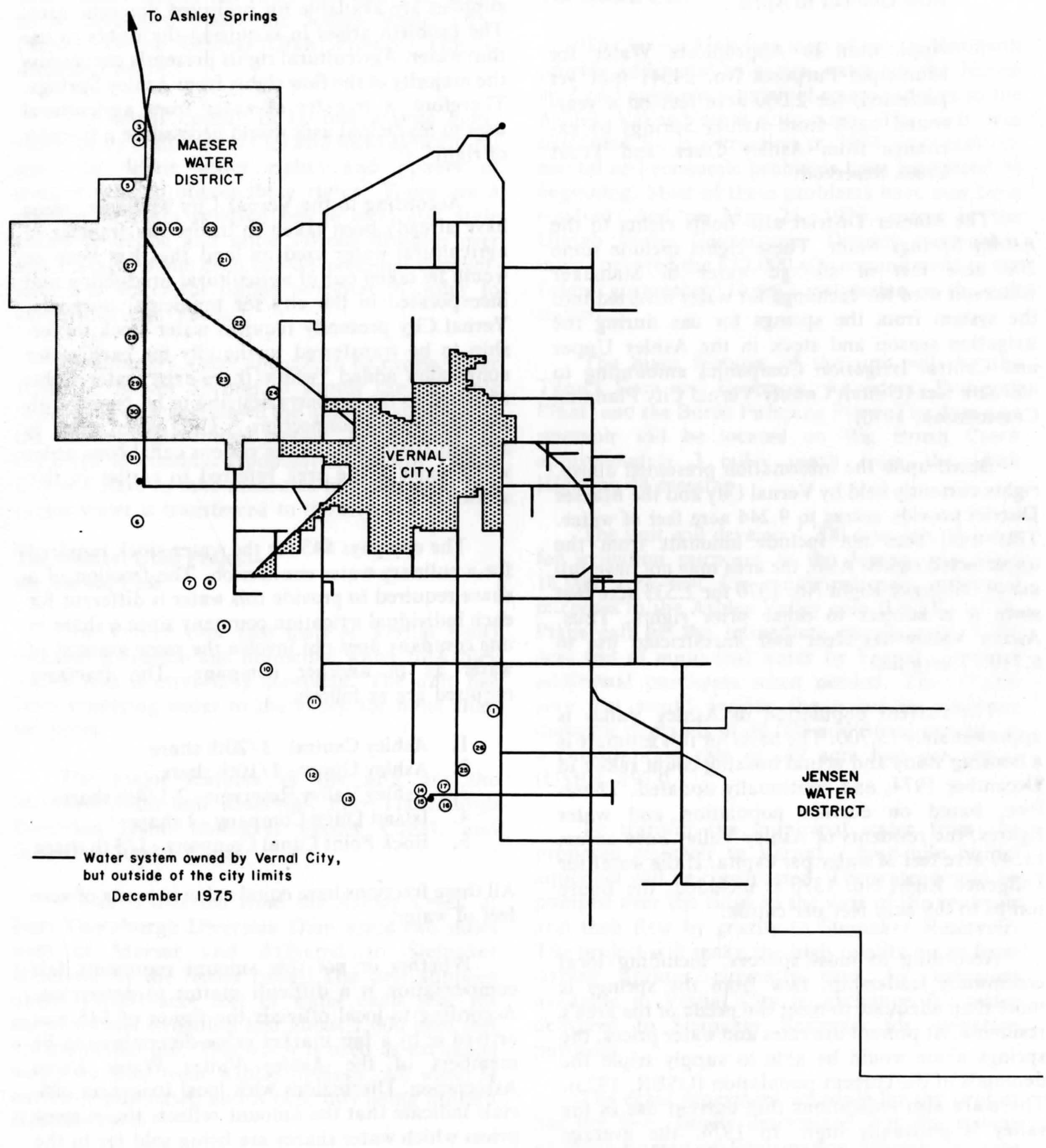

To Ashley Springs
MAESER
WATER
DISTRICT
VERNAL
CITY
JENSEN
WATER
DISTRICT
Water system owned by Vernal City,
but outside of the city limits
December 1975

Figure 3.

6. Application to Appropriate Water for Municipal Purposes No. 24219 (not yet perfected) for 5 second feet (3600 acre feet/year) from Ashley Springs for use from October to April.

7. Application to Appropriate Water for Municipal Purposes No. 24341 (not yet perfected) for 2,000 acre feet on a year-round basis from Ashley Springs by exchange from Ashley Creek and Trout Creek Reservoir.

The Maeser District also holds rights to the Ashley Springs water. These rights include some 200 acre feet of storage water in Steinaker Reservoir used for exchange for water diverted into the system from the springs for use during the irrigation season and stock in the Ashley Upper and Central Irrigation Companies amounting to 460 acre feet (Uintah County-Vernal City Planning Commission, 1970).

Based upon the information presented above, rights currently held by Vernal City and the Maeser District provide access to 9,244 acre feet of water. This total does not include amounts from the unperfected rights. Also, the area may not have full use of Diligence Right No. 1370 for 2,533 acre feet since it is subject to other prior rights. Thus, Ashley Valley has clear and unrestricted use to 6,710.77 acre feet.

The current population of Ashley Valley is approximately 13,700. The basis for this estimate is a housing study and actual housing count taken in December 1974, and continually updated. Therefore, based on current population and water figures, the residents of Ashley Valley have access to .49 acre feet of water per capita. If the water for Diligence Right No. 1370 is included, the figure jumps to .69 acre feet per capita.

According to most sources, including local community leadership, flow from the springs is more than adequate to meet the needs of the area's residents. At present use rates and water prices, the springs alone would be able to supply triple the demands of the current population (USBR, 1973). There are also indications that current use in the valley is unusually high. In 1974, the average annual consumption of water within the Vernal City system was .49 acre feet per capita. Most studies indicate a figure of .25 acre feet per capita is indicative of national domestic water consumption patterns. The previous chapter's discussion on the response of water use to price may suggest that per capita use would decline in response to higher water rates. Also, older parts of the water system need to be repaired and improved and, if done, water waste could be prevented.

Thus, it appears that high quality water supplies are available for projected domestic uses. The problem arises in acquiring the rights to use that water. Agricultural rights presently encompass the majority of the flow rights from Ashley Springs. Therefore, a transfer of water from agricultural uses to municipal uses would necessitate a transfer of right.

According to the Vernal City Manager, steps have already been taken to insure the transfer of agricultural water used on land that has been or would be taken out of agricultural production and incorporated in the city for municipal purposes. Vernal City presently requires water stock ownership to be transferred to the city for each water connection added "where there exist water rights attached to the property desiring to be served with the new water connection." This water stock is actually shares held in the various canal companies which exist in the area referred to earlier in this section.

The city pays $45 for the water stock required for a culinary water connection. The fraction of a share required to provide this water is different for each individual irrigation company since a share in one company does not involve the same amount of water as in another company. The fractions required are as follows:

1. Ashley Central - 1/20th share
2. Ashley Upper - 1/10th share
3. Ashley Valley Reservoir - 2-1/4th shares
4. Island Ditch Company - 1 share
5. Rock Point Canal Company - 1/8 th share

All these fractions have equal value in terms of acre feet of water.

Whether or not this amount represents fair compensation is a difficult matter to determine. According to local officials the figure of $45 was arrived at by a fair market value determination by members of the Ashley Valley Water Users Association. Discussions with local irrigation officials indicate that the amount reflects the current prices which water shares are being sold for in the area. However, the prices which energy developers could pay for this water might be considerably higher. The present holders of rights understand this and translate it into an expectation that water prices may rise. The evidence in this study, however, is that this expectation may well be unfounded unless large-scale commerical operations begin.

Another area of concern is obtaining adequate rights for approved exchange purposes so that the higher quality water from the Ashley Springs can be available for municipal and industrial uses. Thus, plans call for the city to get rights for water to be developed under the Jensen Reclamation Project of the Central Utah Project. This is discussed below.

The courts appear to be one avenue being explored by both Vernal City and local agricultural users to define water rights and powers of communities to obtain these rights. There are a number of cases pending before local and state courts to define and settle various disputes over water usage. Some even involve potential condemnation of water for public purposes in order to supply domestic needs.

In summary, there appears to be excess water from the Ashley Springs to supply the oil shale population over and above the quantity supplied to the existing agricultural sectors. Nonetheless, in the event of continued population growth Vernal City will have to take measures to insure that this excess water is transferred to the city.

The Central Utah Project—
the Vernal Unit

The Vernal Unit (see map of Vernal Unit) provides irrigation and municipal water to Ashley Valley and is essentially complete. The unit has been supplying water to the valley for more than ten years.

The major features of the unit are the Steinaker Dam and Reservoir, Fort Thornburgh Diversion Dam, Steinaker Feeder Canal, and Steinaker Service Canal.

Water is diverted from the Ashley Creek at Fort Thornburgh Diversion Dam some two miles west of Maeser and delivered to Steinaker Reservoir by the feeder canal. The unit supplies about 18,000 acre feet of water each year for supplemental irrigation and about 1,600 acre feet for municipal use. This water is used as exchange water for flow from Ashley Springs. All water is currently purchased and is presently being utilized (USBR, 1973).

The supplemental water supply firms up the previous undependable supply, and in particular late irrigation season water, to about 15,000 acres of cultivated land. The 1,600 acre feet of municipal water is sufficient to provide water for 3,300 persons at a consumption rate of .49 acre feet per capita (USBR, 1973). The Green River is depleted by 12,000 acre feet per year as a result of the Vernal Unit. This results from reservoir evaporation, domestic use, and irrigation consumptive use.

The Jensen Unit

The Jensen Unit (see map of Jensen Unit) will provide additional irrigation water for the Jensen area and augment municipal water supplies to the Ashley Valley-Vernal City area. The unit was scheduled for construction in 1974, but environmental and economic problems have hampered its beginning. Most of these problems have now been resolved, and on May 25, 1976, voters in the Uintah Water Conservancy District overwhelmingly approved the $33,000,000 commitment to the federal government to get construction on the unit started.

The main features of the unit will be the Tyzack Dam and Reservoir, Aqueduct, Pumping Plant, and the Burns Pumping Plant. The dam and reservoir will be located on Big Brush Creek approximately 3 miles south from the Utah Highway 44 crossing.

The unit will develop 4,700 acre feet of water for irrigation purposes in the Jensen area, and 18,000 acre feet for municipal and industrial purposes in the Ashley Valley area (USBR, 1973). Plans call for the immediate purchase of 7,200 acre feet of municipal water by Vernal City with additional purchases when needed. This 18,000 acre feet would provide the water to meet the domestic demands of 38,000 additional persons at a consumption rate of .49 acre feet per capita (USBR, 1973).

To transfer the municipal water from the proposed reservoir to Vernal a four-mile buried aqueduct will be constructed. The water would be pumped over the ridge to the west of the reservoir and then flow by gravity to Steinaker Reservoir. The project will make the high quality water from Ashley Springs currently used by irrigators available to Vernal City in exchange for water delivered to Steinaker Reservoir for irrigation purposes.

The exact repayment schedule for the project has not been finally determined but discussions with the Bureau of Reclamation officials indicate the charges to municipal and industrial users will approach $100 per acre foot. This amount will cover operation and maintenance and interest costs. Although few studies into the value of agricultural water in the Uintah Basin have been conducted, comparative data would indicate that the value of agricultural water would be in the

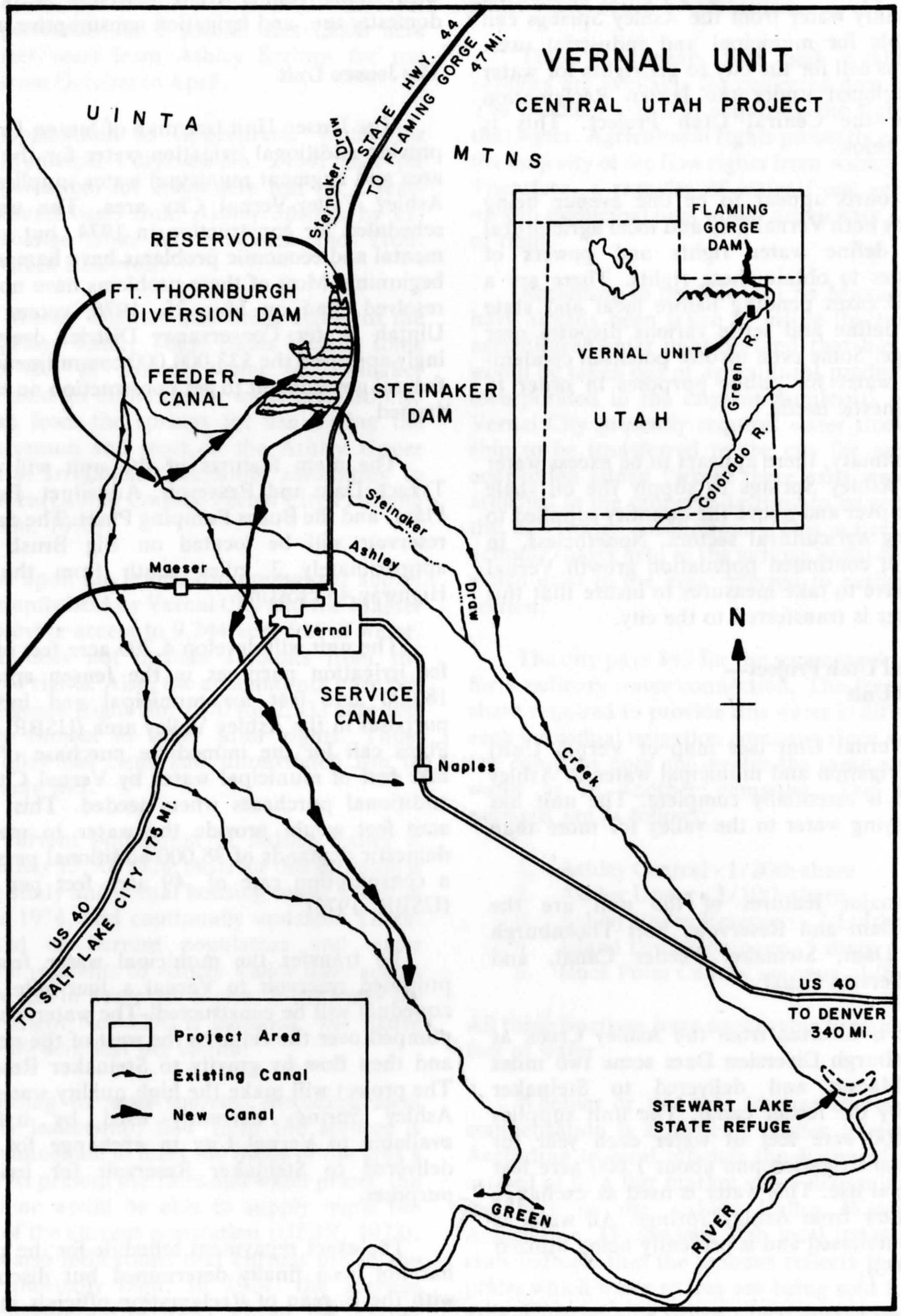

VERNAL UNIT
CENTRAL UTAH PROJECT
UINTA
MTNS
TO FLAMING GORGE 47 Mi.
STATE HWY. 44
Steinaker Draw
RESERVOIR
FT. THORNBURGH
DIVERSION DAM
FEEDER
CANAL
STEINAKER
DAM
FLAMING
GORGE
DAM
VERNAL UNIT
UTAH
Green R.
Colorado R.
Steinaker
Ashley
Draw
Maeser
Vernal
N
SERVICE
CANAL
Naples
Creek
US 40
TO SALT LAKE CITY 175 Mi.
Project Area
Existing Canal
New Canal
US 40
TO DENVER
340 Mi.
STEWART LAKE
STATE REFUGE
GREEN
RIVER

Figure 4.

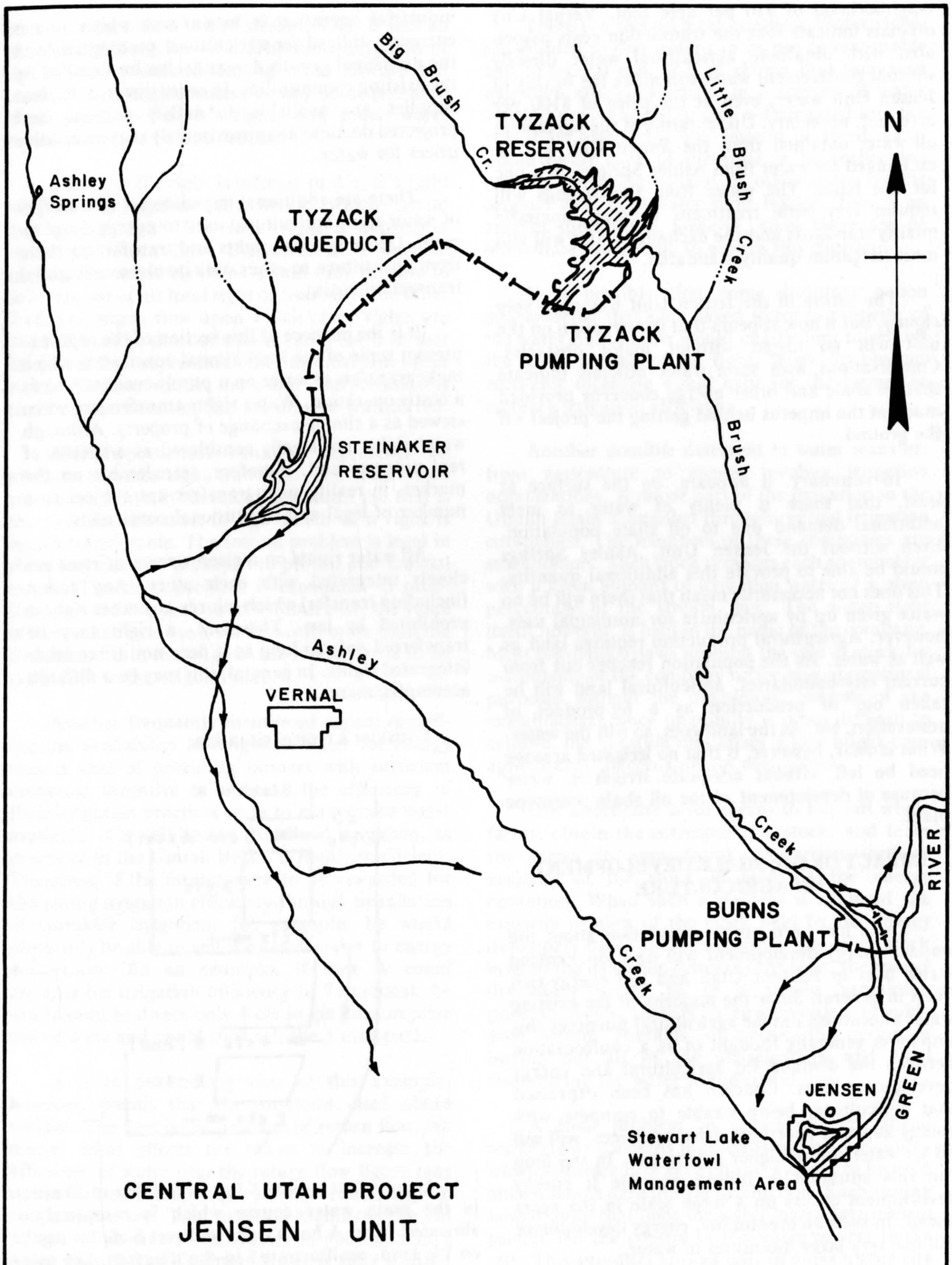

Big Brush Cr.
Little Brush Creek
TYZACK RESERVOIR
N
Ashley Springs
TYZACK AQUEDUCT
TYZACK PUMPING PLANT
Brush
STEINAKER RESERVOIR
Ashley
VERNAL
Creek
RIVER
BURNS PUMPING PLANT
Creek
GREEN
JENSEN
Stewart Lake Waterfowl Management Area
CENTRAL UTAH PROJECT
JENSEN UNIT

Figure 5.

neighborhood of $10 per acre foot. Vernal City officials indicate that the transaction costs associated with obtaining agricultural water directly without replacement water will make the buying of Jensen Unit water, even at the price of $100 per acre foot, necessary. Under terms of the agreement all water obtained from the Jensen Unit will be exchanged for water from Ashley Springs on a one for one basis. The water from the Springs will require very little treatment to meet domestic quality standards and the exchange water will still meet irrigation quality standards.

The future of the Jensen Unit was once very cloudy, but it now appears that construction on the unit will go ahead without major obstacles. Conversations with state water officials indicate that oil shale and other energy concerns provided much of the impetus behind getting the project off the ground.

In summary, it appears, on the surface at least, that there is plenty of water to meet additional demand due to oil shale population. Even without the Jensen Unit, Ashley Springs would be able to provide this additional quantity. This does not necessarily mean that there will be no water given up by agriculture for municipal uses, however. Agricultural production requires land as well as water. As the population reaches out from current city boundaries, agricultural land will be taken out of production as a by-product of annexation, etc. As the land goes, so will the water. What is clear, however, is that no irrigated acreage need be left without adequate irrigation water because of development of the oil shale prototype plant.

IMPACT OF OIL SHALE DEVELOPMENT ON AGRICULTURE

There has been much speculation about the impact energy development will have on existing water uses in Eastern Utah and the energy-rich West in general. Since the majority of the existing water allocations are for agricultural purposes this impact is generally thought of as a confrontation between the demand for agricultural and energy development uses. Concern has been expressed that agriculture, being unable to compete with energy as water shortages drive up prices, will sell off its water to the higher paying use. In the long run this situation is indeed possible if energy development occurs on a large scale in the years ahead. In such an eventuality, energy development will use very large quantities of water.

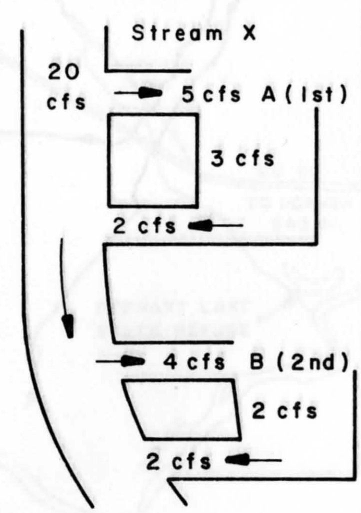
It has been shown earlier in this report, however, that the prototype oil shale operation will not seriously compete with the agricultural economy for water. The location proposed for the industrial operation is in an area which is not currently utilized for agricultural production, and the municipal growth demands can be satisfied by the existing communities. In other words, sufficient supplies are available to satisfy existing and projected demand at approximately current relative prices for water.

There are additional impediments to transfers of water from agricultural uses to energy development. Defining water rights and transferring them from agriculture to other uses involves substantial transaction costs.

It is the purpose of this section of the report to present some of the institutional constraints which make transfers of water on a purely economic basis a costly operation. Water rights transfers are often viewed as a simple exchange of property. Although water rights are legally considered as a species of real property and, therefore, transferable on the market, in reality such transfers are subject to a number of legal and institutional constraints.

All water rights on a given stream or river are closely integrated with each other. Any action (including transfer) which injures any other right is prohibited by law. Therefore, a right may be transferred only so long as it does not affect other integrated rights. In general, this may be a difficult accomplishment.

Consider a typical situation:



Assume that stream X has a total flow of 20 cfs in the main water course which is completely allocated. User A has a right to divert 5 cfs for use on his land, as illustrated in the diagram. Let us suppose that irrigation efficiency is 60 percent. Efficiency is defined as the quantity of water consumptively used as a percentage of the amount diverted. Therefore, 3 cfs are consumptively used on A's property by irrigation. The remaining 2 cfs become return flow to the stream. User B has an inferior right to A for 4 cfs. The remaining flow of the stream is utilized among other downstream users. If an energy concern, or any other potential buyer, were to buy A's right, how much water would the buyer be entitled to?

Although B's right is inferior to A's, B's right is protected against any action which would damage his right. B's water right is dependent upon A's return flow; therefore, if A were to transfer his water right, he would only be able to sell 3 cfs out of his total right of 5 cfs since the other 2 cfs are return flow upon which other rights are dependent. The same situation exists for B in that his return flow represents other downstream water rights. In other words, the usual interpretation is that only the consumptive use may be transferred.

This hypothetical situation represents an obstacle to water right transfers. The transaction costs are essentially threefold in nature: the first is the technical question of how much of a right is legally transferable. The second problem is legal in that every transfer is subject to protest and judicial review. The third problem is economic—if problems one and two are solved without cost, the value of 3 cfs in the new use must be worth more than the 5 cfs diverted in the original use if transfer is to be profitable to the original user.

Another frequently mentioned aspect regarding the availability of irrigation water for energy uses is that of providing farmers with sufficient economic incentive to increase the efficiency of their irrigation practices so as to make more water available. It is well known that flood irrigation, as practiced in the Uintah Basin, is highly inefficient. Therefore, if the farmer were to be rewarded for increasing irrigation efficiency through installation of sprinkler irrigation, for example, he would ostensibly be able to sell the saved water to energy demanders. As an example, if user A could increase his irrigation efficiency to 75 percent, he would need to divert only 4 cfs to get consumptive use of 3 cfs and could thus sell the 1 cfs saved.

A more penetrating view of this example, however, reveals that the problems cited above remain. The first is the problem of return flow. No matter what efforts are taken to increase the efficiency of water use, the return flow figure may not be altered if crop requirements require a given consumptive use. This situation highlights the old adage, "One man's inefficiency is another man's water right." The Colorado River is fully utilized before it runs into the Gulf of California and increasing irrigation efficiency will not add to water availability.

There is a second legal question. Water rights are granted so that water can be put to reasonable and beneficial use. If it is shown that increased irrigation efficiency results in a surplus of water which is not being put to such a designated use, the possibility exists that the amount of saved water would revert back to the state to be reallocated rather than being salable to other users by the original individual water right holder. This is an area of speculation, however, since there are no immediate precedents to govern this decision.

It is possible that some statutory action guaranteeing that such saved water is property of the water right holder would enable him to sell off the saved portion of his right. If so, an obvious economic incentive would exist for the farmer to increase irrigation efficiency.

Another possible deterrent to water transfers from agriculture to energy involves irrigation organizations. A major part of the irrigation in the Uintah Basin is handled through mutual irrigation companies. The members of these companies are stockholders. Such stock provides each shareholder with a given amount of irrigation water or a given percentage of the stream flow. The water right itself, however, is held in the name of the company. Most company bylaws prohibit the sale of stock for use outside of the company or for non-agricultural purposes without the unanimous consent of the stockholders. Since unanimity is often difficult to achieve, the question that arises is how might non-agricultural concerns obtain such water.

One alternative is for energy to buy out whole farms, obtain the corresponding stock, and leave the farms in agricultural production until a majority of the stock is held by the energy operation. When such a position is achieved the majority portion of the stock held by the energy developers could be severed from the other stock held by the irrigation company. At least, the energy developers would be in a strong bargaining position. Again, there is no legal precedent to guide such action. There is, of course, the option of buying out all of the shareholders and then transferring the water to industrial uses.

A final problem in obtaining agricultural water rights concerns municipal zoning ordinances which stipulate how agricultural water is to be used once it leaves agricultural production. Such zoning laws require that once the water leaves agricultural production the control of the water reverts to the city. This situation applies only in areas under city control, however. But as cities and towns anticipate increased population and expand their boundaries, more agricultural land may find itself subject to municipal control as a means of obtaining the water.

The previous pages have not meant to imply that existing agricultural rights will never be taken for energy development. On the contrary, if large scale development should occur then water use in agriculture may be reduced. In that case large numbers of agricultural rights will be purchased together to obtain the necessary water and avoid legal entanglements. The proposed prototype oil shale operation simply does not need enough water to warrant piecing small individual water rights together and facing the legal problems. This is particularly true when the water for the operation is available from other sources.

What then will be the impact of the proposed prototype oil shale development of lease tracts U_a and U_b on the local agricultural production? White River Oil Shale Corporation has stated categorically that there will be no use of existing agricultural rights for the prototype plant. All the evidence that has been available seems to support this claim. Efforts have been directed toward obtaining water from sources that have not been appropriated, such as the White River. It appears that these efforts have succeeded and the proposed dam will be built. The location of the lease tracts is such that no existing agricultural production will be affected.

If anything, it appears that the proposed oil shale development might well have a positive impact on some areas of agriculture resources. Industry, in its efforts to obtain the necessary water from the state, appears willing to subsidize agriculture. For example, the proposed White River Dam, although built primarily to provide water for oil shale, will in fact assist local agriculture by making it possible to irrigate some Indian land and by providing some flood control protection.

Population impacts, although significant, do not appear to be substantial enough to involve significant transfers of water from agriculture to municipal uses. This is particularly true if water for the Jensen Unit of the Central Utah Project is developed.. Lastly, the legal and institutional constraints to efforts by energy to buy up small individual water rights on a piecemeal basis seem to be quite costly.

CONCLUSION

Investigation into the physical availability of water in the oil shale area reveals that the prototype oil shale plant will have little impact on the Uintah Basin's agricultural or municipal water supplies.

Water use for the prototype plant is estimated between 13,000 acre feet per year and 26,000 acre feet per year. The difference between these estimates is the amount of water that will be used for dust control and cooling. If a new town is developed the additional municipal water for the projected population of 10,028 (see Table 2) will also have to be supplied by water near the prototype site. Based upon a consumption rate of .49 acre feet per capita (current Vernal City consumption rate) the on-site population will have to be supplied with an additional 4,914 acre feet per year. This consumption rate is very high, however. Raising the price of water discussed earlier, might lower this amount significantly. If a consumption rate of .25 acre feet per capita is assumed (Project Independence estimates) the domestic water estimates are lowered to 2,507 acre feet per year. Thus, the prototype plant and a new town of 10,028 would require a high estimate of 30,914 acre feet per year and a low estimate of 15,507 acre feet per year (see Tables 5 and 7).

A look at the water supply side reveals that the 36,000 acre feet currently proposed for segregation from the White River Dam would more than supply the high estimate of 30,914 acre feet per year (Tables 6 and 7). It should be mentioned, however, that the proposed dam with its 118,000 acre feet of storage will supply room for some expansion of the prototype operation. (Note: At least 50,000 acre feet will be designated for Indian rights.)

At this time, it appears unlikely that a new town will be built. Therefore, the population impact discussed earlier would have to be absorbed by existing Uintah Basin communities. A look at the projected population increases in Vernal, Roosevelt, and Duchesne indicates an anticipated population increase for that area of 6,011 persons. Utilizing the higher consumption rate of .49 acre feet per capita this population increase would require some 3,253 acre feet per year. The lower rate of .25 acre feet per capita projects a total of 1,661 acre feet per year. Examination of the water supply side for this same area, however, reveals that 40,195 acre feet per year may eventually be available for municipal and industrial use in the Uintah Basin (see Tables 6 and 7).

In summary, the prototype oil shale operation and the associated population increase will have no apparent impact on the Uintah Basin agricultural or municipal water supplies.

Of course, these estimates incorporate only the impact of the prototype operation of a maximum capacity of 100,000 barrels/day. If oil shale operations were to become economically feasible, water demands could expand rapidly. Other large energy developments, i.e., coal gasification and liquefaction, could also expand quickly and demand huge quantities of water. The question then arises as to the capacities of existing water supplies to support a large scale population increase and further industrial development.

Based on the low consumption rate of .25 acre feet per capita the 40,195 acre feet available to the Uintah Basin would support a population of over 150,000. The limiting factor, as far as water for oil shale is concerned, appears to be the industrial water from the White River Dam. If an additional 26,000 acre feet per year is required for each 100,000 barrel/day operation, the White River project would only be able to supply sufficient water for a 200,000 barrel/day industry before impinging upon Indian claims, providing additional water supplies cannot be found.

Examination of the institutional and legal framework of the appropriative doctrine in general and of Utah water law specifically reveals that the basic orientation of such laws is protective of existing water rights. They are protected from harm from other potential water users even though a given water use may be more beneficial in an economic sense.

Although water rights are considered real property statutorily and are transferable on the open market, in reality transfers are restricted by current laws unless the criterion of non-injury to other water rights is met. The fundamental

Table 5. Water requirement demand summary for the prototype oil shale development at various population assumptions.

	High Estimate (a.f./yr)	Low Estimate (a.f./yr)
1. Prototype oil shale plant (max. capacity 100,000 barrels/day)	26,000	13,000
Population:		
2. Total estimated population increase (including Rangely, Colorado) 12,535	6,142[a]	3,134[b]
3. On-site population (assumes new town) 10,028	4,914[a]	2,507[b]
4. Vernal-Ashley Valley (assumes no new town) 3,958	1,940	990
5. Roosevelt (no new town) 1,574	771	394
6. Duchesne (no new town) 479	235	120
7. Other Uintah Basin (no new town) 627	307	157
Totals:		
Plant totals and total population water estimates (1,2)	32,142	16,134
Total estimated Utah (Uintah Basin) water requirement (assumes no new town) (4,5,6,7)	3,253	1,661
Plant total and total Uintah Basin population water estimate (assumes no new town) (1,4,5,6,7)	29,253	14,661

[a]Assumes .49 a.f. per capita
[b]Assumes .25 a.f. per capita

Table 6. Water supply summary.

Prototype plant operation (max. capacity 100,000	Proposed White River Dam segregation of 36,000 a.f. from total of 118,000 a.f. storage
Vernal-Ashley Valley	
(clear and unrestricted rights)	6,711
Rights where title may be under dispute	8,153
Future sources–Jensen Unit	18,000
Subtotal	32,863
Roosevelt	
Uriah Heap Springs, Hancock Cove Well, Campbell Well	5,718
Duchesne	
Murray Springs Area Wells	1,614
Totals:	
White River Dam and Uintah Basin sources	76,195
Uintah Basin sources	40,195

Table 7. Summary comparison of total plant and population water estimates and total Uintah Basin and White River Dam water supply sources.

Requirement/Needs	High a.f./yr	Low a.f./yr	Supply
1. Total plant water requirements and total population water estimates	32,142	16,134	Uintah Basin sources– 40,195 a.f.
2. Total plant water requirements and new town water estimates	30,914	15,507	
3. Total plant water requirements and total estimated Uintah Basin population water estimates (assume no new town)	29,253	14,661	Uintah Basin sources–and White River Dam 76,195 a.f.

underpining of the appropriative doctrine is preservation of the existing right at the expense of later rights. The primary goal of the institutional apparatus of the state (the water law and the office of the State Engineer) is the maintenance of an "equitable" distribution of this public resource.

Unfortunately, this desire for equity often conflicts with efforts to maximize efficiency in water use. It has been shown in this study that although the value productivity of water used in energy production is significantly higher than that of water utilized in agriculture, efforts by energy to bid water away from agriculture are often severely restricted by current legal and institutional restraints. Water may be kept in a less productive use by the high transaction costs associated with transferring water rights. Transfers must be preceded by public hearings and the burden of proof of non-injury to other right holders is on the parties wishing the transfer. This often requires technical information that is expensive to acquire. Because of these transaction costs, oil shale developers may well find it easier and less costly to obtain the needed water from the state's supply of unallocated water, at least for the prototype development.

It has not been the intention of this study to imply that the preservation of existing agricultural rights is of greater importance than obtaining water for oil shale development. Rather, the orientation has been to present the current legal and institutional impediments to water right transfers. Obviously, these restrictions are geared toward preservation of already granted rights. A question might arise, however, concerning the impact on agriculture and other rights if such restrictions did not exist or if the institutional structure were modified to accommodate easier transfer.

It is generally accepted that if agriculture were stripped of the protection it now enjoys that it would not be able to compete economically with municipal and industrial demands. This is particularly true with respect to energy operations such as oil shale where the demand price for water is quite high and the demand curve for water is likely highly inelastic. Expenditures for water constitute a very small proportion of the total costs of producing oil from shale and no good substitutes are available for water in such uses as soil compaction and revegetation. This is tantamount to arguing that the demand curve for water can be expected to be highly inelastic. Thus, no one seems to argue that oil shale producers could not bid water away from agricultural users. In an economic welfare context, however, would this necessarily imply a reduction in social welfare?

If transaction costs were zero, if transfers were made voluntarily, and if no external costs and benefits were imposed on others, the free market solution to the water allocation problem would in reality conduce to maximum economic welfare. Water would move to its highest value and economic efficiency criteria would be satisfied. But how about equity? It must be assumed that if a farmer is receiving sufficient incentive to part with his agricultural water in the market in a voluntary transaction, that he prefers the transfer to maintaining his right. Likewise, the energy developer would be receiving the use of a resource for which he had compensated the farmer. Neither party can be considered to be worse off and, therefore, the Pareto conditions for an optimum are satisfied. This situation reflects the basic free market belief that with the exception of resource transactions involving externalities, the market allocates resources on the most efficient and equitable basis (Mishan, 1969).

There would be some secondary economic effects associated with any decline in agricultural production in the proposed oil shale area, however. Support industries such as equipment retailers, fertilizer suppliers, transport and marketing firms, would appear to be worse off if agriculture declined. The area's economic position in general, however, may not be negatively affected since presumably oil shale development would bring with it jobs, increased commerce and incomes, and more tax revenue. Thus, other secondary businesses would gain and these gains would appear to more than offset the losses to the auxiliary agricultural industries.

The conclusion of this study is that current water laws and institutions will be an important factor in determining how and if water will be available for oil shale development. It has been publicly stated by Utah's prototype oil shale developers that the prototype operation will not attempt to utilize existing agricultural water rights or sources for the initial oil shale operation. This position reflects the belief that the transaction costs associated with obtaining this water are at the moment too high when compared with the possibility of obtaining water from other sources. On the basis of this information, it appears that oil shale development will not have any substantial impact on the area's agriculture in a direct sense. There is the possibility that population increases associated with oil shale will require the affected communities to obtain the additional domestic water from agricultural sources. Proper management coupled with efforts to define ownership of the area's water sources should eliminate many of the problems facing communities in obtaining the needed municipal water. Lastly, long delayed projects like the Jensen Unit of the Central Utah Project would eliminate most of the problems facing industry, municipalities, and agriculture in finding adequate water.

Although there appears to be sufficient water to meet agriculture and energy demands in the Uintah Basin at the moment, the potential for conflict underlies a fundamental inadequacy of current water legislation, i.e., the inability of current water controls to adapt to dynamic change in water demand. Utah water law declares that all water in the state is to be considered the property of the public. This statement does not vest title to the water in the state, but does stipulate that water is community property available only upon compliance with the law. Water, however, is a fugitive resource which is only of non-recreational value when it is taken from its source and is used. The role of institutional controls is ostensibly to manipulate the system to obtain the greatest public benefit. The system becomes onerous, however, when laws and organizations created to be the manipulators prevent economically efficient transfers.

Historically two methods have been employed to ration resources. One is legislative and administrative control. This is the method most commonly utilized in water allocation in Utah today. As a result, agricultural water has been heavily subsidized at the expense of municipal and industrial uses. This has been done by statute and administrative procedures influencing how water would be priced, assigned to land, and development costs distributed. The other method is market allocation by price. What this study has pointed out is that current controls exist to the point that only rarely is there a free market for water (Gardner and Fullerton, 1968).

Hopefully as the fact is faced that water will not be available for all potential competing uses, water institutions can be modified to permit this scarce resource to be allocated to uses and users of greatest productivity and still protect the equity positions held by current right holders.

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PART II

THE EFFECTS OF A CHANGE IN THE VARIABILITY OF WATER

INTRODUCTION

In many cases irrigation water is a random variable, i.e., its quantity is not known ahead of time. In these cases a transfer of irrigation water to an alternative use and/or an alternative drainage can affect the variability of the remaining water even though the average amount of remaining water is unchanged. For example if a portion of a stream flow water supply is diverted there are several ways that this can affect the variability of the remaining water. (1) The diversion of water within the system will be different; thus the return flow from diverted water will be different which can cause a change in the seasonality and variability of the water. (2) If originally a portion of the stream is diverted and now water is transferred at a constant rate, the remaining water will be more variable even if its average amount is unchanged. (3) If a water storage system is constructed on the stream and a portion of the water is transferred the most likely result would be a decrease in the variability and a change in the seasonality of water. In this last case, however, it is the storage facility that caused the decrease in the variability of water not the transfer.

Both a change in the variability and in the seasonality of water have been introduced. However, the analysis will concentrate upon the effects of a change in the variability since the effects of change in seasonality have been analyzed extensively. A change in the variability of irrigation water can have an impact on local agriculture in several ways. It can affect (1) both the variability and average level of farm income (profits), (2) the prices of land and water, (3) the quantity of purchased inputs, and (4) the level of farm production (output). These effects are analyzed for the set of all affected farms. The analyses will be carried out for both the case where the farm managers are assumed to be risk indifferent and the case when they are assumed to be risk averters.

Before discussing these analyses, however, a review of a portion of the recent literature on the economics of uncertainty and a discussion of the techniques of analysis in this area will be presented. The purpose of this is to identify the type of analysis to be used and to state the reasons why this particular approach is used. The techniques of analysis are presented so that they can be referenced later.

A PARTIAL LITERATURE REVIEW OF THE ECONOMICS OF UNCERTAINTY

In the economics of uncertainty there are two main alternative hypotheses concerning human behavior. (1) It is hypothesized that individuals maximize expected (average) utility or alternatively (2) it is hypothesized that individuals maximize utility where utility is a function of expected (average) income or returns and risk. The proxy for risk is almost always the variance of income or returns. This second hypothesis is called the mean-variance hypothesis. Frequently it is hypothesized that firms maximize expected profits. This, however, is not an alternative hypothesis since it can be shown to be contained within the first hypothesis as a special case. The two main hypotheses, however, are not equivalent. While for a large number of analyses the conclusions are identical, there are specific examples in the literature where the conclusions of the two approaches are different.

The contradiction between the two can be viewed by examining some of the characteristics of the two models. In the maximization of expected utility analysis, it is hypothesized that utility is a nondecreasing function of income, $U = U(I)$, and that the expected utility is maximized subject to the constraint of the available alternatives. For example, if x and y are two alternative sources of income and they are both random variables then,

$$E(U(x)) > E(U(y))$$

implies x is preferred to y. In the mean-variance analysis, it is hypothesized that utility is a function of expected (average) income, E(I), and the variance of income (risk $= \sigma_I^2$), $U = U(E(I), \sigma_I^2)$. In addition, for the variance held constant U is assumed to be a nondecreasing function of expected income ($\partial U/\partial E > 0$). In this model utility is maximized subject to the available alternatives. For example, if x and y are two alternative sources of income and they are both random variables then

$$U(E(x), \sigma_x^2) > U(E(y), \sigma_y^2)$$

implies x is preferred to y.

In both of these models the terms risk aversion, risk neutrality, and risk preference are used. A person is risk averse if over a set of choices between a for sure alternative and a risky alternative with equal means he always selects the for sure alternative. He is risk netural if he is indifferent between all such comparisons, and he is risk preferent if he always selects the risky alternative. These three definitions imply for the expected utility hypothesis the following three equivalent definitions. A risk averter is a person with a concave utility function; a risk netural individual is one with a linear utility function; and a risk preferent person is one who has a convex utility function. For the mean-variance hypothesis the original definitions are augmented to allow for comparisons of two risky alternatives. A person is risk averse if for all choices between two alternatives with equal means he selects the one with the lower variance (risk), and a person is risk preferent if he always selects the one with the higher risk.[1]

We are now in a position to demonstrate the contradiction between the two approaches. Let the distributions of x and y be those given in Table 1. In this example x has a higher mean and a lower variance than y; therefore by the mean-variance hypothesis, if the individual is risk averse, x is preferred to y. However, if we suppose that the utility function is $U(I) = \log I$, which is strictly concave, then $E(U(x)) = 0.4$ and $E(U(y)) = 1.02$. Thus under the expected utility hypothesis y is preferred to x (Hanoch and Levy, 1969). In this example the two hypotheses order these two alternatives differently.

Table 1. Distributions for x and y.

x	Pr (x)	y	Pr (y)
1	0.80	10	0.99
100	0.20	1000	0.01
E (x) =	20.8	E (y) =	19.9
Var (x) =	1468	Var (y) =	9703

[1]The assumption that choices are transitive implies that the definition of a risk neutral person does not need to be augmented.

The expected utility maximization hypothesis is the more general of the two, is built upon an axiomatic system of behavior under uncertainty (Arrow, 1971), while the other is not, and offers more promise for explaining human behavior. Thus since the two do not agree, the contradiction is a sign of a deficiency in the mean-variance approach.

With the demonstration in the literature that there are problems associated with defining an increase in the variance to be an increase in risk has come an increased interest in alternative definitions of an increase in risk. Rothschild and Stiglitz have proposed three equivalent definitions (Rothschild and Stiglitz, 1970). The random variable y is more variable, or riskier or more uncertain than another random variable x if:

1. y is equal to x plus noise.
2. Every risk averter prefers x to y.
3. y has more weight in its tails than x.

In all three it is assumed that x and y have the same mean. Number one says that y is distributed as x plus z where z is a random variable (r.v.) with zero mean. Number two says that if

$$E(U(x)) \geqslant E(U(y))$$

for all concave U than x is less risky than y. In number three, "if x and y have density functions f and g, and if g was obtained from f by taking some of the probability weight from the center of f and adding it to each tail of f in such a way as to leave the mean unchanged" then y is more uncertain than x (Rothschild and Stiglitz, 1970). This shift of probability weight from the center to the tails is called "a mean preserving spread."

These three definitions give rise to a common partial ordering of random variables or of their cumulative density functions (c.d.f.'s). The ordering is a partial ordering since there are c.d.f.'s that cannot be ordered by the three definitions. However, if this happens for two random variables, say x and y, then it is possible to find a risk averter that prefers x to y and another risk averter that prefers y to x. Thus it is ambiguous as to which is the riskier of the two. The ordering given by the variance is a complete ordering, and it orders the ambiguous case just described. These ambiguous cases give rise to the cases discussed above where the mean-variance analysis and the expected utility analysis disagree.

RISK AVERTERS AND THE MEAN PRESERVING SPREAD

To illustrate the effects of a mean preserving spread upon a risk averter we examine a for sure and a risky alternative. The for sure alternative is $\bar{x}$ dollars and the risky alternative is x_1 dollars with a probability of 1/2 and x_2 with a probability of 1/2, with

$$\bar{x} = \frac{1}{2}x_1 + \frac{1}{2}x_2$$

In this example we start with all of the probability weight located at the center of the distribution. One-half of the weight is then shifted to x_1 and one-half to x_2 with x_1 and x_2 selected so that the original mean is preserved.

Let U(x) be the risk averter's utility function, and assume that U(x) is strictly concave. The expected level of utility for the for sure alternative is

$$E_F(U(x)) = U(\bar{x})$$

and for the risky alternative is

$$E_G(U(x)) = \frac{1}{2}U(x_1) + \frac{1}{2}U(x_2)$$

The problem is diagrammed in Figure 1. With all of the weight at $\bar{x}$ the mean level of utility is $U(\bar{x})$ which is indicated by the point A. Then as weight is shifted away from $\bar{x}$, values of the function above and below $\bar{x}$ receive weight. For the example $U(x_1)$ and $U(x_2)$ are weighted evenly. The effect of this weighting is given by the point B. Since U(x) is strictly concave this shifting of probability weight to the tails caused the mean value of U to fall. Similarly as the weight is shifted further and further into the tails values of the function further away from $U(\bar{x})$ are given weight and the mean value of U will fall still further. Thus the more weight that is put into the tails holding the mean level of x constant the riskier is the alternative and the lower is the mean value of U. Consequently, the more weight that there is in the tails the less attractive the alternative is to a risk averter.

The conclusions that

$$U(\bar{x}) > \frac{1}{2}U(x_1) + \frac{1}{2}U(x_2)$$

also follows directly from the definition of a strictly concave function. U strictly concave means that for all x_1 and x_2 in the domain of U and all t in the open interval (0, 1) that

$$U(tx_1 + (1-t)x_2) > tU(x_1) + (1-t)U(x_2)$$

Letting $= 1/2$ and noting that $\bar{x} = 1/2\,x_1 + 1/2\,x_2$ we get

$$U(\bar{x}) > \frac{1}{2}U(x_1) + \frac{1}{2}U(x_2)$$

The same conclusions can be shown to hold for more general cases using the appropriate tools. Consider a family of cumulative distribution functions F(x, r) where x is a random variable defined over the interval [a, b] and r is a shift parameter. The c.d.f. is assumed to be twice continuously differentiable in both x and r. Let r_2 be greater than r_1. $F(x,r_2)$ is a mean preserving spread of $F(x, r_1)$ means

$$\int_a^b [F(x, r_2) - F(x, r_1)]\, dx = 0 \quad \ldots\ldots\ldots (1)$$

and

$$\int_a^y F(x, r_2) - F(x, r_1)\, dx \geqslant 0 \qquad a \leqslant y \leqslant b \quad \ldots (2)$$

An alternative definition of c.d.f.'s that are "close" to each other is

$$\int_a^b F_r(x, r)\, dx = 0 \quad \ldots\ldots\ldots\ldots\ldots (1a)$$

and

$$T(y, r) = \int_a^y F_r(x, r)\, dx \geqslant 0 \qquad a \leqslant y \leqslant b$$

$$\ldots\ldots\ldots\ldots\ldots (2a)$$

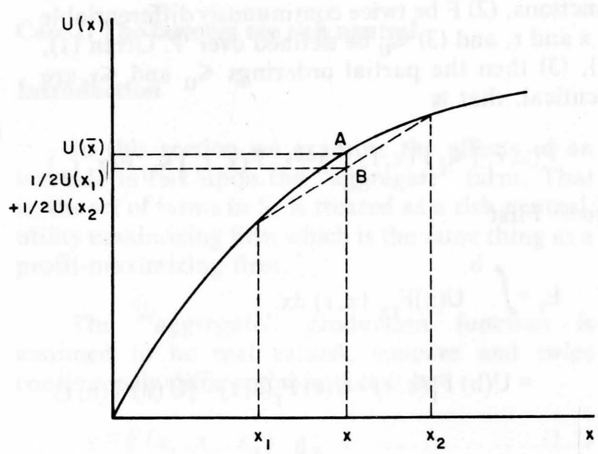

Figure 1. E[U(x)] and U(E[x]).

where $F_r(x, r)$ is the partial derivative of F with respect to r. Equations 1 and 1a insure that mean of x is unchanged by the change in r, and Equations 2 and 2a insure that as r is increased more weight is placed in the tails. In addition, the distribution $F(x, r_1)$ is said to be less risky than $F(x, r_2)$ if Equations 1 and 2 hold. This is symbolized as $F(x, r_1) \leqslant_I F(x, r_2)$ where $\leqslant_I$ is a partial ordering.

The partial ordering given by the set of all risk averters is symbolized by $\leqslant_u$. With the mean of x for r_1 and r_2 equal, $F(x, r_1)$ is said to be less risky than $F(x, r_2)$ if every risk averter prefers r_1 to r_2. That is

$$F(x, r_1) \leqslant_u F(x, r_2) \longleftrightarrow \int_a^b U(x) F_x(x, r_1)\, dx$$

$$\geqslant \int_a^b U(x) F_x(x, r_2)\, dx \quad \ldots\ldots (3)$$

for every bounded concave function U. F_x is the partial derivative with respect to x and is the density function; thus when expected utility is higher for r_1 than r_2, $F(x, r_1)$ ia less risky than $F(x, r_2)$. Alternatively for "close" c.d.f.'s, the partial ordering $\leqslant_u$ indicates an increase in risk if, and only if,

$$E_r = \frac{\partial E(U(x))}{\partial r} = \int_a^b U(x) F_{rx}(x, r)\, dx \leqslant 0 \quad .(3a)$$

for every bounded concave function U.

The partial orderings $\leqslant_I$ and $\leqslant_u$ are equivalent. This equivalence is stated in the following theorem:

Theorem 1: Let (1) Ψ be the set of all bounded concave, twice continuously differentiable utility functions, (2) F be twice continuously differentiable in x and r, and (3) $\leqslant_u$ be defined over Ψ. Given (1), (2), (3) then the partial orderings $\leqslant_u$ and $\leqslant_I$ are identical, that is

$$F(x, r_1) \leqslant_I F(x, r_2) \longleftrightarrow F(x, r_1) \leqslant_u F(x, r_2)$$

Proof: First

$$E_r = \int_a^b U(x) F_{rx}(x, r)\, dx$$

$$= U(b) F_r(b, r) - U(a) F_r(a, r) - [U'(b) T(b, r)$$

$$- U'(a) T(a, r)] + \int_a^b T(x, r) U''(x)\, dx$$

which is generated by twice integrating by parts. Since we are only comparing c.d.f.'s with the same mean $T(b, r) = T(a, r) = 0$, and because $F(a, r) = 0$ and $F(b,r) = 1$ for all $r, F_r(a,r) = F_r(b,r) = 0$. Thus

$$E_r = \int_a^b T(x, r) U''(x)\, dx \quad \ldots\ldots\ldots\ldots (4)$$

which can be used to prove both implications in the theorem. To prove the righthand implication note that $U \varepsilon \Psi$ implies that $U''(x) \leqslant 0$ for all $x \varepsilon [a, b]$ and $F(x,r_1) \leqslant_I F(x,r_2)$ implies that $T(y, r) \geqslant 0$ for all y x [a,b]. These two together imply $E_r \geqslant 0$ which by Equation 3a means $F(x, r_1) \leqslant_u F(x, r_2)$. This proves the righthand implication of the theorem.

To prove the reverse implication we prove that $E_r \leqslant 0$ for all $U \varepsilon \Psi$ implies that $T(x,r) \geqslant 0$ for all $x \varepsilon [a, b]$. This implication is proven by contradiction. We assume the opposite and show that this implies a contradiction. Assume $T(x, r) < 0$ at x_1 which since $T(x, r)$ is continuous implies that there is some neighborhood of x_1 such that $T(x, r) < 0$. Let this neighborhood be $(\alpha, \beta) \subset [a, b]$. Let $\hat{U}$ be an element of Ψ and let $\hat{U}''(x)$ be given by the graph in Figure 2. $\hat{U}$ is concave since $\hat{U}''(x) \leqslant 0$ for all x in (a, b). Since $\hat{U}''(x)$ is zero for all x not in (α, β), only x's in (α, β) are important in determining E_r. $T(x, r)$ is negative and $\hat{U}''(x)$ nonpositive in (α, β) implying that E_r is positive. This generates a contradiction since the original supposition was for $E_r \leqslant 0$; hence, $T(x, r) < 0$ at x_1 is impossible and $T(x, r) \geqslant 0$ for all $x \varepsilon [a, b]$.

In this section the expected utility hypothesis has been selected over the mean-variance hypothesis, and the method of a mean preserving spread has been selected as the measure of increased risk. Below the tools of this section, the definitions and the theorem, are used to analyze in the context of the expected utility hypothesis the effects of an increase in the variability of water.

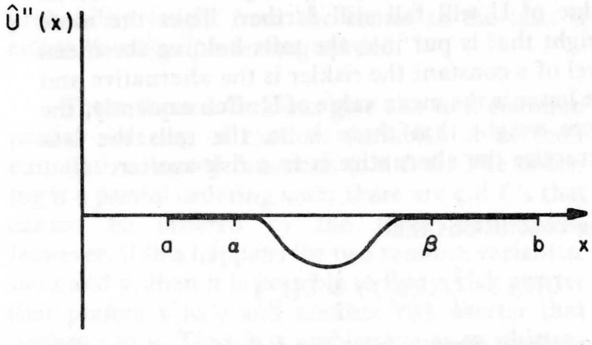

Figure 2. Graph of $\hat{U}''(X)$.

A CHANGE IN THE VARIABILITY OF WATER CAUSED BY A WATER TRANSFER

When some portion of the water in a system is transferred to another use and/or location the possibility exists that the variability of the remaining water will be changed. If the water originally came from a stream flow system and the water transfer is accompanied by the construction of a reservoir, then the variability of the remaining water can be expected to fall, if some portion of a stream flow is transferred then the variability of the remaining water can increase, decrease or remain unchanged depending upon the rules of the transfer.

A case where the variability is increased will be identified. Let the water supply system be a stream flow system with the flow (q) a random variable. Originally the water was divided between two sets of farmers, S_1 and S_2, with each set receiving a portion of the flow. Let τ be the portion going to S_1. The water supplies of S_1 and S_2 were originally random variables given by τq and $(1-\tau)q$, respectively. Let the farmers in S_2 sell their water and let the purchasers of this water receive the mean amount that the S_2 farmers were receiving but let them receive it as a constant flow. Thus the transfer is

$$k = (1-\tau)\bar{q}$$

where k is a constant and $\bar{q}$ is the mean level of the stream flow. The water originally received by S_1 was

$$u = \tau q$$

and it is now

$$v = q - (1-\tau)\,\bar{q}$$

where u and v are both random variables. Let G(v) and F(u) be the c.d.f.'s for v and u, respectively. G can be shown to be a mean preserving spread of F; thus v is more variable than u.

Given that u and v have the same mean a sufficient condition for G to be a mean preserving spread of F is (Rothschild and Stiglitz, 1970)

$$S(t) = G(t) - F(t) \geqslant 0 \qquad \text{if } t \leqslant t^*$$

and

$$S(t) = G(t) - F(t) \leqslant 0 \qquad \text{if } t \geqslant t^*$$

To show that this relationship holds for G and F defined above, let h(q) be the density function for q. The c.d.f.'s for v and u are then given by

$$G(v) = \int_a^{v+(1-\tau)\bar{q}} h(s)\,ds \text{ and } F(u) = \int_a^{\frac{u}{\tau}} h(s)\,ds$$

with these definitions

$$S(t) = \int_a^{t+(1-\tau)\bar{q}} h(s)\,ds + \int_a^{\frac{t}{\tau}} h(s)\,ds$$

which is positive for $t < t^* = \tau\bar{q}$ and is negative for $t > t^* = \tau\bar{q}$. To demonstrate this note that $t<\tau\bar{q}$ and $0 < \tau < 1$ imply

$$\frac{t}{\tau} < t + (1-\tau)\bar{q}$$

which implies that S(t) is positive. S(t) negative for $t>\tau\bar{q}$ is similarly demonstrated.

The conclusion of this section is that a transfer of water that has the above characteristics will cause the remaining water to become more variable in the sense of a mean preserving spread.

THE ANALYSES OF THE EFFECTS OF A CHANGE IN THE VARIABILITY OF WATER

In this section we examine the effects of a change in variability of water upon several important economic variables. The variability is assumed to increase; however, the results are symmetrical so that a decrease in variability will have the opposite results. We study the impact of the additional risk upon the farms in S_1. The variable studies are the mean level of profits and output, the quantity of purchased inputs, and the prices of water and land.

Case I: The farmers are risk neutral

Introduction

In this section we examine the effects of an increase in risk upon the "aggregate" farm. That is, the set of farms in S_1 is treated as a risk neutral, utility maximizing firm which is the same thing as a profit-maximizing firm.

The "aggregate" production function is assumed to be real valued, concave and twice continuously differentiable. Let it be

$$y = \hat{g}(x_1, x_2, x_3) \qquad \ldots\ldots\ldots\ldots\ldots (1.1)$$

where y is output, x_1 is purchased inputs, x_2 is water and x_3 is land. We assume that the land area of the S_1 farm is fixed so that we will be examining

$$y = \hat{g}(x_1, x_2, x_3^O) = g(x_1, x_2) \quad \ldots\ldots\ldots\ldots (1.2)$$

g is assumed to be strictly concave. In the analysis, x_2 is a random variable. Let

$$x_2 = (1 + s)z^O$$

where z^0 is the mean quantity of water received by the S_1 farmers and s is a random variable on the interval [a, b] with a>-1 and the mean of s equal to zero. Let the c.d.f. for s be

$$F(s,r) = \int_a^s f(t, r)\, dt$$

where

$$F_s(s, r) = f(s, r)$$

is the density function for s, and r is the shift parameter for risk. Thus

$$0 = \int_a^b s\, f(s, r)\, ds \quad \text{for all } r$$

With these suppositions the mean level of x_2 is z^0.

Below some of the analyses are carried out for two specific production functions, the Cobb-Douglas and CES. For Cobb-Douglas $\hat{g}$ and g are given, respectively, by

$$y = x_1^{\alpha}\, x_2^{\beta}\, x_3^{\gamma}$$

$$\text{with } \alpha + \beta + \gamma \leqslant 1 \text{ and } \alpha, \beta, \gamma > 0 \quad .(1.1a)$$

and

$$y = k\, x_1^{\alpha}\, x_2^{\beta} \quad \text{with } k = x_3^{O\gamma} \quad \ldots\ldots\ldots\ldots (1.2a)$$

For the CES production function $\hat{g}$ and g are given, respectively by

$$R = [\delta_1\, x_1^{\rho} + \delta_2\, x_2^{\rho} + \delta_3\, x_3^{\rho}] \quad \text{with } \delta_1, \delta_2, \delta_3 > 0$$

$$y = R^{1/\rho}$$

$$\text{with } \delta_1 + \delta_2 + \delta_3 = 1 \text{ and } \rho < 1 \quad ..(1.1b)$$

$$y = [\delta_1 x_1^{\rho} + \delta_2\, x_2^{\rho} + C]^{1/\rho}$$

$$\text{with } C = \delta_3 x_3^{O\rho} \quad \ldots\ldots\ldots (1.2b)$$

It can be shown that Equations 1.2a and 1.2b are both strictly concave in x_1 and x_2 so that they satisfy the restriction placed on Equation 1.2. If Equation 1.1a has constant returns to scale then the limit of Equation 1.1b as ρ goes to zero is Equation 1. 1a; however, since we do not restrict the sum of α, β, and γ to equal one we do not restrict the Cobb-Douglas case to be a special case of the CES case. The relationship between ρ and the elasticity of substitution, σ, is given by

$$\rho = \frac{\sigma - 1}{\sigma}$$

The aggregate profit function is written as

$$\pi = pg(x_1, (1 + s)z^O) - w_1\, x_1 \quad \ldots\ldots\ldots (1.3)$$

where p is the output price, and w_1 is the price of input x_1. The S_1 farms are assumed to be price takers. The expected level of profits can be written as

$$E(\pi) = p \int_a^b g(x_1, (1 + s)z^O)\, f(s, r)\, ds - w_1\, x_1 \quad \ldots\ldots\ldots\ldots (1.4)$$

It is assumed that the farmers maximize this function with respect to x_1. They choose the level of purchased inputs (x_1) that maximizes E. Note that in this formulation only one decision is made for x_1 and that it is made before s is known. If s were known before x_1 was determined, the formulation of the problem would be different.

Before analyzing the effects of a change in the variability of water we examine some of the characteristics of $E(\pi)$. First, g continuous and bounded for all feasible x_1 and z^0 implies that the integral in Equation 1.4 exists. This integral gives the expected value of output, y; therefore, the expected value of y exists. This implies that the expected value of profits exists. Second, g strictly concave in x_1 and x_2 implies the E(y) is strictly concave in x_1 and z. This, in turn, implies the $E(\pi)$ is strictly concave in x_1 and z. Thus the first order condition is both necessary and sufficient for a maximization of $E(\pi)$.

We now prove that g strictly concave implies that E(y) is strictly concave. g strictly concave in x_1 and x_2 implies

$$g[tx_1^O + (1\text{-}t)\, x_1^1, (1 + s)\, (tz^O + (1 - t)\, z^1)]$$

$$> tg\, [x_1^O, (1 + s)\, z^O] \; + (1 - t)\, g[x_1^1, (1 + s)\, z^1] \quad \ldots\ldots\ldots\ldots (1.5)$$

for all x_1^0, x_1^1, z^0, z^1 in the domain of g and $t \in (0, 1)$. Multiplying through by $f(s, r) \geqslant 0$ and integrating over (a, b) with respect to s yields

$$\int_a^b g[tx_1^O + (1-t)x_1^1, (1+s)(tz^O + (1-t)z^1)]$$

$$f(s, r)\, ds > t \int_a^b g[x_1^O, (1+s)z^O]\, f(s, r)\, ds$$

$$+ (1-t) \int_a^b g[x_1^1, (1+s)z^1]\, f(s, r)\, ds \quad \ldots (1.6)$$

Equation 1.6 satisfies the definition of a strictly concave function, implying that E(y) is strictly concave. The profit function is easily shown to be a strictly concave function, and using the above procedure its expected value can be shown to be a strictly concave function.

The effects upon the expected level of profits. We analyze first the effect of an increase in the variability of water upon the mean level of profits. The expected level of profits is a concave function of s; therefore, by Theorem 1 an increase in the variability of water will cause $E(\pi)$ to decrease for each level of x_1. The level of x_1 probably will not remain constant; however, since the entire function will be lower than before, the maximum level of expected profits will be lower.

An alternative way of generating this information is to differentiate the function for the solution level of expected profits ($E(\overline{\pi})$, the bar indicates solution level) with respect to r. The result of this is

$$E_r(\overline{\pi}) = p \int_a^b [g_1(x_1, (1+s)z^O)x_r^1\, f(s, r)$$

$$+ g(x_1, (1+s)z^O)\, f_r(s, r)]\, ds - w_1 x_r^1 \quad \ldots (1.7a)$$

$$= x_r^1 \, [p \int_a^b g_1(x_1, (1+s)z^O) f(s, r)\, ds - w_1]$$

$$+ p \int_a^b g(x_1, (1+s)z_O) f_r(s, r)\, ds \quad \ldots\ldots (1.7b)$$

$$= p \int_a^b g(x_1, (1+s)z^O)\, f_r(s,r)\, ds \quad \ldots (1.7c)$$

$$= p \int_a^b g_{22}(x_1, (1+s)z^O) z^{O^2}\, T(s,r)\, ds \quad \ldots\ldots\ldots\ldots (1.7d)$$

Equation 1.7b is a rearrangement of Equation 1.7a. The term in brackets in Equation 1.7b is zero by the first order condition for an extremum (see below). Equation 1.7d is derived from Equation 1.7c by twice integrating by parts. In the equation T(s, r) is the function defined in Equation 2a, and is nonnegative. The production function is strictly concave implying that g_{22} is negative; therefore, Equation 1.7d is negative as indicated above.

The effects upon x_1. Now we analyze the effect of an increase in the variability of water upon the purchased input. This effect is analyzed using the first order condition for a maximization of Equation 1.4. This first order condition is

$$\frac{\partial E}{\partial x_1} = p \int_a^b g_1(x_1, (1+s)z^O)\, f(s, r)\, ds - w_1 = 0 \quad \ldots\ldots\ldots\ldots (1.8)$$

or

$$pE(g_1) - w_1 = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.8a)$$

This condition says that at equilibrium the mean level of the value of the marginal product is equal to the input price. An increase in r will cause $E(g_1)$ to fall if $g_1(x_1, (1+s)z_0)$ is concave in s. This conclusion is derived by applying Theorem 1. If $g_1(x_1, (1+s)z^0)$ is convex in s then $E(g_1)$ will rise as r increases. If g_1 is neither concave nor convex then there is insufficient information to determine the change in $E(g_1)$. The effect on x_1 can be determined with the aid of Figure 3. Let the price of x_1 be w_1^0 and g_1 be concave in s. The curve labeled $pE^0(g_1)$ is for $r = r^0$ and the one labeled $pE^1(g_1)$ is for $r = r^1$ with $r^1 > r^0$. Thus as r increases from r^0 to r^1 $E(g_1)$ decreases at each x_1 causing the solution x_1 to decrease; consequently $\partial x_1/\partial r = x_r^1 < 0$ for g_1

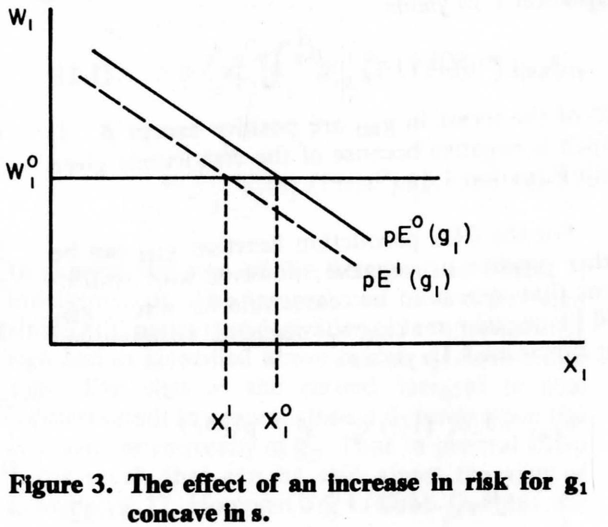

Figure 3. The effect of an increase in risk for g_1 concave in s.

concave in s. For g_1 convex in s the conclusion is the opposite.

These same conclusions can be generated by differentiating the first order conditions with respect to r and solving for x_r^1. This yields

$$x_r^1 = \frac{-\int_a^b g_1(x, (1+s)z^o) f_r(s, r)\, ds}{\int_a^b g_{11}(x_1, (1+s)z^o f(s, r)\, ds} \quad ..(1.9)$$

The denominator is negative since g_{11} is negative everywhere in the domain of g. Thus x_r^1 has the same sign as the numerator. Twice integrating the numerator by parts yields

$$N = \int_a^b g_{221}(x_1, (1+s)z^o)z^{o^2}\, T(s, r)\, ds \,.(1.10)$$

where T(s, r) is the function defined in Equation 2a). Since $T(s, r) \geqslant 0$ for all $s\varepsilon[a, b]$ and the square of $z^0(z^{0^2})$ is positive, the sign of g_{221} determines the sign of N. If g_1 is concave in x_2 then $g_{221} \leqslant 0$ for all $s\varepsilon[a, b]$ and $N \leqslant 0$ which yields

$$x_r^1 \leqslant 0$$

and if g_1 is convex in x_2 then $g_{221} \geqslant 0$ and $N \geqslant 0$ implying that

$$x_r^1 \geqslant 0$$

In general x_r^1 can be either negative or positive; however, if the production function is Cobb-Douglas or CES then x_r^1 is restricted. For the Cobb-Douglas production function g_{221} is negative implying that x_r^1 is negative. Differentiating Equation 1.1a yields

$$g_{221} = \alpha\beta(\beta-1)\, x_1^{\alpha-1}\, x_2^{\beta-2}\, x_3^{\gamma} \quad ....(1.11)$$

All of the terms in g_{221} are positive except β - 1, which is negative because of the restrictions given with Equation 1.1a.

For the CES production function g_{221} can be either positive or negative; however with restrictions that appear to be reasonable for water, g_{221} will be negative making x_r^1 negative. Differentiating Equation 1.1b yields

$$g_{221} = \delta_1\, \delta_2\, (1-\rho)\, x_1^{\rho-1}\, x_2^{\rho-2}\, R^{(1/\rho)-2}$$

$$(\epsilon_{yx_2}\, (1-2\rho) + \rho-1) \quad ....(1.12)$$

where

$$\epsilon_{yx_2} = \frac{\partial y}{\partial x_2} \cdot \frac{x_2}{y}$$

ϵ_{yx_2} is the elasticity of production with respect to x_2. All terms in Equation 1.12 except the last parenthetical expression are positive; therefore that last expression determines the sign of g_{221}.

Examine the parenthetical expression. Let

$$A = \phi\,(1-2\rho) + \rho-1 \qquad \text{where } \phi = \epsilon_{yx_2} \quad .(1.13)$$

First note that CES is homogeneous of degree 1 in x_1, x_2, and x_3 implying

$$1 = \epsilon_{yx_1} + \epsilon_{yx_2} + \epsilon_{yx_3}$$

thus we seek the characteristics of A for

$$0 < \phi < 1$$

and

$$\rho < 1$$

Manipulations of Equation 1.13 show that $A > 0$ if and only if

a) for $0 < \phi < \frac{1}{2}$ $\qquad \rho > \frac{1-\phi}{1-2\phi} > 0$

b) and for $\frac{1}{2} < \phi < 1$ $\qquad \rho < \frac{1-\phi}{1-2\,\phi} < 0$

Condition a) fails since it implies that ϱ is greater than 1; therefore condition b) is the necessary and sufficient condition for A to be positive. In b) ϵ_{yx_2} is greater than one-half and ρ is negative. The condition ρ is negative is equivalent to the condition that the elasticity of substitution is less than one. Thus if either of these fail A, g_{221} and x_r^1 are all negative. If both of these hold, then condition b) holds and x_r^1 will be positive. This is summarized in Table 2.

If a market for water exists and the farmers in S_1 are price takers, then the price of water will be equal to the average level of the value of the

Table 2. The sign of x_r^1 for the CES production function.

	$0<\phi<½$	$½<\phi<1$
$0<\rho<1$	$x_r^1<0$	$x_r^1<0$
$\rho<0$	$x_r^1<0$	$x_r^1 \geqslant 0$

marginal product of water. Evaluating this at its mean we have

$$\epsilon_{yx_2} = \frac{\partial y}{\partial x_2} \cdot \frac{x_2}{y} = \frac{w_2 x_2}{py}$$

The term w_2x_2 is the expenditure on water and py is total revenues. Thus ϵ_{yx_2} is equal to waters share of total receipts. The available evidence indicates that this share is less than one half implying that if the production function is CES it is reasonable to expect x_r^1 to be negative.

The effect upon the mean level of output. The question of whether the farmers increase or decrease production when water becomes more variable is analyzed next. The equation for the mean level of production is

$$E(y) = \int_a^b g(x_1, (1+s)z^o)\, f(s, r)\, ds \qquad \ldots (1.14)$$

If x_1 is treated as the solution level for the maximization of Equation 1.4, then Equation 1.14 gives the expected level of the solution level of output. Differentiating this solution level with respect to r yields

$$E_r(\bar{y}) = \int_a^b [g_1(x_1, (1+s)z^o)\, x_r^1\, f(s, r)$$

$$+ g(x_1, (1+s)z^o\, f_r(s, r)]\, ds$$

$$= x_r^1 \int_a^b g_1(x_1, (1+s)z^o)\, f(s,r)\, ds$$

$$+ \int_a^b g(x_1, (1+s)z^o)\, f_r(s,r) ds \quad ..(1.15)$$

Using Equation 1.7c the second righthand term can be shown to be negative. The integral in the first righthand term is positive since the marginal physical product is positive; thus this term has the same sign as x_r^1. If x_r^1 is negative, then $E_r(\bar{y})$ is negative; however if x_r^1 is positive then $E_r(\bar{y})$ is indeterminant. $E_r(\bar{y})$ will be negative if the production function is Cobb-Douglas and if the production function is CES the sufficient conditions for $E_r(\bar{y})$ to be negative are the same as those for x_r^1 and they are summarized in Table 2.

The effects upon the prices of water and land. We now analyze the effect of an increase in the variability of water upon the combined return to water and land and the return to each individually. An increase in r will cause the combined yield to fall assuming that $\hat{g}$ is homogeneous of degree 1 in all three inputs. The effect upon the return to water or the price of water is in general indeterminant; however, if $\hat{g}$ is Cobb-Douglas or CES with the elasticity of substitution greater than one (σ>1), then the price will fall. The effect upon the price of land is also in general indeterminant; however, if the production function is Cobb-Douglas or CES with the elasticity of production with respect to water less than one-half, then the effect is negative.

If the individual farmers in S_1 are price takers, then the input prices will be equal to the expected value of the marginal product. With $\hat{g}$ homogeneous of degree 1 the term profits used above is nothing more than the combined return to water and land, and expected profits the expected combined return. Since an increase in r causes expected profits to fall, it will cause the expected combined return to fall.

The effect of r upon the return to water can be analyzed by examining the expected value of the marginal product of water. This mean value is given by

$$E(VMP_z) = p \int_a^b g_z(x_1, (1+s)z^o\, f(s, r) ds \qquad \ldots\ldots\ldots (1.16)$$

Differentiate Equation 1.16 with respect to r while treating x_1 as the solution level from the maximization of Equation 1.4. The result of this is

$$E_r(\overline{VMP_z}) = p \int_a^b [x_r^1\, g_{1z}(x_1, (1+s)z^o)\, f(s,r)$$

$$+ g_z(x_1, (1+s)z^o) f_r(s,r)]\, ds$$

$$= p \left\{ x_r^1 \int_a^b g_{1z}(x_1, (1+s)z^o)\, f(s,r) ds \right.$$

$$\left. + \int_a^b g_z(x_1, (1+s)z^o)\, f_r(s,r) ds \right\} \quad .(1.17)$$

In general the sign of the first term in braces is indeterminant. The integral can have either sign since the cross partial derivative g_{1z} can have either sign and as identified above so can x_r^1 have either sign. The sign of the second integral is also indeterminant in general since it depends upon the concavity or convexity of g_z. Thus in general there is not much that can be said about the sign of Equation 1.17. However if $\hat{g}$ is Cobb-Douglas the sign is negative and if $\hat{g}$ is CES a sufficient condition for Equation 1.17 to be negative is the elasticity of substitution greater than on (σ>1).

For the Cobb-Douglas production function x_r^1 is negative and g_{1z} is positive. The first term in braces is, therefore, negative. Twice integrating by parts the second term in braces yields

$$B = \int_a^b g_{ssz}(x_1, (1+s)z^o)\, T(s, r)ds \quad \ldots .(1.18)$$

the term T(s,r) is defined in Equation 2a and is nonnegative; therefore, the sign of B depends upon the sign of g_{ssz}. Differentiation of Equation 1.1a yields

$$g_{ssz} = \beta^2(\beta\text{-}1)x_1^{\alpha}(1+s)^{\beta-2}\, z^{\beta-1}\, x_3^{o\gamma} \quad \ldots .(1.19)$$

All terms in Equation 1.19 are positive except (β-1); thus g_{ssz} is negative for Cobb-Douglas implying that B is negative. The term in braces in Equation 1.17 is negative and p is positive; therefore Equation 1.17 is negative for the Cobb-Douglas production function.

For the CES production function the sign of x_r^1 is determined by condition b) given above. The cross partial derivative g_{1z} is positive implying that condition b) which is summarized in Table 2 determines the sign of the first term in braces in Equation 1.17. To examine the second term using Equation 1.18 differentiate Equation 1.1b. The result is

$$g_{ssz} = \delta_2 z^{\rho-1} R^{(1/\rho)-1}(1+s)^{\rho-2}(1-\rho)(\delta_2(1+s)z]^{\rho}$$

$$R^{-1} -1)\,(\delta_2\ [(1+s)z]^{\rho} R^{-1}(1\text{-}2\rho)+\rho)$$

$$= \delta_2 z^{\rho-1} R^{(1/\rho)-1}(1+s)^{\rho-2}(1-\rho)(\epsilon_{yx_2}-1)$$

$$(\epsilon_{yx_2}(1\text{-}2\rho)+\rho) \quad \ldots\ldots\ldots\ldots(1.20)$$

All terms in Equation 1.20 are positive except the last two parenthetical expressions. The term (ϵ_{yx_2}-1) is negative and the last term can be either positive or negative. To examine the last term let

$$C = \phi(1\text{-}2\rho)+\rho \qquad \text{where } \phi = \epsilon_{yx_2} \quad \ldots(1.21)$$

Manipulations of Equation 1.21 for 0<ϕ<1 and ρ<1 yield C<0 if and only if

c) for $0<\phi<1/2 \qquad \rho<\dfrac{\phi}{2\phi\text{-}1}<0$

d) and for $1/2<\phi<1 \qquad \rho>\dfrac{\phi}{2\phi\text{-}1}>0$

Condition d) fails since it implies that ρ is greater than 1; therefore condition c) is the necessary and sufficient condition for C to be negative. In condition c) ρ is negative (σ<1) and ϵ_{yx_2} is less than one-half. When both of these conditions hold C is negative and g_{ssz} is positive. When either one of these conditions fails C is positive and g_{ssz} is negative. Table 3 summarizes these conclusions.

Return now to the examination of the sign of $E_r(VMP_z)$ in Equation 1.17. The second term in braces which is called B in Equation 1.18 has the sign of g_{ssz}. This sign is given in Table 3. The first term in braces has the sign of x_r^1 and its sign is given in Table 2. An examination of these two tables yields ρ greater than zero (σ>1) as a sufficient condition for E_r ($\overline{VMP_z}$) to be negative. For other conditions the sign is indeterminant.

The effect of r upon the return to land can be analyzed by examining the expected value of the marginal product of land. This mean value is given by

$$E(VMP_{x_3}) = p\int_a^b \hat{g}_3(x_1, (1+s)z^o, x_3^o)\, f(s, r)\, ds$$

$$\ldots\ldots\ldots\ldots(1.22)$$

Treat x_1 as the optimum x_1 and differentiate Equation 1.22 with respect to r. The result is

$$E_r(\overline{VMP_{x_3}}) = p\int_a^b [x_r^1\hat{g}_{13}\, f(s,r) + \hat{g}_3\, f_r(s,r)]\, ds$$

$$= p\left\{x_r^1\int_a^b \hat{g}_{13}(x_1, (1+s)z^o, x_3^o)\right.$$

$$f(s,r)\, ds + \int_a^b \hat{g}_3(x_1, (1+s)z^o, x_3^o)$$

$$\left. f_r(s,r).ds\right\} \quad \ldots\ldots\ldots\ldots(1.23)$$

Table 3. The sign of g_{ssz} for CES production function.

	$0<\phi<\frac{1}{2}$	$\frac{1}{2}<\phi<1$
$0<\rho<1$	$g_{ssz}<0$	$g_{ssz}<0$
$\rho<0$	$g_{ssz}\gtrless 0$	$g_{ssz}<0$

In general the sign of Equation 1.23 is indeterminant. As with Equation 1.17 the signs of both terms in braces are indeterminant in general. However, if $\hat{g}$ is Cobb-Douglas or CES with the elasticity of production with respect to x_2 less than one-half then the sign is negative.

If the production function is Cobb-Douglas the first term in braces is negative. The cross partial derivative $\hat{g}_{13}$ is positive and x_r^1 is negative. The second term in braces is also negative. To prove this integrate the term twice by parts. The result is

$$D = \int_a^b \hat{g}_{223}\,(x_1, (1+s)z^o, x_3^o)z^{o^2}\,T(s, r)\,ds \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1.25)$$

The sign of this integral depends upon $\hat{g}_{223}$. Differentiating Equation 1.1a yields

$$\hat{g}_{223} = \beta(\beta\text{-}1)\,\gamma x_1^{\alpha}\, x_2^{\beta-2} x_3^{\gamma-1}$$

which is negative for the restrictions given with Equation 1.1a; consequently, both terms in braces in Equation 1.23 are negative. $E_r(VMP_3)$ is, therefore, negative since p is positive.

If the production function is CES the first integral in Equation 1.23 is positive so the sign of the first term in braces depends upon the sign of x_r^1. Information about that sign is summarized in Table 2. Now examine using Equation 1.25 the sign of the second term in braces. The sign of this term is determined by $\hat{g}_{223}$. This derivative is

$$\hat{g}_{223} = \delta_2\,\delta_3\,(1\text{-}\rho)\,x_3^{\rho-1}\,x_2^{\rho-2}\,R^{(1/\rho)-2}$$

$$(\epsilon_{yx_2}(1\text{-}2\rho) + \rho\text{-}1) \qquad \ldots\ldots\ldots(1.26)$$

The last term of Equation 1.26 determines the sign of $\hat{g}_{223}$ since the other terms are positive. The last term is equal to A given in Equation 1.13. Above the sign of A determined the sign of x_r^1. Here the sign of A determines the sign of D in Equation 1.25 and, therefore determines the sign of the second term in Equation 1.23. Thus A determines the sign of both terms in Equation 1.23. Consequently the sign of E_r (VMP_3) and the sign of x_r^1 agree so that Table 2 summarizes information about the sign of both. As argued above it is reasonable to expect ϵ_{yx_2} to be less than one-half; thus, it is reasonable to expect E_r (VMP_{x_3}) to be negative.

Summary of Case I. In this section we have analyzed the effect of an increase in risk upon several important variables. The results for the general case were mostly indeterminant. That is, if the only restriction that we place on the production function is that it be strictly concave then the effect upon only one variable is determinant. Fortunately, it is the effect upon the most important variable that is determinant. An increase in risk will cause expected profits to fall. Thus an increase in risk will harm the farmers. If the production function is Cobb-Douglas then the effect on each of the variables examined is determinant. In each case the effect is negative. If the production function is CES then the effects are determinant for certain values of the parameters of the function.

The results of this section are summarized in Table 4. In the table a minus sign indicates that the sign of the partial derivative is negative. An I indicates that the sign is indeterminant, and a conditional statement with a sign indicates a sufficient condition for the sign to hold.

Case II: The farmers are risk averse

In this section the set of farms in S_1 is treated as a risk averse, utility maximizing entity. It is assumed that there exists an "aggregate" production function that relates inputs to output for the S_1 set. The utility function which is maximized is strictly concave since the group is assumed to be risk averse. As above, when the conclusions are indeterminant for the general case the Cobb-Douglas and CES production functions are analyzed to determine if answers exist for these special cases. At some points in this section a specific utility function is assumed. The utility function has the property of constant risk aversion.

The first problem analyzed in this section is the effect of changing the assumption of risk

Table 4. Summary of the effects.

Variable	Production Function: Concave	Cobb-Douglas	CES
$E_r(\bar{\pi})$	-	-	-
x_r^1	I	-	+ if c - if a or b
$E_r(\bar{y})$	I	-	+ if c - if a or b
$E_r(\overline{VMP_z})$	I	-	- if b
$E_r(\overline{VMP_3})$	I	-	- if a or b + if c

a) $0 < \epsilon_{yx_2} < ½$

b) $0 < \rho < 1$

c) $\rho < \dfrac{1\text{-}\epsilon_{yx_2}}{1\text{-}2\epsilon_{yx_2}} < 0$

neutrality to one of risk aversion. The other problem analyzed is that of an increase in the variability of water (risk). The impacts of these changes upon profits, output, quantity demanded of the purchased input, and the prices of land and water are all analyzed. The impacts of both the change from risk neutrality to risk aversion and for an increase in the degree of risk aversion are analyzed. In the latter of these the utility function is assumed to exhibit constant risk aversion. This utility function is also used in parts of the analysis of an increase in the variability of water.

Some preliminaries

It is assumed that the utility function,

$$U = U(\pi) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

is strictly monotone increasing, strictly concave, and thrice continuously differentiable. The utility function that exhibits constant risk aversion will have the property

$$\theta = -\frac{U''(\pi)}{U'(\pi)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

where θ is the "degree of risk aversion" and is a positive constant. This measure of risk aversion was suggested independently by Pratt (1964) and by Arrow (1963). Equation 2.2 is a second order homogeneous linear differential equation which has the general solution

$$U(\pi) = \zeta - \psi e^{-\theta\pi} \quad (2.3)$$

where ζ and ψ are arbitrary constants of integration. ψ is positive since $U(\pi)$ is assumed to be strictly monotone increasing, and ζ is also positive since $U(\pi)$ is assumed to be positive. The magnitudes of ζ and ψ, however, do not affect the expected utility maximization solutions; hence their magnitudes are unimportant.

Let profits be given by

$$\pi = \pi(x,p,w) = pg(x) - w'x \quad \ldots\ldots\ldots (2.4)$$

where x is a vector of inputs, w is a vector of input prices; g is the production function and p is the output price. Given that g(x) is concave and that p is positive, then $\pi(x, p, w)$ is concave in x. This follows from π being a positive linear combination of concave functions. Combining Equations 2.1 and 2.4 yields

$$U = U(\pi(x,p,w)) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

which is strictly concave in x.

The proof that Equation 2.5 is strictly concave in x is as follows.

$U(\pi)$ strictly concave means

$$U((1-t)\pi^{o} + t\pi) > (1-t)\,U(\pi^{o}) + t\,U(\pi) \quad \ldots (2.6)$$

for all π^0, π in the domain of U and all $0<t<1$. $\pi(x, p, w)$ concave in x means

$$\pi(\hat{x},p,w) \geqslant (1-t)\,\pi(x^{o},p,w) + t\,\pi(x,p,w)$$

$$\hat{x} = (1-t)x^{o} + tx \quad \ldots\ldots\ldots\ldots\ldots (2.7)$$

for all x^0, x in the domain of g(x) and $0 \leqslant t \leqslant 1$. $U(\pi)$ a strictly monotone increasing function means

$$U(\pi^2) > U(\pi^1) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

for $\pi^2 > \pi^1$. Combining Equations 2.7 and 2.8 yields

$$U(\pi(\hat{x},p,w)) \geqslant U((1-t)\,\pi(x^{o},p,w) + t\,\pi(x,p,w)) \quad \ldots\ldots\ldots (2.9)$$

Letting $\pi^0 = \pi(x^0, p, w)$ and $\pi = \pi(x, p, w)$ and combining Equations 2.6 and 2.9 yields

$$U(\pi(\hat{x},p,w)) \geqslant U((1-t)\pi^{o} + t\pi) > (1-t)\,U(\pi^{o}) + t\,U(\pi)$$

or

$$U(\pi(\hat{x},p,w)) > (1-t)\,U(\pi(x^{o},p,w)) + t\,U(\pi(x,p,w)) \quad \ldots\ldots\ldots (2.10)$$

which means that U is strictly concave in x.

Define

$$x_2 = (1+s)z$$

and

$$E(U) = \int_a^b U(\pi(x_1, (1+s)z,p,w)\, f(s,r)ds$$

where x_1 and x_2 are the only variable inputs. The fact that U is strictly concave in x implies that E(U) is also strictly concave in x. The proof of this is as follows. U strictly concave in x implies

$$U(\pi(\hat{x}_1, (1+s)\hat{z},p,w)) > (1-t)U(\pi(x_1^{o},(1+s)z^{o},p,w)) + t\,U(\pi(x_1,(1+s)z,p,w))$$

where

$$\hat{x}_1 = (1\text{-}t)x_1^o + tx_1$$

$$\hat{z} = (1\text{-}t)z^o + tz$$

for all x_1^0, x_1, z^0, z, and s in the domain of π and 0<t<1. Multiplying through by f(s,r) $\geqslant$ 0 and integrating over [a, b] with respect to s yields

$$\int_a^b U(\pi(\hat{x}_1, (1+s)\hat{z},p,w))\, f(s,r)ds > (1\text{-}t)$$

$$\int_a^b U(\pi(x_1^o, (1+s)z^o, p,w))\, f(s,r)ds$$

$$+\, t\int_a^b U(\pi(x_1, (1+s)z,p,w))\, f(s,r)ds \qquad (2.11)$$

thus E(U(π)) is strictly concave in x_1 and z.[2]

The utility functions that will be examined in this section are strictly concave; thus the first order condition for a maximization of expected utility will be both necessary and sufficient for a maximum, since E(U(π)) is strictly concave in the inputs.

The effects of risk aversion

We now examine the effect of changing the assumption of risk neutrality to risk aversion. We analyze the effects upon expected profits first then upon the quantity of the purchased input, the expected level of output, and last upon the prices of water and land. These analyses as those presented above assume that land and the mean quantity of water are constant.

The effect upon the expected level of profits. Given that a risk averse set of S_1 farmers uses a different quantity of the purchased input than a risk indifferent set, the expected level of profits will be lower for the risk averse set than for the risk indifferent set. This follows from the fact that the risk indifferent set will maximize expected profits; thus any movement away from their solution will lower profits.

The effects upon x_1 and upon the expected level of output. We examine now the effect upon the quantity of the purchased input and upon the expected level of output. The quantity of the purchased input can be either larger or smaller for the risk averse set than for the risk neutral set depending upon the sign of the second partial derivative g_{21}. If g_{21} is positive (negative), then the risk averse set uses less (more) x_1 than does the risk neutral set. The Cobb-Douglas and CES production functions, Equations 1.1a and 1.1b have g_{21} positive; thus if either of these production functions hold, the change of assumption will lower the quantity of the purchased input, x_1. The expected level of output will increase when x_1 does and decrease when x_1 does, since g_1 is positive. Thus if g_{21} is positive (negative) then the expected level of output will be less (more) for the risk averse set than for the risk neutral set.

We now prove these conclusions. The function to be maximized is the expected utility function

$$E(U) = \int_a^b U(pg(x_1, (1+s)z^o) - w_1 x_1)\, f(s,r)ds \qquad (2.12)$$

the first order condition for a maximum of E(U) is

$$\frac{\partial E(U)}{\partial x_1} = \int_a^b U'(\pi)\, (pg_1(x_1,(1+s)z^o)\text{-}w_1)\, f(s,r)ds = 0 \qquad (2.13)$$

or

$$E[U'(\pi)\cdot(pg_1 - w_1)] = pE[U'(\pi)g_1] - w_1\, E[U'(\pi)] = 0$$

or

$$p\left\{E[U'(\pi)]\,E[g_1] + \text{cov}[U'(\pi),g_1]\right\} = w_1 E[U'(\pi)]$$

or

$$p\,E[g_1] = w_1 - p(\text{cov}[U'(\pi),g_1]) \,/\, E[U'(\pi)] \qquad (2.13a)$$

In this last expression $U'(\pi)$ is positive; thus $E[U'(\pi)]$ is positive. The sign of the last term, therefore, depends upon the sign of the covariance between $U'(\pi)$ and $g_1(1 + s)z^0$). For the risk neutral set $U'(\pi)$ is a constant and the covariance is zero. For this case Equation 2.13a becomes Equation 1.8a as stated earlier. That is, the maximization of expected profits is the same thing

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[2] Since x_1 can be treated as a vector, this proof holds for any number of nonrandom variables.

as the maximization expected utility if the utility function exhibits risk neutrality. A sufficient condition for the $\text{cov}[U'(\pi), g_1]$ to be positive (negative) is for U_s' and g_{s1} to have the same sign (opposite signs) where

$$U_s' = \frac{\partial U'(\pi)}{\partial s} = U''(\pi) p g_2 z^o$$

and

$$g_{s1} = g_{21} z^o$$

The utility function is strictly concave, implying that $U''(\pi) \leqslant 0$. This means that $U_s' \leqslant 0$ for all $s \varepsilon [a, b]$. If g_{21} is positive as in Cobb-Douglas and CES then the two have opposite signs and the convariance is negative. If g_{21} is negative then the two terms have the same sign and the covariance is positive. Thus with g_{11} negative and g_{21} positive (negative) the solution x_1 for the risk averse set is less (greater) than the solution x_1 for the risk neutral set. With g_{21} positive (negative) $pE[g_1] > w_1$ ($< w_1$) which implies a smaller (larger) quantity of x_1 than does $pE[g_1] = w_1$ which is the risk netural solution.

The effect upon the price of water. We now examine the effect of risk aversion upon the price of water. Here we assume as we did above that the mean quantity of water is constant, z^0, and examine the effects of risk aversion upon the price of water. It is assumed that competition among the S_1 farmers for the water competes the price of water, w_z, to a level such that

$$\int_a^b U'(\pi)(pg_z - w_z) f(s,r) ds = 0 \quad \ldots.(2.14)$$

or

$$w_z = \frac{pE[U'(\pi) g_z]}{E[U'(\pi)]}$$

or

$$w_z = pE[g_z] + p(\text{cov}[U'(\pi), g_z]) \;/\; E[U'(\pi)] \quad \ldots\ldots\ldots(2.14a)$$

That is, the mean quantity of water is fixed and the farmers in S_1 compete for that quantity till the price of the water just satisfies the first order condition for water. If the set is risk neutral then U' is a constant and the covariance is zero. This implies that w_z is equal to the expected value of the value of the marginal product of water which was discussed in Case I. The term $E[g_z]$ will be smaller for risk aversion than for risk neutrality. The reason for this is the change in x_1. The x_1 in risk aversion is smaller (larger) than the one in risk neutrality if g_{21} is positive (negative) implying that $g_z = g_2(1+s)$ is lower at each s causing $E[g_z]$ to be lower under risk aversion than risk neutrality. If the second righthand term is negative then w_z is lower for risk aversion; however, if that term is positive, the effect of risk aversion is indeterminant. The effect of the two terms is opposite in sign for this case. The second righthand term has the same sign as the covariance term, and the covariance is negative if U_s' and g_{sz} have opposite signs. As noted above U_s' is negative; therefore the sign of the covariance is determined by g_{sz}. If g_{sz} is positive then the covariance is negative and w_z is lower for risk aversion than risk neutrality.

If the production function is Cobb-Douglas as given by Equation 1.1a then g_{sz} is positive and w_z is lower for risk aversion than for risk neutrality. This derivative is given by

$$g_{sz} = \beta^2 x_1^{\alpha} (1+s)^{\beta-1} z^{\beta-1} x_3^{\alpha} \quad \ldots\ldots(2.15)$$

which is clearly positive. However, if the production function is CES as given by Equation 1.1b then g_{sz} can be either positive or negative. This derivative is given by

$$g_{sz} = \delta_2 R^{1/\rho-1} z^{\rho-1}(1+s)^{\rho-1}[(1-\rho)\,\epsilon_{yx_2} + \rho] \,.(2.15a)$$

The sign of the term in brackets determines the sign of g_{sz} since the rest of the expression is positive. The bracketed term is positive for $\varrho > 0$ ($\sigma>1$) and is negative for some combinations of ϱ and ε_{yx_2} for $\rho<0$ ($\sigma<1$). For $\rho<0$ and $\varepsilon_{yx_2} > 0$ the bracket term is negative if

$$\sigma < 1 - \epsilon_{yx_2} < 1$$

and is positive if

$$\sigma > 1 - \epsilon_{yx_2}$$

where σ is the elasticity of substitution and is given by

$$\sigma = \frac{1}{1-\rho}$$

Therefore if the elasticity of substitution is sufficiently large the price of water will be lower for risk aversion than for risk neutrality. And if the elasticity of substitution is sufficiently small then the direction of the effect is indeterminant.

The effect upon the price of land. Next we examine the price of land. We assume that competition among the S_1 farmers for the fixed quantity of land will compete the price of land, w_3, to a level such that

$$\int_a^b U'(\pi)(pg_3 - w_3)\, f(s,r)ds = 0 \quad \ldots\ldots (2.16)$$

or

$$w_3 = \frac{pE[U'(\pi)g_3]}{E[U'(\pi)]}$$

or

$$w_3\, pE[g_3] + p(\mathrm{cov}[U'(\pi), g_3]) \;/\; E[U'(\pi)] \quad \ldots\ldots\ldots (2.16a)$$

As above the risk neutral solution is where $w_3 = pE[g_3]$ or the price of land is equal to the mean value of the value of the marginal product of land. The first righthand term will be larger for risk aversion than risk neutrality if g_{12} and g_{13} agree in sign and smaller if they disagree in sign. If g_{12} is positive (negative) then x_1 is smaller (larger) under risk aversion and g_{13} positive (negative) implies that g_3 is smaller at each s. These imply that $E[g_3]$ is lower for risk aversion than for risk neutrality. The same steps yield for a disagreement in signs $E[g_3]$ larger for risk aversion.

The sign of the second term agrees with the sign of the covariance term. The covariance term is negative (positive) if U_s' and g_{s3} disagree (agree) in sign. Since U_s' is negative, the second term will be negative (positive) if g_{s3} is positive (negative). Combining the results we have w_3 lower for risk aversion if $E[g_3]$ is lower for risk aversion and the covariance is negative. These conditions will exist if g_{12} and g_{13} agree in sign and if $g_{s3} = g_{23}z$ is positive. If the production function is Cobb-Douglas or CES then g_{12}, g_{13} and g_{23} are all positive, implying that w_3 is lower for risk aversion than for risk neutrality. If $E[g_3]$ is higher for risk aversion and the covariance is negative then w_3 will be higher for risk aversion than risk neutrality. This result will hold if g_{12} and g_{13} disagree in sign while g_{23} is negative.

The effects of an increase in risk aversion

Introduction. Here we analyze the effects of an increase in risk aversion. To do this we assume that the utility function exhibits constant risk aversion and differentiate different functions with respect to the "degree of risk aversion." The utility function is by Equation 2.3

$$U = \zeta - \psi e^{\theta\pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

where θ is the "degree of risk aversion."

With this utility function expected utility is given by

$$E(U) = \int_a^b (\zeta - \psi e^{-\theta\pi})\, f(s,r)ds \quad \ldots (2.17)$$

where

$$\pi = pg(x_1, (1+s)z^o) - w_1 x_1$$

and the first order condition for a maximum of expected utility is given by

$$E_{x_1}(U) = \int_a^b (pg_1(x_1, (1+s)z^o) - w_1)\, e^{-\theta\pi}\, f(s,r)ds = 0 \quad \ldots\ldots\ldots (2.18)$$

Before proceeding to the individual analyses we note an important characteristic of these results. In the limit as θ goes to zero, the solution level of x_1 goes to the risk indifferent or expected profit maximization solution. The solution level of x_1 is defined by Equation 2.18, and the limit of Equation 2.18 as θ goes to zero is

$$\int_a^b (pg_1(x_1,(1+s)z^o) - w_1)\, f(s,r)ds = 0 \quad . (2.18a)$$

which is first order condition for the risk neutral case Equation 1.8. Thus in the limit θ goes to zero the solution x_1 goes to the solution that was analyzed in the risk neutral section. An additional important point is that the functional relationship between x_1 and θ is continuous given the continuity assumptions that were made for U and g.

The effect upon x_1. We examine first the effect of an increase in risk aversion (θ) upon x_1 then upon expected profits, expected output, and the prices of land and water. To examine the effect upon x_1 we differentiate the first order condition with respect to θ and then evaluate the results. The result of this differentiation is

$$\frac{\partial x_1}{\partial\theta} = x_\theta^1 = \frac{N}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.19)$$

where

$$N = \int_a^b (pg_1 - w_1)\, \pi e^{-\theta\pi}\, f(s,r)ds$$

$$D = \int_a^b [pg_{11} e^{-\theta\pi} - \theta (pg_1 - w_1)^2 e^{-\theta\pi}] f(s,r)ds \qquad \text{..........(2.20)}$$

Since g is convex, $g_{11} \leqslant 0$ and D is negative; therefore the sign of x_θ^1 is the oppositve of that of N. Below it is proven that if g_{21} is positive (negative) then x_θ^1 is negative (positive). For some production functions the use of the purchased input will increase as risk aversion increases and for others it will decrease. If the production function is either Cobb-Douglas or CES then g_{21} will be positive and x_θ^1 will be negative.

We now prove that $g_{21} > 0$ (<0) implies that N>0 (<0) which implies that x_θ^1 <0 (>0). In the proof we use the following definitions:

1) x_1^o is the solution to Equation 2.18

2) s^o is defined by $pg_1(x_1^o, (1+s^o)z^o) - w_1 = 0$

3) $\pi_o(s) = pg(x_1^o, (1+s)z^o) - w_1 x_1^o$

4) $\pi_o(s^o) = pg(x_1^o, (1+s^o) - w_1 x_1^o$

5) $g_1^o(s) = g_1(x_1^o, (1+s)z^o)$

Evaluate N at x_1^0. Multiply the first order condition by $\pi_0(s^0)$

$$\pi_o(s^o) \int_a^b (pg_1 - w_1) e^{-\theta\pi} f(s,r)ds = 0$$

and subtract the result from N. This yields

$$N = \int_a^b (pg_1^o(s) - w_1) [\pi_o(s) - \pi_o(s^o)] e^{-\theta\pi_o(s)} f(s,r)ds$$

$$N = \int_a^{s^o} (pg_1^o(s) - w_1) [\pi_o(s) - \pi_o(s^o)] e^{-\theta\pi_o(s)} f(s,r)ds + \int_{s^o}^b (pg_1^o(s) - w_1)[\pi_o(s) - \pi_o(s^o)] e^{-\theta\pi_o(s)} f(s,r)ds \qquad \text{..........(2.21)}$$

Examine the first integral in Equation 2.21. The bracketed term is negative for all $s<s^0$ since it is zero at s^0 and

$$\frac{d\pi_o(s)}{ds} = pg_2(x_1^o, (1+s)z^o)z^o > 0$$

If $g_{21} > 0$ (<0) then the parenthetical expression is negative (positive) for all $s<s^0$. The other two terms are positive, i.e.,

$$e^{-\theta\pi_o(s)} f(s,r) \geqslant 0$$

therefore the first integral is positive (negative) if $g_{21} > 0$ (<0). The second integral is examined in like fashion. The bracketed term is positive for all $s>s^0$ since it is zero at s^0 and $\pi_0'(s) > 0$. The parenthetical expression is positive (negative) if $g_{21} > 0$ (<0). Since the two integrals agree in sign and their signs are as stated in the original statement, the proof is complete.

The effect upon E(π). We now examine the effect of an increase in risk aversion upon the expected level of profits. The expected level of profits is given by

$$E(\pi) = \int_a^b [pg(x_1, (1+s)z^o) - w_1 x_1] f(s,r)ds \qquad \text{............(2.22)}$$

This equation gives the solution level of expected profits if x_1 is treated as the solution x_1. Differentiating Equation 2.22 with respect to θ treating x_1 as a function of θ yields

$$E_\theta(\bar{\pi}) = x_\theta^1 \int_a^b (pg_1 - w) f(s,r)ds \qquad \text{.....(2.23)}$$

It was demonstrated above in connection with Equation 2.13a that the integral in Equation 2.23 is positive (negative) if g_{21} is positive (negative). x_θ^1 is negative (positive) if g_{21} is positive (negative); thus the two terms in Equation 2.23 are opposite in sign. This implies that $E_\theta(\bar{\pi})$ is negative. The more risk averse the set of S_1 farmers is, the lower will be the solution average level of profits.

The effect upon E($\bar{y}$). The solution expected level of output will increase or decrease depending upon what happens to x_1. If x_1 increases (decreases) as risk aversion increases then so will the solution expected level of output. This is proven as follows. The expected level of output is given by

$$E(y) = \int_a^b g(x_1, (1+s)z^o) f(s,r)ds \qquad \text{....(2.24)}$$

Differentiating Equation 2.24 with respect to θ, treating x_1 as a function of θ yields

$$E_\theta[\bar{y}] = x^1_\theta \int_a^b g_1(x_1, (1+s)z^o)\, f(s,r)ds \qquad \ldots\ldots\ldots\ldots(2.25)$$

Thus the sign of $E_\theta(\bar{y})$ is the same as that of $x_\theta{}^1$ since the integral in Equation 2.25 is positive.

The effect upon w_z. The analysis of the change in the price of water is similar to that of the last section. Again we assume that the S_1 farmers compete the price of water to a level such that Equation 2.14 holds, or in terms of the current utility function

$$\int_a^b (pg_z - w_z)e^{-\theta\pi}\, f(s,r)ds = 0 \qquad \ldots\ldots(2.26)$$

That is, w_z is defined by Equation 2.26. To determine the effect of an increase in risk aversion differentiate Equation 2.26 with respect to θ. This differentiation yields

$$w^z_\theta = \Big\{ x^1_\theta \int_a^b pg_{1z}\, e^{-\theta\pi} f(s,r)ds - \int_a^b (pg_z - w_z)\, e^{-\theta\pi}\, [\pi + \theta x^1_\theta\, (pg_1 - w_1)]\, f(s,r)ds \Big\} \Big/ \int_a^b e^{-\theta\pi}\, f(s,r)ds \qquad \ldots(2.27)$$

The denominator is positive, thus, the sign of Equation 2.27 is determined by the term in braces. The sign of the term in braces is in general indeterminant; however, its sign can be determined for θ "close" to zero for certain cases by letting θ go to zero in the limit. The limit of $w_\theta{}^z$ as θ goes to zero is

$$\lim_{\theta\to 0} w^z_\theta = \int_a^b pg_{1z}\, f(s,r)ds \cdot \lim_{\theta\to 0} x^1_\theta - \int_a^b (pg_z - w_z)\, \pi f(s,r)ds \qquad \ldots(2.28)$$

The first term in this limit is negative. The integral in this term is positive (negative) if g_{21} is positive (negative) and limit of $x_\theta{}^1$ as θ goes to zero is finite and is negative (positive) if g_{21} is positive (negative). Thus the two signs are opposite and the term is negative.

The second righthand term can be written

$$-\Big\{ \int_a^b (pg_z - w_z)\, f(s,r)ds \cdot \int_a^b \pi f(s,r)ds + \mathrm{cov}[pg_z, \pi] \Big\} \qquad \ldots\ldots\ldots\ldots(2.29)$$

The first term in this expression is zero since the first integral is the limit of Equation 2.26 as θ goes to zero. This integral is, therefore, equal to zero. The sign of the covariance term is positive (negative) if π_s and g_{sz} agree (disagree) in sign. $\pi_s = pg_2z$ is positive, and g_{sz} can be either positive or negative. Combining these ideas we get Equation 2.28 negative if g_{sz} is positive and indeterminant if g_{sz} is negative since in this case the two terms would have opposite signs. If the production function is Cobb-Douglas then g_{sz} is positive (see the discussion related to Equation 2.15) or if the production function is CES with

$$\sigma > 1 - \epsilon_{yx_2} \qquad \ldots\ldots\ldots\ldots(2.30)$$

where σ is the elasticity of substitution and ϵ_{yx_2} is the elasticity of production with respect to x_2 then g_{sz} is positive (see the discussion related to Equation 2.16). Since the functions are continuous in θ there exists an interval about zero for which the conclusions derived from Equation 2.28 hold; therefore for θ "small" and g_{sz} positive, $w_\theta{}^z$ is negative.

The effect upon w_3. The analysis of the effect of a change in risk aversion on the price of land is similar to that just presented for the price of water. We assume that competition among the S_1 farmers for the fixed quantity of land will compete the price of land, w_3, to a level such that Equation 2.16 holds, or using the current utility function that

$$\int_a^b (pg_3 - w_3)e^{-\theta\pi}\, f(s,r)ds = 0 \qquad \ldots\ldots(2.31)$$

Differentiating Equation 2.31 with respect to θ, treating x_1 as a function of θ yields

$$w^3_\theta = \Big\{ x^1_\theta \int_a^b pg_{13}\, e^{-\theta\pi} f(s,r)ds - \int_a^b (pg_3 - w_3)\, (\pi + \theta x^1_\theta\, pg_1)\, f(s,r)ds \Big\} \Big/ \int_a^b e^{-\theta\pi}\, f(s,r)ds \qquad \ldots(2.32)$$

As in the previous case we take the limit as θ goes to zero. This limit is

$$\lim_{\theta \to 0} w_\theta^3 = \int_a^b pg_{13}\, f(s,r)\, ds \quad \lim_{\theta \to 0} x_\theta^1$$

$$- \int_a^b (pg_3 - w_3)\, \pi\, f(s,r) ds \quad ..(2.33)$$

The first term is positive if g_{13} and g_{12} disagree in sign since both the integral and the limit will have the same sign. These two parts of the first term will disagree in sign if g_{13} and g_{12} agree in sign. This will cause the first term to be negative. The second term can be written as

$$-\left\{\int_a^b (pg_3 - w_3)\, f(s,r) ds \int_a^b \pi\, f(s,r) ds\right\}$$

$$+ \operatorname{cov}[pg_3, \pi]$$

The first term of this expression is zero since it is the limit of Equation 2.31 as θ goes to zero. The covariance is positive (negative) if $g_{S3} = g_{23}z$ is positive (negative) since π_s is positive. Collecting these pieces of information we have for θ "close" to zero $w_\theta{}^3$ negative if g_{13} and g_{12} agree in sign and g_{23} is positive, and $w_\theta{}^3$ will be positive if g_{13} and g_{12} disagree in sign and g_{23} is negative. If the production function is Cobb-Douglas or CES then g_{13}, g_{12}, and g_{23} will all be positive and the sufficient conditions for $w_\theta{}^3$ to be negative will be satisfied.

The effects of an increase in risk

In this section we analyze the effects of an increase in risk upon the expected level of real income (utility), the expected level of money income (profits), the quantity of the purchased input, the expected level of output, and the prices of water and land.

The effect upon real income. The effect of an increase in risk upon the expected level of real income (utility) is tautological. The utility function is concave; therefore, a change in risk is an increase if, and only if, the expected level of utility falls. That is, by definition an increase in risk makes a risk averter worse off. These statements hold the quantities of the inputs constant; however, if the inputs are variable the statement still holds. This follows since the entire expected utility function is shifted down; thus the maximum level of expected utility must shift down as risk increases.

The effect upon x_1. We examine now the effect of an increase in risk upon the quantity of the purchased input. This effect is examined by examining the derivative of x_1 with respect to r. This derivative is derived by differentiating the first order condition Equation 2.13 with respect to r. This derivative is

$$\frac{\partial x_1}{\partial r} = x_r^1 = -\frac{N}{D} \quad \ldots\ldots\ldots\ldots\ldots (2.34)$$

where

$$N = \int_a^b U'(\pi)\, (pg_1 - w_1)\, f_r(s, r) ds$$

$$D = \int_a^b [U''(\pi)(pg_1 - w_1)^2 + U'(\pi)\, pg_{11}]\; f(s,r) ds$$

D is negative for U and g concave; thus the sign of $x_r{}^1$ agrees with the sign of N. N is negative (positive) if the product $U'(\pi)\ (pg_1 - w_1)$ is concave (convex) in s. In general the conditions specified for U and g do not imply that this product is either concave or convex. The sign of $x_r{}^1$ is, therefore, in general indeterminant on a prior grounds. If, however, the utility function exhibits constant risk aversion and the production function is Cobb-Douglas or CES then some sufficient conditions for the determination of the sign of $x_r{}^1$ can be identified.

If the utility function has constant risk aversion, Equation 2.3, then N and D can be written

$$N = \int_a^b (pg_1 - w_1) e^{-\theta\pi}\, f_r(s,r) ds$$

$$D = \int_a^b [pg_{11} - \theta(pg_1 - w_1)^2]\, e^{-\theta\pi}\; f(s,r) ds$$

Some of the sufficient conditions for the determination of the sign of $x_r{}^1$ can be identified for some values of θ by taking the limit of $x_r{}^1$ as θ goes to zero. As θ goes to zero x_1 goes to the risk neutral solution and N and D go to

$$\lim_{\theta \to 0} N = \int_a^b (pg_1 - w_1)\, f_r(s,r) ds$$

$$= p \int_a^b g_1\, f_r(s,r) ds$$

$$\lim_{\theta \to 0} D = p \int_a^b g_{11}\; f(s,r) ds$$

thus

$$\lim_{\theta \to 0} x_r^1 = \frac{-\int_a^b g_1 f_r(s,r)ds}{\int_a^b g_{11} f(s,r)ds} \quad \ldots\ldots(2.35)$$

which is Equation 1.9. Thus in the limit as θ goes to zero the derivative x_r^1 for the risk aversion case goes to the solution for the risk neutral case, and since these functions are continuous in θ there exists some neighborhood of zero for which the risk neutral solution holds. This implies that if the utility function is not "too" risk averse then the risk neutral analysis holds. In addition if it does not hold for all constant risk aversion utility functions, then the value of θ is a determinant of the sign of x_r^1. It was proven in the risk neutral chapter that if the production function is Cobb-Douglas then Equation 2.35 is negative. If the production function is CES then x_r^1 can be either positive or negative; however either $\rho>0$ or $\epsilon_{yx_2} < 1/2$ are sufficient for it to be negative.

The effect upon E(π). The effect of an increase in risk upon the expected level of profits is analyzed by differentiating the expected profit function. The procedure used for expected utility is not sufficient since expected profits are not maximized. The expected profit function shifts down as risk increases since this function is concave; however, since x_1 changes as risk changes the possibility exists that we shift to a point on the lower function with a higher expected profit.

The expected profit function is

$$E(\pi) = \int_a^b (pg(x_1,(1+s)z^o - w_1 x_1) f(s,r)ds \quad \ldots\ldots\ldots\ldots(2.36)$$

Differentiating this function with respect to r yields

$$E_r(\overline{\pi}) = x_r^1 \int_a^b (pg_1 - w_1) f(s,r)ds$$

$$+ \int_a^b (pg - w_1 x_1) f_r(s,r)ds \quad \ldots\ldots(2.37)$$

The second righthand integral is negative since the profit function is concave in s. In general the sign of the first term is indeterminant. It was demonstrated in connection with Equation 2.13a that the integral of this term is positive (negative) if g_{21} is positive (negative); thus this term will have the same (opposite) sign as x_r^1 if g_{21} is positive (negative). However, in general the sign of x_r^1 is indeterminant. If we let the utility function exhibit constant risk aversion and let θ go to zero this term and $E_r(\overline{\pi})$ are both determinant. In the limit as θ goes to zero the integral of the first term goes to zero since it becomes the first order condition. Thus for θ "close" to zero $E_r(\overline{\pi})$ is negative since the second term is negative.

The effect upon E(y). We next analyze the effect of an increase in risk upon the mean level of output. This is achieved by examining the partial derivative of the expected value of the solution level of output with respect to r. The expected level of output is given by

$$E(y) = \int_a^b g(x_1,(1+s)z^o) f(s,r)ds \quad \ldots\ldots(2.38)$$

and the partial derivative of E(y) with respect to r, treating x_1 as the solution value is

$$E_r(\overline{y}) = x_r^1 \int_a^b g_1 f(s,r)ds + \int_a^b g f_r(s,r)ds \quad \ldots\ldots\ldots\ldots(2.39)$$

The integral in the first term is positive; thus the sign of this term agrees with the sign of x_r^1. The second term is negative since g is concave in s. Thus a sufficient condition for $E_r(\overline{y})$ to be negative is x_r^1 negative. If x_r^1 is positive then the sign of $E_r(\overline{y})$ is indeterminant since the two terms disagree in sign.

The effect upon w_z. The next analysis is that of the effect of an increase in r upon the price of water. In this analysis as in many of the others the effect for the general case is indeterminant; however, for special cases the sign of the effect can be determined. In these special cases we analyze the sign of the partial derivative of w_z with respect to r for θ "close" to zero. For these cases the conclusions are the same as those for the risk neutral case and were analyzed in connection with Equation 1.17.

As in the earlier analyses of impacts upon the price of water, we assume that competition among the S_1 farmers competes w_z to a level such that

$$\int_a^b (pg_z - w_z) U'(\pi) f(s,r)ds = 0 \quad \ldots\ldots(2.40)$$

Differentiating Equation 2.40 with respect to r, treating x_1 as a function of r yields

$$w_r^z = \left\{ x_r^1 \int_a^b pg_{1z}\, U'(\pi)\, f(s,r)ds \right.$$

$$+ x_r^1 \int_a^b (pg_z - w_z)(pg_1 - w_1) U''(\pi)\, f(s,r)ds$$

$$\left. + \int_a^b (pg_z - w_z)\, U'(\pi)\, f_r(s,r)ds \right\} \Big/ \int_a^b U'(\pi)$$

$$f(s,r)ds \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.41)$$

The sign of this expression is not implied by the assumed characteristics of U and g; thus in general this sign is indeterminant. If we assume a constant risk aversion utility function then Equation 2.41 becomes

$$w_r^z = \left\{ x_r^1 \int_a^b pg_{1z} e^{-\theta\pi} f(s,r)ds \right.$$

$$- \theta x_r^1 \int_a^b (pg_z - w_z)(pg_1 - w_1) e^{-\theta\pi} f(s,r)ds$$

$$\left. + \int_a^b (pg_z - w_z) e^{-\theta\pi} f_r(s,r)ds \right\} \Big/ \int_a^b e^{-\theta\pi}$$

$$f(s,r)ds \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.42)$$

The sign of Equation 2.42 is also indeterminant from the a priori conditions on g. However, in the limit as θ goes to zero w_r^z goes to

$$\lim_{\theta \to 0} w_r^z = x_r^1\, p \int_a^b g_{1z}\, f(s,r)ds$$

$$+ \int_a^b (pg_z - w_z)\, f_r(s,r)ds$$

$$= p \left\{ x_r^1 \int_a^b g_{1z}\, f(s,r)ds \right.$$

$$\left. + \int_a^b g_z\, f_r(s,r)ds \right\} \quad \ldots\ldots\ldots (2.43)$$

which is the same result that was given in Equation 1.17.

Since the functions are continuous in θ there is an interval about zero for which the risk neutral results describe the risk aversion case. The sign of Equation 2.43 is also in general indeterminant; however, it was proven above that if the production function is Cobb-Douglas then w_r^z is negative or if it is CES with $\varrho > 0$ $(\sigma > 1)$ then w_r^z is negative.

The effect upon w_3. The analysis of the effect of a change in risk upon the price of land, w_3, is very similar to that of w_z. We examine the sign of w_r^3 which in general is indeterminant. If we assume that the utility function exhibits constant risk aversion and let θ go to zero in the limit this case again approaches the risk neutral case. We assume competition yields a w_3 such that

$$\int_a^b (pg_3 - w_3) U'(\pi)\, f(s,r)ds = 0 \quad \ldots\ldots (2.44)$$

Differentiating Equation 2.44 with respect to r yields

$$w_r^3 = \left\{ x_r^1 \int_a^b pg_{13}\, U'(\pi)\, f(s,r)ds \right.$$

$$+ x_r^1 \int_a^b (pg_3 - w_3)(pg_1 - w_1)\, U''(\pi)\, f(s,r)ds$$

$$+ \int_a^b (pg_3 - w_3)\, U'(\pi)$$

$$\left. f_r(s,r)ds \right\} \Big/ \int_a^b U'(\pi)\, f(s,r)ds \quad \ldots (2.45)$$

The sign of Equation 2.45 is indeterminant given the assumed characteristics of U and g. If, however, we assume a constant risk aversion utility function and take the limit of w_r^3 as θ goes to zero we get

$$\lim_{\theta \to 0} w_r^3 = p \left\{ x_r^1 \int_a^b pg_{13}\, f(s,r)ds \right.$$

$$\left. + \int_a^b g_3\, f_r(s,r)ds \right\} \quad \ldots\ldots\ldots (2.46)$$

which is the same as Equation 1.23. The conclusions of the analysis of Equation 1.23 was that in general its sign is indeterminant; however, if the production function is Cobb-Douglas or CES with the elasticity of production with respect to x_2 less than one-half, then w_r^3 is negative. Since the above functions are continuous in θ there exists some interval above zero for which these conclusions hold for risk aversion case.

Summary of Case II

In this section we examined the effects of risk aversion and the effects of an increase in risk upon several important economic variables. In both analyses we examined the effects upon expected profits, the level of the purchased input (x_1), expected output, and the prices of water and land. In the analysis of an increase in risk we also examined its impact upon the expected level of real income (utility).

In Table 5 we summarize the results of the analysis of the effects of risk aversion. In that analysis we compared the risk aversion solution to the risk neutral solution and we differentiated the variables with respect to the "degree" of risk aversion, θ. The two analyses yielded very similar results; however the partial derivatives of the price of water, $w_\theta{}^z$, and of the price of land, $w_\theta{}^3$, with respect to θ were determinant only for θ "close" to zero. In the table a minus sign that is unqualified indicates that the variable is negative. A sign with a qualification indicates that the condition(s) is (are) sufficient for the sign to hold.

The two parts of the table are very similar and only the portion related to the partial derivatives will be discussed here. An increase in risk aversion will lower expected profits. The precautionary actions of risk averters will lower expected profits. These actions, however, may either increase or decrease the quantity of the purchased input and expected output. This can cause the price of water to fall or maybe to rise. The price of land can either increase or decrease. If, however, the production function is Cobb-Douglas the ambiguity just discussed disappears. All of these effects are negative ($w_\theta{}^z$ and $w_\theta{}^3$ hold for θ "close" to zero). And if the production function is CES the effects are all negative with some qualifications. A negative sign on $w_\theta{}^z$ and $w_\theta{}^3$ hold for θ "close" to zero and certain values of the parameters of the production function.

Table 6 summarizes the results of the analysis of an increase in risk. In this analysis the variables were differentiated partially with respect to r where

Table 6. Summary of the effects of an increase in risk.

Variable	Production Function: Concave	Cobb-Douglas	CES
$E_r(\bar{U})$	-	-	-
$E_r(\bar{\pi})$	- if d and e + if d and f	- if d	- if a and d or b and d + if c and d
x_r^1	- if d	- if d	- if d
$E_r(\bar{y})$	- if d and e	- if d	- if a and d or b and d
w_r^z	I	- if d	- if b and d
w_r^3	I	- if d	- if a and d or b and d + if c and d

a) $0 < \epsilon_{yx_2} < ½$

b) $0 < \rho < 1$

c) $\rho < \dfrac{1-\epsilon_{yx_2}}{1-2\epsilon_{yx_2}} < 0$

d) θ "close" to zero

e) $g_{221} < 0$

f) $g_{221} > 0$

Table 5. Summary of the effects of risk aversion.

Variable	Production Function: Concave	Cobb-Douglas	CES	Variable	Production Function: Concave	Cobb-Douglas	CES
$E(\bar{\pi}_A)$-$E(\bar{\pi}_N)$	-	-	-	$E_\theta(\bar{\pi})$	-	-	-
$\bar{x}_A^1 - \bar{x}_N^1$	- if a + if b	-	-	x_θ^1	- if a + if b	-	-
$E(\bar{y}_A)$-$E(\bar{y}_N)$	- if a + if b	-	-	$E_\theta(\bar{y})$	- if a + if b	-	-
$w_A^z - w_N^z$	- if c	-	- if d	w_θ^z	- if c and e	- if e	- if d and e
$w_A^3 - w_N^3$	- if f + if g	-	-	w_θ^3	- if e and f + if e and g	- if e	- if e

a) $g_{21} > 0$

b) $g_{21} < 0$

c) $g_{sz} > 0$

d) $\sigma > 1-\epsilon_{yx_2}$

e) θ "close" to zero

f) g_{12} and g_{13} agree in sign and $g_{23} > 0$

g) g_{12} and g_{13} disagree in sign and $g_{23} < 0$

r is the shift parameter in the density function. An increase in r causes a shift of the density function that has the characteristics of a mean preserving spread. An increase in risk will lower real income (expected utility) for the S_1 set of farmers. This is not too surprising since it simply says that risk averters are made worse off by an increase in risk, which is true by definition. The other effects are indeterminant except in the limit as θ goes to zero. In the limit as θ goes to zero the results go to the risk neutral results. Since the functions are continuous in θ there exists an interval about zero for which the risk neutral results hold for risk averters. That is, if the utility function is not "too" risk averse then the risk neutral conclusions hold. If the risk neutral conclusions do not hold for all risk averters then the degree of risk aversion becomes a determinant of the sign of the partial derivatives.

For θ "close" to zero expected profits fall as risk increases. The quantity of the purchased input and the mean level of output will decrease (increase) if g_{221} is negative (positive), and in general the sign on w_r^Z and w_r^3 are indeterminant. However, if the production function is Cobb-Douglas all of the above partial derivatives are negative for θ "close" to zero. If the production function is CES then for θ "close" to zero the values of the parameters affect the signs.

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