Irrigation development potential on the Colorado River Indian Reservation

IRRIGATION DEVELOPMENT POTENTIAL
ON THE COLORADO RIVER INDIAN RESERVATION

by

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PREFACE

This Master's Thesis is based on research conducted by the Economic Research Service for use in the Colorado River Indian Reservation (CRIR) Study. The Colorado River Indian Reservation Study is a USDA Interagency Cooperative River Basin Study begun in 1979 at the request of the Colorado River Indian Tribes. Information resulting from this research is to be used by the Colorado River Indian Tribes and participating USDA agencies to evaluate options available to the Tribe for developing its land and water resource base.

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ABSTRACT

Linear programming techniques were used to evaluate various levels of irrigation system development on the Colorado River Indian Reservation. The recommended level of irrigation development on the CRIR was defined as that level which maximized total annual net returns to agriculture. Maximization of net returns involved the implementation of both on-farm and off-farm improvements on existing irrigated lands. On-farm improvements included improved water management, land leveling, ditchlining, and field reorganization. Off-farm improvements included canal reconstruction, installation of measuring structures and improved system management. Water savings resulting from proposed improvements on existing irrigated lands would be made available for new land development. An estimated 23,588 acres of new land were identified for development in the Arizona portion of the Reservation.

CHAPTER 1

INTRODUCTION

Water is increasingly a constraint on irrigated agriculture in Arizona. Greater demands for water from non-agricultural sectors have tightened supplies of surface water available for irrigation. Meanwhile, falling water tables and increased power costs have resulted in rising costs of pumped groundwater. Recent legislation on groundwater pumping has formally limited the level of future groundwater pumping in critical management areas of the state (1980 Arizona Groundwater Law). Such economic and institutional limitations have forced reductions in agricultural water use which has served to encourage the development of more efficient irrigation systems in water-short areas.

In contrast, water on the Colorado River Indian Reservation has not generally been perceived as a limiting factor of production. Water supplies for irrigation on the Reservation are fixed through an annual entitlement of surface water from the Colorado River. At present, the annual water entitlement exceeds required diversions for existing cropland acres. Farm-operators are generally not limited as to the amount of water which may be applied over a cropping season. The on-farm costs of irrigation water on the Reservation are substantially lower than for other irrigated areas of the state dependent upon groundwater.

As a consequence of plentiful supplies of irrigation water at low water prices, relatively little attention has been given to the development of highly productive, water-use efficient irrigation systems. Lower yields and higher input requirements associated with the majority of existing systems have meant reduced potential earnings for farm operators. To the extent that land rent reflects the level of farm earnings, lower farm earnings have meant reduced revenues for tribal landholders.

Low levels of water use efficiency on existing croplands may also limit the development of additional lands for irrigation on the Reservation. The Colorado River Indian Tribes (CRIT) are anxious to expand their irrigated acreage base in the coming years. Most of the tribes' water entitlement however, must currently be diverted to meet irrigation needs on existing croplands. The amount of water available for future development will depend largely on improvements in the water-use efficiency of existing systems.

In order to achieve maximum returns from tribal land and water resources over the long term, substantial improvement in existing irrigation systems on the Reservation may be required. The Colorado River Indian Tribes have requested the assistance of the USDA in evaluating measures to improve productivity and water use efficiency on existing systems. The USDA will also evaluate options for development of new lands on the Reservation.

Description of Study Area

The Colorado River Indian Reservation (CRIR) is situated along the Colorado River, approximately 160 miles west of Phoenix, Arizona and 115 miles north of Yuma, Arizona. The Reservation covers an area of

268,850 acres, extending roughly forty miles north and south along the river. Of total acres on the Reservation, 225,914 acres (85%) are located within La Paz County, Arizona and 43,936 acres (16%) lie west of the river within Riverside and San Bernardino Counties, California. Parker, Arizona, lying within the northern boundaries of the Reservation, serves as the county seat of the newly formed La Paz county and the center of commercial activity in the area (Figure 1).

The Colorado River Indian Tribes are a composite of several tribal groups. The largest tribal group within the Reservation is the Mojove; other groups include the Chemehuevi, Navajo and Hopi. The population of the Colorado River Indian Tribes was estimated to be 1,745 in 1978.[1] In addition to Indian tribal members, there are several thousand non-Indians residing on and in the vicinity of the Reservation. During the summer months, the local population increases as tourists and summer residents take advantage of the area's popular recreation attractions. A significant number of migrant farm workers also enter the area during periods of harvest.

The Colorado River Indian Reservation is held in trust by the United States for the Colorado River Indian Tribes. The majority of Reservation land is in communal ownership under the jurisdiction of the Tribes. Responsibility for the general management of tribal interests is vested in the Colorado River Indian Tribal Council, the elected governing body of the Reservation. The Bureau of Indian Affairs (BIA),

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1. Source: 1979 Arizona Statistical Abstract.

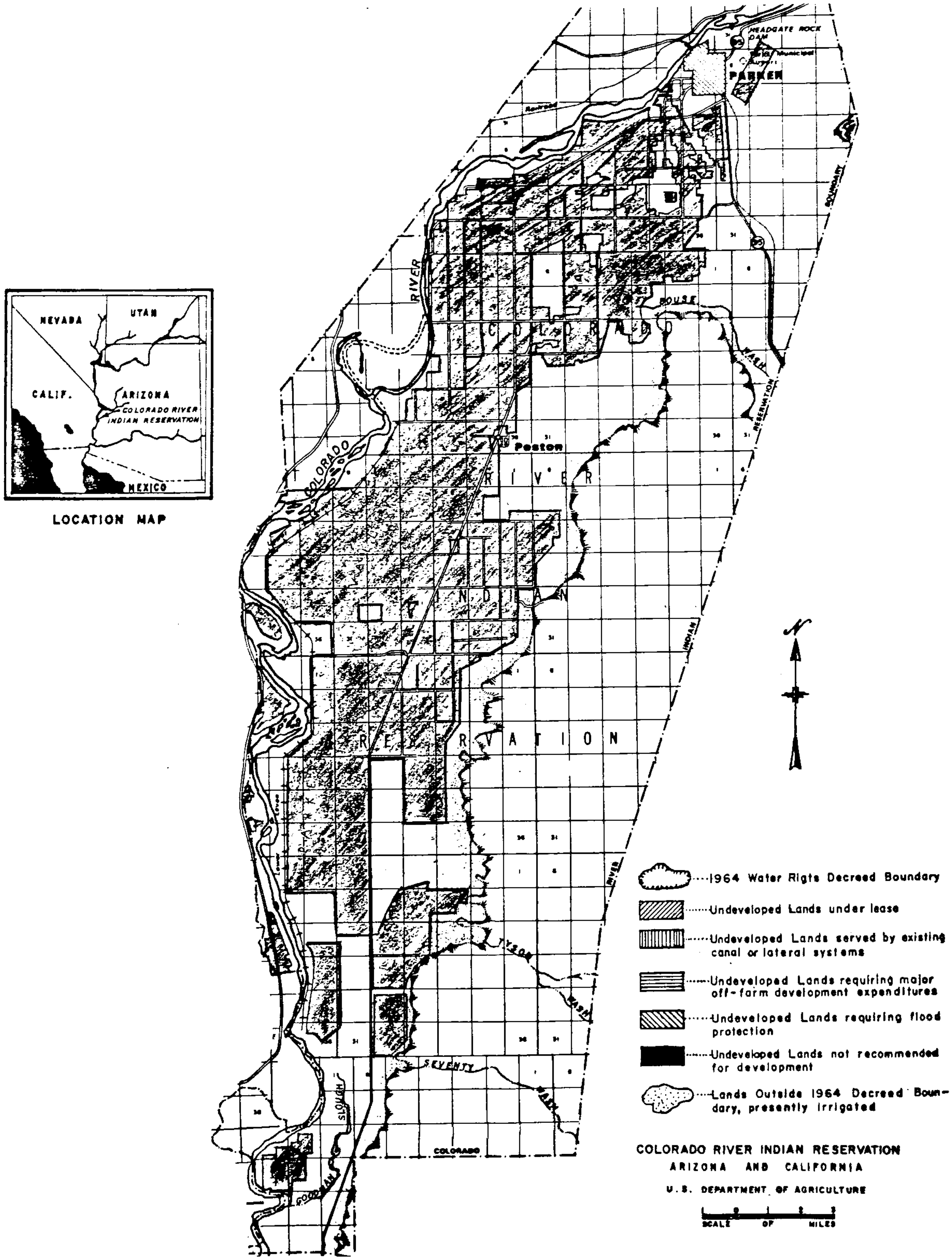

Figure 1. Existing irrigated lands, Colorado River Indian Reservation

through its Colorado River Agency at Parker, administers a broad range of assistance and advisory programs on behalf of the Tribes.

Irrigated agriculture is the single most important industry on the Reservation. Fertile desert soils, a long, frost-free growing season, a plentiful supply of irrigation water and attractive leasing terms have contributed to the expansion of the agricultural sector since the early sixties. The Tribes, however, have sought in recent years to diversify the Reservation's economic base. Retail trade, recreation, and tourism account for a significant portion of total employment among Tribal members. Local public administration is also an important source of employment. Industries such as construction, manufacturing, transportation, financial services and mining account for lesser levels of employment.[1] Propsects for continued growth in the areas of recreation, tourism and light industry are considered promising.

Overview of Irrigated Agriculture on the CRIR

Acreage Base

In 1981, there were an estimated 77,272 acres of irrigated cropland on the Reservation. Approximately 72,630 acres of cropland are located on the historical floodplain of the Colorado River within Arizona, termed the Arizona valley lands. Of the remaining irrigated acres, 1,400 acres are located on the Arizona mesa lands to the northeast while 3,242 acres are located west of the Colorado River in the California portion of the Reservation. In addition to existing

1. Source: "Parker, Arizona: Economic Base Analysis Resource Paper," Arizona Office of Economic Planning, Development and Community Affairs.

developed acres, there are roughly 30,000 acres of undeveloped land with cropland potential which are under consideration for future development (Table 1).

Irrigation Water Supply

The Colorado River is the primary source of water for irrigation. Under a 1964 Supreme Court Decree, the Colorado River Indian Tribes were granted an annual entitlement of 717,148 acre-feet of surface water from the Colorado River for irrigation purposes. The water entitlement provides for a per-acre application of 6.5 acre-feet of water over an estimated 107,585 acres cited as irrigable under the Decree. Pumped groundwater is used to service irrigated acreage on the higher mesa lands as well as on small portions of acreage in the valley.

Crops Produced

A variety of crops are produced on the Reservation. Cotton and alfalfa are the most important crops, accounting for roughly eighty percent of total cropped acreage in recent years. Small grains such as wheat and barley have accounted for about ten percent of total cropped acreage. The remaining acreage is generally planted to a mix of high valued specialty crops including lettuce and melons.

On-Farm Irrigation Systems

On-farm irrigation systems on the Reservation include surface irrigation and sprinkler systems. Surface irrigation systems are used on the large majority of irrigated acres. With surface systems, water

Table 1. Existing Developed Acres and New Land Acres by Sub-Area, CRIR, 1981

Sub-Area	Developed Acres	New Land Acres	Developed Plus New Land
Arizona Valley	72,630	17,288	89,918
Arizona Mesa	1,400	6,300	7,700
California Valley	3,242	5,237	8,479
Total	77,272	28,825	106,097

Source: Soil Conservation Service, Parker, Arizona.

is distributed over the field by means of gravity through a system of furrows or borders. Furrow irrigation is commonly used for cultivated row crops such as cotton, sorghum and vegetables. Furrows are typically spaced from 30 to 40 inches apart and are normally six to eight inches in depth. The border method is commonly used for the irrigation of close-growing field crops such as alfalfa, small grains and pasture. Borders may be spaced from 50 to 100 feet apart to form basins. Where field slope is steep and/or non-uniform, a system of 'corrugations' or shallow, more closely spaced furrows may be used in lieu of borders.

Surface systems have been classified as level basin, uniform sloped and rough sloped systems based on the gradient of the field. Rough slope fields are those which slope in at least two directions (sidefall and endfall). Slope in the direction of water flow tends to be substantial, i.e., exceeding 0.5% (one-half foot in one-hundred feet). The grade is often uneven, with high and low spots. Uniform slope fields are those which slope in one direction (endfall) only. Slope may vary from as low as 0.05% to greater than 1.0%. The grade is uniformly smooth. Level basin fields are those with zero slope or slope not to exceed 0.05%. The grade is uniformly smooth. Level basin systems are considered to have the highest yield and water use potentials of on-farm systems on the Reservation; rough sloped systems have the lowest yield and water use potentials.

The length of water run refers to the length of the field in the direction of the flow of water across the field. Water runs are expressed in feet and represent the (unadjusted) distance from the field irrigation ditch to the farm road or field edge on the opposite side.

Water run lengths are normally designed to provide for an even distribution of water across the field, based on the water intake rate of the soil and the slope of the field. Typical water run lengths for surface irrigation systems on the Reservation are 1,320 feet (one-quarter mile) and 660 feet (one-eighth mile). Runs of 1,320 feet are generally recommended for fine and medium soils with low water intake rates; runs of 660 feet are recommended for coarse (sandy) soils with higher intake rates.

Water is delivered from the farm gate to the field through a network of on-farm ditches. Approximately 1.25 miles of on-farm ditch are required to serve 160 acres with fields of 1,320 runs; approximately 2.25 miles of ditch are required to serve 160 acres with fields of 660 runs. On-farm ditches may be lined or unlined. Where soils are relatively heavy, unlined ditches may function reasonably well. With most improved systems, ditches are generally lined with concrete or some other substance reasonably impervious to water.

Sprinkler irrigation systems on the Reservation are limited to irrigated acreage on the mesa and small portions of low lying valley lands. Sprinkler systems are best suited to coarse soils with high water intake rates on rolling terrain not suited to surface systems. The most predominant type of sprinkler in use on the Reservation is the sideroll system, although several center pivot systems are currently in operation. Crops typically grown under sprinkler systems include alfalfa and small grains.

Off-Farm Irrigation Delivery System

Water diverted from the Colorado River for irrigation use is delivered to the farms through a network of off-farm canals, laterals and pumping stations, termed the 'off-farm delivery system.' The off-farm delivery system is constructed, maintained and managed by the Bureau of Indian Affairs (BIA) on behalf of the Colorado River Indian Tribes.

Prices for irrigation water are set by the Bureau of Indian Affairs. Prices are fixed such that total revenues from water delivered cover operation and maintenance costs of the off-farm delivery system. The price per acre-foot (AF) of water in 1981 was two-tiered: $3.20/AF for the first five acre-feet applied per acre, and $5.50/AF for each additional acre-foot.

Agricultural Leasing

Before the late fifties, relatively little agricultural leasing was practiced on the CRIR. Interest in leasing increased, however, over the following years. The development of a tribal agricultural leasing policy had two objectives:

1. Promote the development of Reservation lands by outsiders with capital and technical expertise in irrigated agriculture.
2. Enable the Tribe and private landholders on the Reservation to earn a greater return from their land resource than they could by farming it themselves.

Despite the growing demand for leased agricultural land, rapid expansion of irrigated acreage on the CRIR did not occur until the mid-sixties due to uncertainties involving Tribal water rights. With the 1964 Supreme Court Decree, which fixed the Tribes' Colorado River water entitlement, the way was open for the development of new lands under long term lease agreements. Several large development leases were contracted, resulting in an accelerated expansion of irrigated acreage.

The large majority of cropped acreage on the CRIR is currently farmed under lease agreement with the Tribe or private tribal landholders. Agricultural lands are leased by Indian tribal members, non-Indian farmers and larger corporate farms - including the Tribes' own corporate entity, the Colorado River Indian Tribes (CRIT) Farms. In 1980, there were 34 Indian-operated farms of more than forty acres on the Reservation. Indian operated farms - including CRIT Farms - accounted for 16,793 acres of irrigated farmland or 22% of total cropland acreage. Non-Indian leases, including individual operators and corporate farms, accounted for 59,446 acres or 78% of total cropland acreage.

There are essentially three types of agricultural leases for cropland on the Reservation. These include 1) short term leases, 2) mid-term improvement leases, and 3) long term development leases. Short term leases typically extend over a five year period and are designed for developed lands in which no major capital improvements are required of the lessee. Mid-term improvement leases generally extend over a ten year period. Such leases are structured for lands which have already been developed and farmed but which require further capital improvements of the lessee in order to meet current Soil Conservation Service (SCS) standards for high efficiency systems. Long term development leases generally extend over twenty-five years. Long term development leases are designed for lands which have not previously been developed and which require extensive capital outlays.

Land rents are generally determined through a public bidding process. Typical land rents for improved irrigation systems under short term lease range from about $150.00 to over $200.00/acre/year. Reduced rents are accepted by the Tribe for acreage under mid-term improvement leases and long-term development leases in return for system improvements installed by the lessee. Under a typical development lease for new land, rent may be $10.00/acre/year over the first five years, with increases of $5.00/acre/year for each subsequent five year period.

The Problem

Although 75,000 acres of cropland were under production in 1981, high levels of productivity and water-use efficiency were achieved on only a small portion of cropland irrigated. The majority of on-farm physical irrigation systems on the Reservation are considered to have low yield and water use efficiency potentials. Moreover, levels of on-farm irrigation water management (IWM) on the CRIR are considered poor relative to other irrigated areas of the state. Yield and water use efficiency potentials of existing physical systems are often not achieved due to low levels of on-farm water management.

The off-farm delivery system on the Reservation is presently operated at a relatively low level of efficiency. Limited capacity of the existing canal system and generally low levels of off-farm system management result in delays in irrigation delivery and insufficient or fluctuating heads of water delivered in certain areas of the Reservation. System management potentials at the farm level are consequently limited by problems of the off-farm delivery system. In addition, water losses resulting from regulatory 'spills' and seepage through unlined canals are substantial.

Low levels of irrigation system development on existing irrigated lands present two problems for the Tribe. The first problem involves yield levels and input use on existing on-farm irrigation systems. With sloping irrigation fields and low levels of water management, it is relatively difficult to ensure an even distribution of water across the field. Non-uniform penetration of water through the crop root zone results in reduced crop yields and relatively high requirements for water, fertilizer, herbicides, and irrigation labor. Low yields and higher production costs may reduce net incomes of farm operators. Rental earnings of tribal landholders are also reduced.

The second problem involves irrigation system efficiencies on existing developed lands, and water availability for new land development. The tribal entitlement of water for agricultural use currently exceeds the water use requirements of existing irrigation systems on the Reservation. However, an additional 30,000 acres of potential cropland are under review for development on the Arizona portion of the Reservation. It is estimated that with projected increases in system efficiencies through 2010, there would be sufficient water available to irrigate only 12,400 additional acres.[1] A more significant expansion of irrigated acreage on the Reservation will depend on efforts to improve system efficiencies of both on-farm irrigation systems and the off-farm delivery system.

Opportunities for Irrigation System Development

Various types of irrigation system improvements may be implemented to improve crop yields and water use efficiency on existing irrigated lands. Improvements in on-farm irrigation systems include improved water management, land leveling and soil swapping, ditchlining, field reorganization and ditch construction, and measuring structures. Improvements in the off-farm delivery system include improved system management, canal widening and lining, turnouts with measuring structures, check gates and measuring devices.

Irrigation water management, or IWM, refers to the management of irrigation applications according to the water use needs of the crop. A high level of on-farm irrigation water management requires 1) that soil moisture is measured throughout the crop season, 2) that irrigation applications are scheduled according to crop needs, and 3) that irrigation applications are measured to ensure that crop needs are met. High

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1. Projected increases in system efficiencies were based on ongoing levels of federal assistance, i.e. on-farm technical assistance (SCS), cost-sharing for on-farm physical system improvements, and financing of off-farm structural improvements (BIA).

Irrigation requirements for new lands were based on the assumption that highest efficiency systems (possible) are installed and appropriate levels of water management are practiced.

levels of water management are necessary to achieve yield and water use potentials associated with a given physical irrigation system. High levels of water management may also result in reduced fertilizer losses due to deep percolation, reduced weed control problems and reduced irrigation labor costs. Investments in on-farm irrigation water management include training (and maintaining) of qualified on-farm irrigation personnel, installation of on-farm water measuring structures and investments in related equipment such as soil moisture measuring devices.

Land leveling to reduce field slope is proposed for a majority of fields on the Reservation. Level basin systems with appropriate water run length and ditch carrying capacity are considered to have greater management potentials than irrigation systems with field slope. More uniform water penetration throughout the crop root zone contributes to increased crop yields and reduces water losses due to seepage below the root zone. Under proper management, water losses due to run-off at the end of the field are eliminated. Reduced irrigation flow time due to larger heads of water applied under level basin systems may reduce irrigation labor requirements.

Adjustments in field length are proposed for existing sloping systems of 1,320 foot water runs on coarse soils. Adjustments involve the reduction in water runs from 1,320 feet to 660 feet, and the reorganization of the existing on-farm ditch system. With reduced water runoff lengths on coarse soils, water may be distributed more uniformly through the crop root zone over the entire length of the field. Water losses due to deep percolation at the head of the field are minimized.

Soil swapping may be recommended on selected irrigation fields with mixed soils. Soil swapping refers to the removal and exchange of soils within a field in order to obtain uniform soil/water intake rates across the field. Uniform soil/water intake rates enhance management potentials of the on-farm irrigation system. Soil swapping is normally recommended to remove pockets of sandy soil from fields of predominantly fine or medium soils. Soil swapping is generally undertaken in connection with other operations such as land leveling and field reorganization.

The lining of on-farm ditches is proposed for a large portion of irrigated acres served by unlined ditches. Ditch lining is generally undertaken in connection with other on-farm physical system improvements such as land leveling and field reorganization. The lining of on-farm ditches reduces water losses due to seepage through ditch walls, particularly on coarse sandy soils. Lining of ditches also minimizes ditch maintenance problems resulting from weed buildup, rodent burrowing and collapsing. Lined ditches help to ensure a dependable flow of water which is essential for high levels of on-farm irrigation water management. Lined ditches may also result in increased acreage planted as farm equipment may be operated closer to ditch banks with less risk of ditch damage.

Improvements in the off-farm delivery system may improve both yields and water use efficiency at the farm level by removing limitations to on-farm irrigation management. The widening of selected laterals is needed to increase the water carrying capacity of the existing off-farm delivery system. Increased carrying capacities would permit improved irrigation scheduling as well as greater heads of water required to serve projected increases in level basin systems. Measuring flumes and check gates are needed to more effectively regulate water flows through the canal/lateral system. Portable measuring devices at the farm gate are required to assess on-farm water use and water charges more accurately. In addition, increased and better qualified system personnel (i.e., managers, ditch riders) and automated delivery systems may be required to ensure an adequate and timely supply of irrigation water for users of the system.

Improvements in the off-farm delivery system may also result in reductions in off-farm water losses. The lining of selected canals and laterals would reduce water losses due to seepage. Increased regulation of water flows through the canal and lateral system with improved levels of system management may result in reduced losses to regulatory waste, or water 'spills'.

Research Objective

The main objective of this research is to identify the optimal level of irrigation development on the Colorado River Indian Reservation. Irrigation development includes management and physical system improvements on existing developed lands as well as system development on new lands. The optimal level of irrigation development is defined by that set of improved practices, improved physical systems, and new land development which maximizes total annual net returns to agriculture.[1]

In order to achieve the main objective, the following specific objectives were defined:

1. Identify a set of resource treatment alternatives (RTA) used in classifying existing (and potential) irrigation systems on the Reservation.
2. Develop data on yield, production inputs, costs and returns by crop, soil, land treatment and level of management.
3. Develop costs associated with categories of on-farm and off-farm irrigation improvements on existing developed land and new lands.
4. Formulate and conduct a linear programming analysis to evaluate net returns and resource use for irrigation development alternatives evaluated.

Selection of an optimal level of irrigation development on the Reservation is based on a 'time-static' analysis; that is, implementation rates of irrigation improvements are not considered in assessing costs and benefits. The optimal level of irrigation development, as defined here, serves as the basis for Implementation Plans evaluated in a subsequent phase of the CRIR economic analysis. Implementation Plans

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1. Criterion for the selection of a recommended level of system development, i.e., maximization of total net returns to agriculture, is consistent with guidelines set forth in 'Principles and Guidelines for USDA River Basin Studies.' It is assumed that tribal interests are served by this selection criterion through returns to Indian operated farms and rental payments on acreage farmed under lease.

reflect implementation rates of recommended improvements over time under alternate levels of federal assistance available. Federal assistance programs which may influence the implementation of irrigation improvements include on-farm technical assistance, federal cost-sharing for on-farm physical improvements, and federal financing of off-farm structural improvements. Other factors such as land leasing and water policy are also to be addressed.[1]

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1. A discussion of Implementation Plans evaluated in the CRIR study is included in a report document entitled 'An Analysis of the Benefits and Costs of Selected Irrigation Technologies-Colorado River Indian Reservation,' ERS, Tucson.

CHAPTER 2

METHODS AND DATA

The Linear Programming System

Linear programming (LP) is an analytical tool useful in solving resource allocation problems. A series of linear programming models have been developed by the Economic Research Service (ERS) for use in the CRIR economic analysis. The CRIR linear programming models were designed to measure the impact of alternate levels of irrigation system development on net returns and resource use, subject to assumptions on resource availability, production requirements by system, and expected returns.

The MINOS linear programming solver, developed at Stanford University, was used in the CRIR study. Implementation of the CRIR linear programming analysis was accomplished through a series of programs designed to operate on the Control Data Corporation CYBER 170 series computer at Oregon State University, Corvallis, Oregon (ERS, Western Regional Office). Matrix generator programs were developed to create (LP) model matricies compatible with MINOS from files of data prepared. Accompanying these matrix generator programs are interactive job control generator programs which enabled the researcher to generate LP models, solve for their solutions, and store their solutions for later analysis. A report writer program and accompanying job control generator program were also developed for use in the study. The report writer program generates information on costs and returns, production levels and resource use levels from selected LP solutions. This information is displayed in a report format which permits comparisons among multiple model solutions.

The CRIR Data Base

The data base for the CRIR linear programming analysis was developed jointly by the Economic Research Service and the Soil Conservation Service (SCS). The data base draws on information provided by various governmental agencies involved with the agricultural sector on the Reservation. Additional information was obtained through direct interviews with local farmers and farm suppliers. Recorded data were used as available. Where recorded data were not available, values were based on judgement estimates by SCS technicians involved in irrigated agriculture on the Reservation.[1]

Resource Treatment Applied

The Resource Treatment Applied, or RTA, refers to the existing physical irrigation system and existing level of irrigation water management for a given field. On-farm irrigation systems were classed according to RTA in order to assist study participants in estimating production inputs, yields and cost and returns by irrigation system.

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1. Data and data assumptions are detailed in a report document entitled 'An Analysis of the Benefits and Costs of Selected Irrigation Technologies--Colorado River Indian Reservaiton,' ERS, Tucson. Selected data tables are included in this thesis.

Sixteen RTA's were defined for use in the study. RTA's 1 through 14 represent acreage developed in surface systems. The RTA designation for surface systems indicates the gradient or slope of the field, the condition of on-farm ditches, the length of water runs, the need for on-farm pumping, and the level of irrigation water management practiced. RTA's 15 and 16 represent acreage in sprinkler systems under alternate levels of irrigation water management practiced (Table 2).

New Lands

New lands refer to undeveloped acres in the base year (1981) which have potential for irrigation development. New land parcels evaluated in the LP analysis were based on recommendations by the Soil Conservation Service. Most of the new land parcels evaluated were among those cited as irrigable under the 1964 Supreme Court Decree, and therefore qualified for a water entitlement under the original allocation. Selected parcels cited as irrigable under the Decree were excluded from the LP analysis, due to one or more of the following reasons: (1) the land is considered prime wildlife habitat and is recommended for nondevelopment; (2) the land is assumed to have a higher potential value in nonagricultural uses (i.e., commercial/residential); (3) the land has since been developed in nonagricultural uses; (4) the land is not recommended for irrigated agriculture due to high costs of flood protection. Selected parcels without water entitlement were included in the analysis due to their likelihood of development based on high cropland potential, moderate development cost and/or existing lease arrangements. It was

Table 2. RTA Components by Resource Treatment Applied

Irrigation System Type	RTA	RTA Components[a]				
		Gradient	Ditches	Water Run (feet)	IWM	Pumping
Flood w/o Pumping	1	RS	UL	1,320	UM	--
	2	US	UL	1,320	UM	--
	3	US	L	1,320	UM	--
	4	US	L	660	UM	--
	5	US	L	1,320	M	--
	6	US	L	660	M	--
	7	LB	L	1,320	UM	--
	8	LB	L	660	UM	--
	9	LB	L	1,320	M	--
	10	LB	L	660	M	--
Flood w/ Pumping	11	LB	L	1,320	UM	P
	12	LB	L	660	UM	P
	13	LB	L	1,320	M	P
	14	LB	L	660	M	P
Sprinkler	15	RS	--	--	UM	P
	16	RS	--	--	M	P

[a]Symbols, RTA Components = RS - Rough Slope
US - Uniform Slope
LB - Level Basin
UM - Unmanaged
M - Managed
UL - Unlined
L - Lined
P - Pumping
-- - Not Applicable

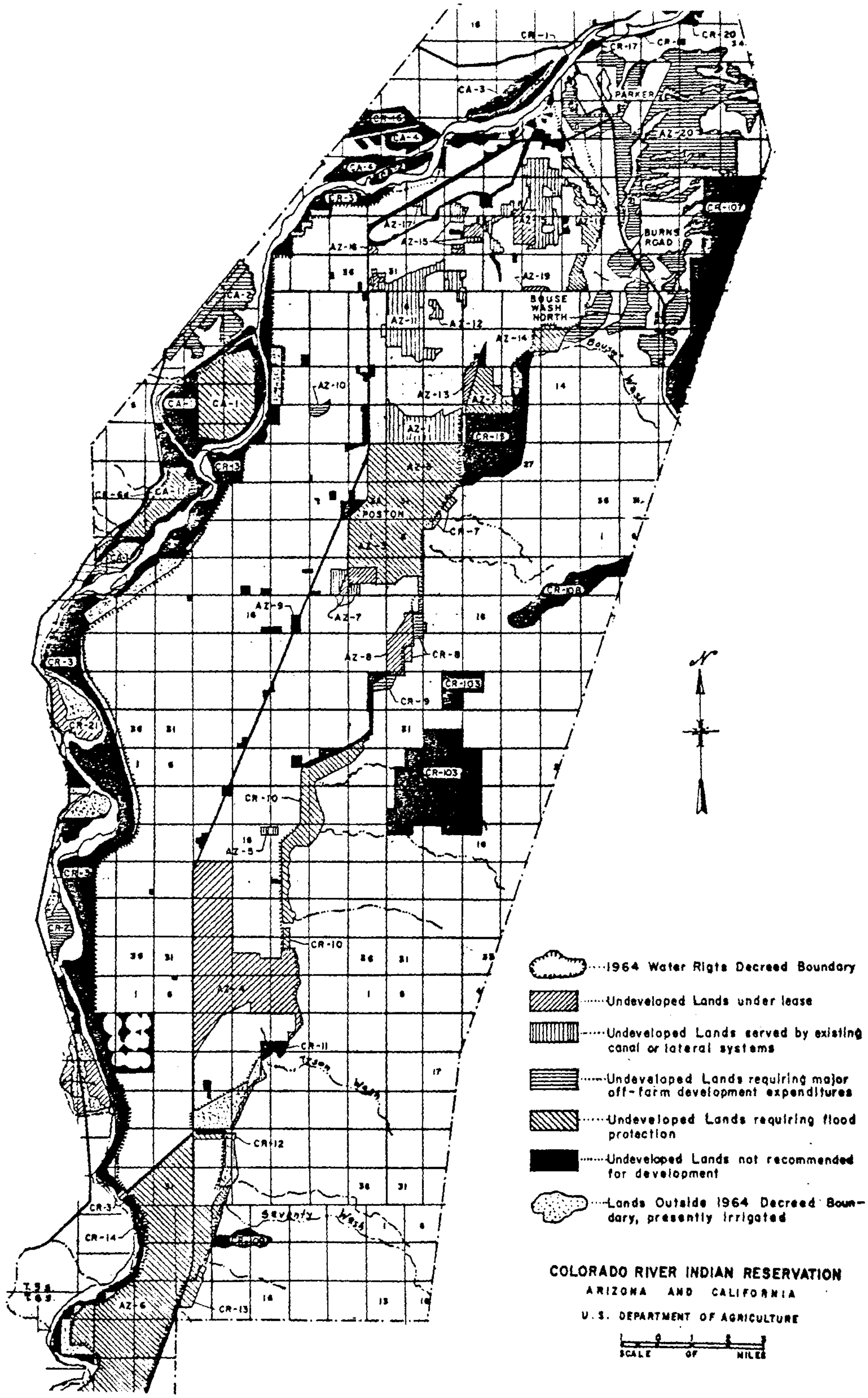

Figure 2. Undeveloped lands with irrigation potential, Colorado River Indian Reservation

assumed that entitlement water may be used on parcels not cited in the Decree, as long as total diversion does not exceed total entitlement (Figure 2).

Soil Categories

For study purposes, soils on the Reservation were classified as fine, medium or coarse according to their water intake rate. Water intake rate refers to the rate at which water passes through the soil, expressed in inches per hour. Water intake rate categories were defined as follows:

fine soil (S1) - less than 0.3 inches per hour

medium soil (S2) - from 0.3 to 0.7 inches per hour

coarse soil (S3) - greater than 0.7 inches per hour

Crops and Crop Sequences

Crops evaluated in the study include cotton, alfalfa, small grain, lettuce and melon. Selection of crops was based on total acreage and/or total production value by crop in 1981.

Crop sequences evaluated in the study represent typical multi-year crop rotations observed on the Reservation. Crop sequences were defined by SCS technicians familiar with cropping patterns on the Reservation (Table 3).

Acreage

Acres were estimated by on-farm irrigation system (RTA) and soil to reflect existing and future levels of irrigation development. Acres by soil were based on a soil survey of existing and potential croplands.

Table 3. Crop Sequence Categories

1. Continuous Cotton
   (10 year cotton limit, followed by five year alfalfa stand)

2. Continuous alfalfa

3. 3 years alfalfa, 2 years Cotton

4. 3 years cotton, 2 years small grain single-cropped
   (5 year rotation--cotton, SG, cotton, SG, cotton)

5. 1 year lettuce/small grain double crop

6. 1 year melon/small grain double crop

7. 4 years alfalfa, 1 year small grain double cropped
   (sprinkler systems)

Acres by RTA/soil were based on SCS field records and judgment estimates of SCS technicians familiar with field conditions on the Reservation (Table 4). Acres of potential new land development were based on SCS on-site evaluations and records provided by the Bureau of Indian Affairs (BIA).

Acres were estimated by crop and crop sequence to reflect cropping patterns under existing conditions. Acres by crop reflect average crop acres for years 1977-1981 based on BIA Annual Crop reports. Acres by crop sequence were based on judgment estimates of SCS technicians familiar with cropping practices on the Reservation.[1]

Crop Budgets

Crop budgets were developed by crop evaluated in the study. Budgets for cotton, alfalfa (alfalfa hay and stand establishment) and small grain (wheat) were generated on the Arizona Crop Budgeting System, developed by the Cooperative Extension Service, University of Arizona. Budgets for the specialty crops, lettuce and melon, were generated on the FEDS Budgeting System developed by the Economic Research Service, USDA. Field operations, material input levels and yield levels specified in the initial crop budgets reflect production on high efficiency irrigation systems (RTA 10, medium textured soil) for a mid-sized 800-acre farm in 1981. Initial crop budgets serve as the 'base budgets' from which revisions were made to reflect production under alternate field conditions evaluated.

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1. Acres by crop and crop sequence are displayed for the base year in Chapter 4, Table 18.

Table 4. Irrigated Acreage by RTA and Soil[a]

RTA COMPONENTS	RTA NUMBER[b]																Totals
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Flood Sprinkler	F	F	F	F	F	F	F	F	F	F	F	F	F	F	S	S	
Type Slope	RS	US	US	US	US	US	LB	LB	LB	LB	LB	LB	LB	LB	RS	RS	
Water Mgmt.	UM	UM	UM	UM	M	M	UM	UM	M	M	UM	UM	M	M	UM	M	
Ditch Type	UL	UL	L	L	L	L	L	L	L	L	L	L	L	L			
Run length	1,320	1,320	1,320	660	1,320	660	1,320	660	1,320	660	1,320	660	1,320	660			
Pumping											P	P	P	P			
ACRES BY RTA/SOIL	6,537	23,242	12,347	10,168	3,632	4,358	3,632	2,905	1,451	1,453	726	726	145	218	872	218	72,630
Fine	2,905	10,168	5,810	1,453	1,816	726	2,179	363	726	364	581	0	73	0	0	0	27,164
Medium	1,453	4,358	4,358	1,452	1,816	1,453	1,453	363	725	363	145	0	72	0	218	73	18,302
Coarse	2,179	8,716	2,179	7,263	0	2,179	0	2,179	0	726	0	726	0	218	654	145	27,164
PERCENT BY RTA/SOIL	9.0	32.0	17.0	14.0	5.0	6.0	5.0	4.0	2.0	2.0	1.0	1.0	0.2	0.3	1.2	0.3	100.0
Fine	4.0	14.0	8.0	2.0	2.5	1.0	3.0	0.5	1.0	0.5	0.8	0.0	0.1	0.0	0.0	0.0	37.4
Medium	2.0	6.0	6.0	2.0	2.5	2.0	2.0	0.5	1.0	0.5	0.2	0.0	0.1	0.0	0.3	0.1	25.2
Coarse	3.0	12.0	3.0	10.0	0.0	3.0	0.0	3.0	0.0	1.0	0.0	1.0	0.0	0.3	0.9	0.2	37.4

[a]Acreage shown includes 72,630 acres of existing developed lands in the Arizona valley portion of the Reservation, 1981.

[b]For a listing of symbols associated with RTA components, refer to Table 2.

Cost and returns computed for the base crop budgets were adjusted in a two-phase process to reflect a range of field conditions on the Reservation. In phase one, production inputs and yield levels were modified by RTA/soil to reflect alternate physical irrigation systems, levels of water management and soil categories evaluated. Production input levels adjusted by RTA/soil involve water use, fertilizer use, irrigation labor machine operations and harvest operations.

In phase two, production inputs and yield levels by crop/RTA/soil were adjusted by crop sequence and lease scenario. Crop sequences were defined to reflect the effect of alternate rotations on yield levels and production inputs. Yields, production inputs and cropping patterns by crop sequence were further modified to reflect differences under extended-term land development leases.

The ANR Program

Adjustments to costs and returns in the base crop budgets were computed by means of the Annualized Net Return program, or ANR program. The ANR program was written in FORTRAN 5 for use on the DEC-10 Computer System, The University of Arizona. The ANR program was used in computing returns above variable cost by crop/RTA/soil (Table 5). The ANR program was also used in computing annualized returns above variable cost by RTA/soil for multi-year crop sequences defined. Annualized net returns represent a weighted average of net returns for multi-year cropping sequence, expressed on an annual basis (Table 6). A modified version of the ANR program was used in computing annualized fixed machine costs and annualized land rent.

Table 5. Gross Returns, Total Variable Cost and Returns over Total Variable Cost by Crop, RTA and Soil,[a/b]

RTA COMPONENTS		RTA NUMBER[c] 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Flood/Sprinkler		F	F	F	F	F	F	F	F	F	F	F	F	F	F	S	S
Type Slope		RS	US	US	US	US	US	LB	LB	LB	LB	LB	LB	LB	LB	RS	RS
Water Management		UM	UM	UM	UM	M	M	UM	UM	M	M	UM	UM	M	M	UM	M
Ditch Type		UL	UL	L	L	L	L	L	L	L	L	L	L	L	L		
Run length		1,320	1,320	1,320	660	1,320	660	1,320	660	1,320	660	1,320	660	1,320	660		
Pumping												P	P	P	P		
COTTON																	
Fine	GR	804	956	956	956	1,015	1,015	1,112	1,112	1,421	1,421	1,112	---	1,421	---	---	---
	TVC	610	618	610	610	616	616	599	595	646	646	602	---	647	---	---	---
	NR	194	338	346	346	399	399	514	518	775	775	511	---	773	---	---	---
Medium	GR	804	956	956	956	1,049	1,049	1,176	1,174	1,421	1,421	1,176	---	1,421	---	---	---
	TVC	610	618	610	610	623	623	611	607	652	646	614	---	653	---	---	---
	NR	194	338	346	346	426	426	565	567	769	775	562	---	767	---	---	---
Coarse	GR	761	829	829	863	---	956	---	1,015	---	1,222	---	1,015	---	1,222	---	---
	TVC	617	609	598	591	---	599	---	580	---	608	---	583	---	610	---	---
	NR	145	220	231	272	---	357	---	435	---	613	---	432	---	611	---	---
ALFALFA[d]																	
Fine	GR	541	631	631	694	844	844	928	928	1,081	1,081	928	---	1,081	---	---	---
	TVC	252	237	229	236	249	249	242	238	246	246	246	---	249	---	---	---
	NR	289	393	402	458	562	562	686	690	835	835	682	---	832	---	---	---
	ANR, Stand	188	286	295	348	446	446	563	567	702	702	559	---	699	---	---	---
Medium	GR	613	721	721	766	811	811	928	928	1,081	1,081	928	---	1,081	---	676	901
	TVC	256	247	239	244	249	249	242	238	253	246	246	---	256	---	296	309
	NR	357	473	482	522	562	562	686	690	828	835	682	---	824	---	380	592
	ANR, Stand	251	362	371	409	446	446	563	567	696	702	559	---	692	---	305	501
Coarse	GR	613	694	694	694	---	730	---	811	---	901	---	811	---	901	676	901
	TVC	273	263	252	236	---	240	---	236	---	233	---	241	---	245	296	309
	NR	340	431	442	458	---	490	---	575	---	668	---	570	---	656	380	592
	ANR, Stand	234	321	332	348	---	378	---	459	---	547	---	454	---	543	305	501
SM.GRAIN																	
Fine	GR	281	311	311	311	370	370	400	400	474	474	400	---	474	---	---	---
	TVC	191	187	179	179	186	186	182	180	183	183	184	---	184	---	---	---
	NR	90	124	132	132	184	184	218	220	290	290	216	---	290	---	---	---
Medium	GR	281	326	326	326	370	370	400	400	474	474	400	---	474	---	296	370
	TVC	191	180	181	181	186	186	182	180	188	183	184	---	190	---	214	218
	NR	90	136	145	145	184	184	218	220	286	290	216	---	284	---	82	152
Coarse	GR	207	237	237	266	---	340	---	340	---	400	---	340	---	400	296	370
	TVC	184	183	173	174	---	181	---	172	---	177	---	174	---	178	214	218
	NR	23	53	64	92	---	159	---	168	---	222	---	166	---	222	82	152
LETTUCE																	
Fine and Medium	GR	---	---	2,556	2,556	---	---	2,752	2,752	2,752	2,752	2,752	---	2,752	---	---	---
	TVC	---	---	1,841	1,841	---	---	1,941	1,940	1,935	1,935	1,942	---	1,936	---	---	---
	NR	---	---	714	714	---	---	812	813	817	818	811	---	816	---	---	---
MELON																	
Fine and Medium	GR	---	---	2,187	2,187	---	---	2,499	2,499	2,499	2,499	2,499	---	2,499	---	---	---
	TVC	---	---	1,459	1,459	---	---	1,606	1,605	1,597	1,597	1,608	---	1,598	---	---	---
	NR	---	---	728	728	---	---	893	894	902	902	891	---	901	---	---	---

Table 5, Continued.

[a]Gross Return (GR) were based on estimated yields by RTA/soil and 1982 normalized crop prices. Total Variable Cost (TVC) were based on estimated production inputs by crop/RTA/soil and 1982 input prices. Net Returns (NR) represents Gross Returns over Total Variable Cost.

[b]The symbol (--) indicates that total acreage for a given crop/ RTA/ soil was negligible.

[c]For a listing of symbols associated with RTA components, refer to Table 2.

[d]Gross Return, Total Variable Cost and Net Return estimates were based on a single year of Alfalfa hay. Annualized net returns (ANR) were estimated for a three year alfalfa stand in which annual alfalfa yields are .85, 1.05 and .95 of base yields estimated by RTA/soil. Stand establishment cost was $180.00 for surface systems and $132.00 for sprinkler systems. Annual net returns were discounted at 8.125% over the life of the stand.

Table 6. Computation of Annualized Net Returns[a]

$$ANR = \frac{\sum_{y=1}^{Y} \frac{GRy - TCy}{(1 + r)^y}}{\sum_{y=1}^{Y} \frac{1}{(1 + r)^y}}$$

where ANR = Annualized returns over variable cost[b]

Y = Number of years in planning period (25 years)[c]

y = Specific year within planning period Y

GRy = Gross returns in year y

TCy = Total variable costs in year y

r = Discount rate (8.125%)[d]

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[a]Source: Alpin, Richard D.

[b]Annualized fixed production costs-land rent, machine ownership-were added to annualized return over variable cost (computed separately) in estimating annualized returns over total cost.

[c]Crop sequences were defined over a twenty-five year planning period, corresponding to the duration of a standard long term development lease.

[d]The discount rate was fixed at 8.125%, i.e., discount rate published for use in federal water resource development projects - Principles and Guidelines, 1983.

Product Prices

Product prices for cotton, alfalfa hay, and wheat were based on 1982 normalized prices published by ERS, USDA. Normalized prices represent a five-year weighted average of annual prices by crop. Product prices for lettuce and cantaloupe were based on procedures set forth by ERS for computing price levels on crops for which normalized prices were not available[1] (Table 7).

Crop Yield

Crop yields were estimated to reflect alternate field conditions and levels of management practiced. Yield by crop, RTA/soil and crop sequence were based on information obtained from farmers' records, records on impacts of applied conservation practices, detailed field observations, and judgement estimates of SCS technicians. Other data sources such as Arizona Stabilization and Conservation Service (ASCS) records, BIA Annual Crop Reports and cotton gin records were also utilized.

Yields differences by irrigation system reflect the difficulty in maintaining correct moisture levels throughout the crop's root zone over the cropping season. The efficiency with which moisture is maintained in the root zone is determined by the physical irrigation system and the level of management of that system. The maintenance of a high quality soil base is needed to provide sufficient organic matter for plant growth and good tilth for water movement and aeration. The proper

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1. Agricultural Price Standards, Fiscal Year 1983, Reference Handbook, U.S. Water Resources Council.

Table 7. Normalized Crop Prices

Cotton	$ .846/ lb.[a]	
Cotton Lint	- $ .747/ lb.	
Cotton Seed	- $122.33 / ton	
Alfalfa Hay	- $ 90.11 / ton	
Small Grain	- $148.00 / ton	
Lettuce	- $ 9.83 / cwt.[b]	
Melon	- $ 15.62 / cwt.[c]	

[a]Price level given above for cotton represents an aggregate price for cotton lint and cotton seed. It was assumed that for every pound of cotton lint there are 1.652 pounds of cotton seed (based on ratio of lint to seed - Cotton Budget, 1982 Arizona Field Crop Budgets, Yuma County.) The value of 1.652 lbs. cottonseed equals $.099; .747 + .099 = .846.

[b]Product price given for lettuce is based on a three-year average of price levels for 'Yuma' lettuce, 1979-81. Annual prices were obtained from the Statistical Reporting Service, USDA.

[c]Product price given for melon is based on a three-year average of price levels for cantaloupe, 1979-81. Annual prices were obtained from the Statistical Reporting Service, USDA.

application of chemical inputs (i.e., fertilizers, pesticides and herbicides) is also important in obtaining highest yields (Table 8).

Total Irrigation Requirement

Total Irrigation Requirement (TIR) refers to the quantity of water actually utilized by a crop over a cropping season, irrespective of system losses. Total irrigation requirement is defined as the crop's consumptive use requirement plus the crop's leaching requirement plus any special requirements, minus effective rainfall, expressed on a per acre basis.

Consumptive use refers to water consumed through transpiration and evaporation. Transpiration refers to water drawn from the soil to meet the crop consumptive requirement for tissue building as well as for transpiration of moisture through the leaves. Evaporation refers to water which evaporates from adjacent soils, water surfaces or surfaces of the plant. Consumptive use estimates for cotton, alfalfa, and small grain are based on on-site measurements conducted by SCS field personnel in 1981. Consumptive use estimates for lettuce and cantaloupe were based on figures published for crops produced in Central Arizona, Technical Release 21.

Leaching requirement refers to the amount of water necessary to pass water soluble salts through the soil profile so as to maintain the salt concentration in the root zone at an acceptable level. Estimates of leaching requirement by crop were obtained from SCS Leaching Requirement Tables based on an assumed salt concentration of 700 PPM for water applied.

Table 8. Crop Yields by RTA and Soil[a/b]

		Unit	RTA NUMBER 1	2	3	4	5	6	7[d]	8[d]	9[d]	10[d]	15	16
RTA COMPONENTS														
Flood/Sprinkler			F	F	F	F	F	F	F	F	F	F	S	S
Type Slope			RS	US	US	US	US	US	LB	LB	LB	LB	RS	RS
Water Mgmt.			UM	UM	UM	UM	M	M	UM	UM	M	M	UM	M
Ditch Type			UL	UL	L	L	L	L	L	L	L	M		
Run length			1,320	1,320	1,320	660	1,320	660	1,320	660	1,320	660		
YIELD BY RTA/SOIL														
COTTON	Fine	Lbs.	950	1,130	1,130	1,200	1,200	1,315	1,315	1,315	1,680	1,680	—	—
	Medium	"	950	1,130	1,130	1,130	1,240	1,240	1,390	1,390	1,680	1,680	—	—
	Coarse	"	900	980	980	1,020	—	1,130	—	1,200	—	1,440	—	—
ALFALFA	Fine	Ton	6.0	7.0	7.0	7.7	9.0	9.0	10.3	10.3	12.0	12.0	—	—
	Medium	"	6.8	8.0	8.0	8.5	9.0	9.0	10.3	10.3	12.0	12.0	7.5	10.0
	Coarse	"	6.8	7.7	7.7	7.7	—	8.1	—	9.0	—	10.0	7.5	10.0
SM. GRAIN	Fine	Ton	1.9	2.1	2.1	2.1	2.5	2.5	2.7	2.7	3.2	3.2	—	—
	Medium	"	1.9	2.2	2.2	2.2	2.5	2.5	2.7	2.7	3.2	3.2	2.0	2.5
	Coarse	"	1.4	1.6	1.6	1.8	—	2.3	—	2.3	—	2.7	2.0	2.5
LETTUCE	Fine	Cwt.	—	—	260	260	—	—	280	280	280	280	—	—
	Medium	"	—	—	260	260	—	—	280	280	280	280	—	—
	Coarse	"	—	—	—	—	—	—	—	—	—	—	—	—
MELONS	Fine	Cwt.	—	—	140	140	—	—	160	160	160	160	—	—
	Medium	"	—	—	140	140	—	—	160	160	160	160	—	—
	Coarse	"	—	—	—	—	—	—	—	—	—	—	—	—

[a]Crop yields shown represent 'base yields' by RTA/soil. Base yields were adjusted to reflect the impact of alternate crop rotations.

[b]The symbol (—) indicates that total acreage for a given crop/RTA/soil was negligeable.

[c]For a listing of symbols associated with RTA components, refer to Table 2.

[d]Yields for RTA 11 through 14 are identical to those shown for RTA 7 through 10 respectively.

Special water requirements are included for lettuce for the purpose of germination, cooling and quality control. Special requirements were estimated by SCS field staff, Parker, Arizona.

Effective rainfall refers to rainfall which contributes towards meeting a crop's water use requirements. Effective rainfall by crop, soil, and slope was estimated by SCS field staff, Parker, Arizona.

On-Farm Water Use Efficiency

On-farm water use efficiency refers to the efficiency with which water is applied to the field to meet a crop's consumptive use requirement, leaching requirement and other special requirements. Factors affecting the level of water use efficiency on a given field include the water intake rate of the soil, the degree of slope and uniformity of the field surface, the length of the water run, the level of water management practiced and the crop planted. On-farm water use efficiencies were estimated by crop for each crop/RTA/soil combination identified. Estimated efficiencies were based on soil moisture and water applied measurements for twenty specific sites on the Reservation by USDA Agricultural Research Service and the Soil Conservation Service. Information from farm records and BIA records on water delivered were also used as available (Table 9).

Total Irrigation Application

Total irrigation application (TIA) represents a crop's total irrigation requirement, adjusted for water-use efficiency by crop/RTA/soil (Table 9) and assumed 'deficit irrigation' on selected RTA's. Deficit irrigation refers to a condition in which 1) total irrigation

Table 9. On-Farm Water Use Efficiencies by Crop, RTA and Soil[a]

RTA COMPONENTS		RTA NUMBER[b] 1	2	3	4	5	6	7[c]	8[c]	9[c]	10[c]	15	16
Flood Sprinkler		F	F	F	F	F	F	F	F	F	F	S	S
Type Slope		RS	US	US	US	US	US	LB	LB	LB	LB	RS	RS
Water Mgmt.		UM	UM	UM	UM	M	M	UM	UM	M	M	UM	M
Ditch Type		UL	UL	L	L	L	L	L	L	L	M		
Run Length		1,320	1,320	1,320	660	1,320	660	1,320	660	1,320	660		
WATER USE EFFICIENCY BY RTA/SOIL													
Cotton	Fine	.4	.5	.5	.5	.6	.6	.65	.7	.9	.9	--	--
	Medium	.4	.5	.5	.5	.6	.6	.65	.7	.8	.9	--	--
	Coarse	.35	.4	.4	.5	--	.6	--	.6	--	.8	--	--
Alfalfa	Fine	.4	.5	.5	.5	.6	.6	.65	.7	.9	.9	--	--
	Medium	.4	.5	.5	.5	.6	.6	.65	.7	.8	.9	.50	.50
	Coarse	.35	.4	.4	.5	--	.6	--	.6	--	.8	.50	.65
Small Grain	Fine	.4	.5	.5	.5	.6	.6	.65	.7	.9	.9	--	--
	Medium	.4	.5	.5	.5	.6	.6	.65	.7	.8	.9	.50	.65
	Coarse	.35	.4	.4	.5	--	.6	--	.6	--	.8	.50	.65
Lettuce	Fine	--	--	.3	.3	--	--	.5	.5	.7	.7	--	--
	Medium	--	--	.3	.3	--	--	.5	.5	.7	.7	--	--
	Coarse	--	--	--	--	--	--	--	--	--	--	--	--
Melon	Fine	--	--	.3	.3	--	--	.5	.5	.7	.7	--	--
	Medium	--	--	.3	.3	--	--	.5	.5	.7	.7	--	--
	Coarse	--	--	--	--	--	--	--	--	--	--	--	--
Alfalfa Stand Est.	Fine	.4	.5	.5	.5	.6	.6	.65	.7	.9	.9	--	--
	Medium	.4	.5	.5	.5	.6	.6	.65	.7	.8	.9	--	--
	Coarse	.35	.4	.4	.5	--	.6	--	.6	--	.8	--	--

[a]The symbol (--) indicates that totaly acreage for a given crop/RTA/soil was negligeable.

[b]For a listing of symbols associated with RTA components, refer to Table 2.

[c]Efficiences for RTA 11 through 14 are identical to those shown for RTA 7 through 10 respectively.

application is less than needed to achieve yield potentials of the irrigation system, and/or 2) water is withheld during critical phases of the crop's growing season, resulting in a reduction in yield. Deficit irrigation is most predominant on poor irrigation systems with low management potentials. Assumptions on deficit irrigation by RTA were based on SCS on-site field investigation (Table 10).

Chemical Inputs

Chemical production inputs include fertilizers, pesticides and herbicides. Chemical input requirements were estimated for each of the five crops evaluated. Assumptions on chemical input requirements by crop were based on discussions with farmers, local suppliers and SCS technicians familiar with cropping practices on the Reservation. Costs were based on 1982 prices for agricultural inputs in Yuma County, Arizona.

Fertilizer requirements for cotton and small grain were modified to reflect differences by irrigation system and soil. Fertilizer requirements for cotton and small grain were based on estimated levels of nitrogen drawn from the soil for crop production and estimated nitrogen application efficiencies. Fertilizer requirements for alfalfa hay, alfalfa stand establishment, lettuce and melons were assumed constant for all irrigation systems and soils.

Irrigation Labor

Irrigation labor requirements were estimated by crop, irrigation system and soil. Irrigation labor requirements reflect estimated irrigation flow-time per crop-acre, based on total irrigation application

Table 10. Total Water Application by Crop, RTA and Soil[a/b]

RTA COMPONENTS		Unit	RTA NUMBER[c] 1	2	3	4	5	6	7	8	9	10	15	16
Flood/Sprinkler			F	F	F	F	F	F	F	F	F	F	S	S
Type Slope			RS	US	US	US	US	US	LB	LB	LB	LB	RS	RS
Water Mgmt.			UM	UM	UM	UM	M	M	UM	UM	M	M	UM	M
Ditch Type			UL	UL	L	L	L	L	L	L	L	M		
Run length			1,320	1,320	1,320	660	1,320	660	1,320	660	1,320	660		
Cotton	Fine	A/F	6.9	5.8	5.8	5.8	5.4	5.4	4.9	4.5	3.5	3.5	—	—
	Medium	"	6.9	5.8	5.8	5.8	5.4	5.4	4.9	4.5	4.0	3.5	—	—
	Coarse	"	7.9	6.9	6.9	5.8	—	5.4	—	5.3	—	4.0	—	—
Alfalfa	Fine	"	11.5	9.7	9.7	9.7	9.0	9.0	8.0	7.5	5.8	5.8	—	—
	Medium	"	11.5	9.7	9.7	9.7	9.0	9.0	8.0	7.5	6.5	5.8	9.7	8.3
	Coarse	"	13.1	11.5	11.5	9.7	—	9.0	—	8.7	—	6.5	9.7	8.3
Small Grain	Fine	"	4.0	3.4	3.4	3.4	3.2	3.2	2.8	2.6	2.0	2.0	—	—
	Medium	"	4.0	3.4	3.4	3.4	3.2	3.2	2.8	2.6	2.3	2.0	3.4	2.9
	Coarse	"	4.7	4.0	4.0	3.4	—	3.2	—	3.0	—	2.3	3.4	2.9
Lettuce	Fine	"	—	—	3.6	3.6	—	—	2.4	2.4	1.7	1.7	—	—
	Medium	"	—	—	3.6	3.6	—	—	2.4	2.4	1.7	1.7	—	—
	Coarse	"	—	—	—	—	—	—	—	—	—	—	—	—
Melons	Fine	"	—	—	4.8	4.8	—	—	3.2	3.2	2.3	2.3	—	—
	Medium	"	—	—	4.8	4.8	—	—	3.2	3.2	2.3	2.3	—	—
	Coarse	"	—	—	—	—	—	—	—	—	—	—	—	—

Table 10, Continued.

[a]Total water Application by crop/RTA/soil reflect assumptions on 1) total irrigation requirement (TIR) by crop, 2) on-farm water use efficiency by crop/RTA/soil, and 3) deficit irrigation practiced by RTA/soil

1) Total Irrigation Requirement (TIR)

TIR = CU + LR + SR − ER

Where TIR = Total Irrigation Requirement
CU = Crop Consumptive Water Use
LR = Leaching Requirement
SR = Special Requirements
ER = Effective Rainfall

Water Use Assumptions by Crop (AF)

Crop	CU	LR	SR	ER		TIR	
				Sloping	Flat	Sloping	Flat
Cotton	3.23	.11	—	.08	.17	3.26	3.17
Alfalfa	5.33	.23	—	.17	.33	5.39	5.23
Wheat	1.88	.06	—	.04	.13	1.90	1.81
Lettuce	.71	.04	.50	.04	.04	1.21	1.21
Melons	1.46	.13	—	.01	.01	1.58	1.58

2) On-Farm Water Use Efficiency

TIR_1 Adjusted for system efficiency =

$$\frac{CU + LR + SR - ER}{EFF}$$

Where EFF = On Farm Water Use Efficiency by Crop/RTA/Soil (Table 9)

3) Deficit Irrigation

TWA, RTA's 5-14, and 16 = 1.00 (TIR, adjusted for efficiency)
TWA, RTA's 2(S1,S2), 3(S1, S2), 4 and 15 = .90 (TIR, adjusted for efficiency)
TWA, RTA's 1, 2(S3) and 3(S3) = .85 (TIR, adjusted for efficiency)

[b]The symbol (—) indicates that total acreage for a given crop/RTA/soil was negligeable.

[c]For a listing of symbols associated with RTA components, refer to Table 2.

and rate of water applied. Assumptions on total irrigation application, rate of water applied, and number of irrigations required were developed by SCS irrigation specialists. Wages for irrigators were based on 1982 prices for agricultural inputs in Yuma County, published by the Cooperative Extension Service, University of Arizona.

Harvest Cost

Harvest cost was estimated by crop for alternate irrigation systems and soils evaluated. Harvest costs were based on yield/cost functions defined by crop. Harvest costs for cotton, alfalfa and small grain were based on budget data published by the Cooperative Extension Service, University of Arizona. Harvest costs for lettuce and melon were based on budget data published by the Cooperative Extension Service, University of Arizona.

Machine Cost

Machine costs were based on a machine complement developed by ERS for a representative mid-sized 800 acre farm in 1981. Machine complements indicate the type, size and number of equipment pieces available. Selection of equipment pieces was based on farm records provided by Farmers Home Administration (FHA) as well as discussions with local farmers and SCS technicians familiar with machine operations on the Reservation.

Variable machine costs refer to machine operating costs such as repairs, fuel and oil costs which vary with hours of machine use. Variable machine costs were adjusted to reflect alternate irrigation systems (RTA), soils and crop sequences evaluated. Adjustments in variable machine cost reflect assumptions involving operation requirements by field condition. Operation requirements adjusted by field condition include plowing, ripping, disking and cultivating. Information on machine operations was based on discussions with local farmers and SCS technicians familiar with operations on the Reservation.

Fixed machine costs represent machine ownership costs which are borne irrespective of the level of machine use. Fixed machine costs include depreciation, taxes, housing, interest and insurance cost. Fixed machine costs were assumed to be the same for all field conditions.

Fixed and variable machine costs were based on 1982 farm machinery costs developed by the Cooperative Extension Service, University of Arizona.

Land Rent

Land rent was estimated by agricultural lease category evaluated in the study. Land rent for standard five year leases were estimated by soil and irrigation system (RTA). Land rent for mid-term improvement leases and long term development leases were estimated by soil and level of physical improvements required under the terms of the lease.

Information on agricultural leases and land rent was based on the NADSAT Project Report #18, prepared by the Office of Arid Land Studies, University of Arizona. Additional information was obtained through disscussions with BIA Land Operations personnel and SCS technicians familiar with leasing arrangements on the Reservation.

Irrigation Development Cost

Levels of irrigation development were evaluated for existing irrigated lands and new lands. Irrigation development includes on-farm physical system development, improved on-farm water management, off-farm structural development and improved management of the off-farm delivery system. Irrigation development costs reflect 1981 (base year) prices. Annual costs for physical improvements were based on an amortization period of fifty years (with replacement) and a discount factor of 8.125%.[1]

Cost of on-farm improvements on existing irrigated lands were estimated by RTA transfer. RTA transfers represent the upgrading of existing irrigation systems (RTA's) resulting from on-farm physical improvements and/or improved on-farm water management. Physical land treatment costs were based on SCS field records and judgement estimates of SCS technicians involved with irrigation development on the Reservation. Costs associated with on-farm water management were based on rates charged by private irrigation consultants employed on the Reservation in 1981 ($7.00/acre/year).

Costs of on-farm irrigation development on new lands were estimated by new land parcel. On-farm development on new lands includes brush clearing and removal, land leveling and ditch installation. Costs of off-farm structural development were estimated by parcel or parcel group. Off-farm development on new lands includes canal/lateral

1. Irrigation development costs are displayed (by Increment) in Chapter 4, Table 21.

construction, off-farm measuring flumes, pumping stations and wells. Development costs for new lands were based on SCS on-site evaluations, BIA land records and data published in the Boyle Engineers Consulting Report.

Management requirements of the off-farm delivery system were estimated for future development alternatives evaluated. Costs of off-farm management were increased to reflect (1) improved system efficiences on existing irrigated lands, and (2) irrigation expansion on new lands. Increases in management costs were estimated by SCS technicians familiar with off-farm system requirements.

Technical assistance required to implement on-farm irrigation system improvements were also estimated. Technical assistance requirements reflect estimated man-hours required per acre of system improvement, based on SCS field experience in previous irrigation project areas. Physical improvements involving land leveling and/or ditch construction are assumed to require 1.0 man/hours of technical assistance per acre. Improvements in on-farm water management are assumed to require .5 man-hours of technical assistance per acre.

The Linear Programming Model

The study area modelled in the LP analysis includes existing and potential cropland in the Arizona valley, and potential cropland on the Arizona mesa. These lands account for more than 90% of total existing and potential cropland on the Reservation. Existing cropland on the Arizona mesa and all croplands in California were excluded from the LP analysis, as these lands are subject to constraints on water use separate from that applying to Arizona lands under the 1964 Supreme Court Decree[1]. Recommendations for irrigation development presented in this thesis apply to those lands within the study area modelled[2].

A series of linear programming models were developed to reflect irrigation development alternatives within the study area. Development alternatives represent combinations of physical irrigation improvements, improved water management and new land development. Development alternatives evaluated are discussed in Chapter 3.

'Region-wide' models (as opposed to 'representative farm' models) were used in the analysis. Resource constraints involve land, water and management levels defined on a region-wide basis. Farm production, net returns and resource use were aggregated over the study area.

Components of the Model

Production alternatives defined in the study represent production of a specified sequence of crops by soil, irrigation system, level of water management, and lease scenario evaluated.

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1. The Tribe contends that water pumped from wells on the mesa is groundwater, and should therefore not be counted against the Tribe's total diversion of Colorado River water. Groundwater flow patterns on the Reservation are currently under study. Water used on new lands developed on the mesa was assumed to be counted against the Tribe's total diversion.

Total water available for crop production in California was set equal to the entitlement fixed for California lands under the 1964 Decree. It was assumed that water rights may not be transferred between states.

2. The final USDA report on the CRIR study will ultimately include proposals for each of the three sub-areas--Arizona valley, Arizona mesa and California valley.

System transfer alternatives represent production alternatives in which on-farm irrigation improvements are implemented. Irrigation improvements include improved irrigation management, improvements in the existing physical system under mid-term improvement leases, and development of new lands under long-term development leases.

Net return coefficients were estimated by production alternative. Net return coefficients represent the annualized return over variable cost by crop sequence, soil and irrigation system (or system transfer).

Yield and input coefficients were also estimated by production alternative. Yield coefficients indicate the average per-acre yield by crop for a given production alternative. Input coefficients indicate the level (or cost) of selected production inputs by production alternative, expressed on an annual per-acre basis. Input coefficients include acre-feet of water use by RTA/soil and crop sequence, plus selected fixed production costs such as (annualized) fixed machine cost, (annualized) land rent and (amortized) on-farm irrigation system development cost.

Resource constraints were defined to reflect levels of water, land and management under development alternatives evaluated. Water constraints define the upper limit on total acre-feet of water available for farm delivery (net of losses in the off-farm delivery system). Acreage constraints include 1) upper and lower limits on acres by RTA/soil combination, 2) upper limits on total acres under level basin systems, 3) upper limits on total acres under irrigation water management, and 4) upper limits on new land developed. Additional constraints were developed to reflect assumptions on acres by crop sequence and lease type[1].

The objective criterion used in solving for model solutions was maximization of (annual) on-farm net return to agriculture, subject to production alternatives and resource constraints specified. On-farm net return was defined as (annualized) gross return minus (annualized) variable costs minus (annual) on-farm system development cost, minus (annual) land rent[2].

Land and water resources were allocated among production alternatives to maximize net returns, subject to constraints specified. Expenditures on irrigation system development required to achieve an optimal allocation of land and water resources were computed from the model solutions.

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1. Resource constraints are discussed more fully in Chapter 3 under "Variable Adjustments by Model".

2. Fixed costs such as machine ownership costs and off-farm system development costs were not included in the LP objective function. Fixed costs were included however in computing total net return by development alternative (Chapter 5).

CHAPTER 3

ANALYSIS

The linear programming analysis developed for use in the Colorado River Indian Reservation study includes the Base Year Analysis and the Incremental Analysis.

Base Year Analysis

A linear programming model was developed for the base year to reflect resource use and production associated with irrigated agriculture on the Reservation in 1981.

The first objective of the analysis was to calibrate model coefficients for use in the overall linear programming analysis. Calibration of coefficient values was accomplished by cross-checking summary information derived from the base year model solution (i.e., total acres by crop, average crop yields, total production and total water use) against information obtained from alternative sources. Where discrepancies occurred, assumptions on acreage, yields and water use by irrigation system were reevaluated and adjusted as necessary to more accurately reflect existing conditions in the base year.

The second objective of the analysis was to define a benchmark condition for use in evaluating irrigation development alternatives. The base year model solution serves as a benchmark condition against which alternate levels of irrigation system development are evaluated. Estimated returns and resource use levels by development alternative are compared against returns and resource use levels computed for the base year. Changes in cost, returns, and resource use levels, as well as percent rates of change, were computed in the LP Comparison Report program.

Incremental Analysis

Under the Incremental Analysis, a series of linear programming models were used to evaluate the impact of future irrigation development alternatives on the Reservation.

The first objective of the analysis was to identify that level of irrigation development which maximizes annual net returns among development alternatives evaluated. That level of development which maximizes net returns constitutes the recommended level of irrigation system development.

The second objective of the analysis was to evaluate the relative contribution of various categories of irrigation improvements. Benefits include increased net returns resulting from (1) system improvements on existing irrigated lands and (2) system development on new land acres. Benefits also include increased water savings resulting from system improvements on existing irrigated acres; water 'saved' on existing irrigated lands is thus available for irrigation of additional new lands.[1]

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1. No dollar value was assigned to water savings with system improvements on existing irrigated lands. Water savings have value to agriculture on the Reservation to the extent that these savings are used to irrigate additional new lands.

'Increments' were defined to reflect irrigation development alternatives for the Reservation. An LP model was developed to represent each development alternative, or Increment, evaluated. Increment models represent alternate levels of irrigation water management (on-farm and off-farm), physical development on existing irrigated lands (on-farm and off-farm), and irrigation development on new lands.

Eight Increment models were evaluated in the analysis (Table 11). Increments were ranked (1 through 8) according to total cost of development. Increment 1 represents the least cost development alternative. An additional category of improvements is introduced with each subsequent Increment evaluated, each Increment building on the previous one. Increments 1 through 4 are limited to improvements on existing irrigated lands. Increments 5 through 8 include system improvements on existing irrigated lands plus development of alternate levels of new land.

The ordering of Increments for existing irrigated lands was based on a per-acre analysis of costs and returns by on-farm system improvement.[1] It was assumed for the analysis that system improvements are implemented according to their expected return per dollar invested; those improvements with the highest return are implemented next, and so

1. Cost, return and cost/return ratios were evaluated by on-farm RTA transfer evaluated in the CRIR study. RTA transfers represent the upgrading of an on-farm irrigation system resulting from a given system improvement or combination of system improvements (i.e., water management, levelling, field reorganization, ditch lining). See "CRIR Data Tables, Part C, Evaluation of Economic Returns to Alternate On-Farm System Transfers, Existing Developed Acreage," ERS, Tucson.

Table 11. Categories of Irrigation System Improvements Introduced by Increment

Existing Developed Acres

Increment 0 - Base Year, modified

Increment 1 - Improved on-farm irrigation water management
- Improved off-farm delivery system management

Increment 2 - On-farm levelling
Medium-efficiency systems
RTA 3 (fine and medium soil), 4, 5, 6

Increment 3 - On-farm levelling/ditch construction
Low-efficiency systems
RTA 1, 2, 3 (coarse soil)

Increment 4 - Off-farm structural improvements

New Land Acres

Increment 5 - Acres currently under development, and undeveloped acres under existing development lease
(5,912 net acres; Arizona)

Increment 6 - Undeveloped acres serviceable by existing off-farm delivery system which are unleased as of 1983
(1,483 net acres; Arizona)

- Undeveloped acres serviceable with new canal/lateral reaches and/or further improvements on existing canal/ laterals; moderate off-farm development expenditures (2,595 net acres; Arizona)

Increment 7 - Undeveloped acres serviceable with new canal/lateral reaches and/or further improvements on existing canal/ laterals; heavy off-farm development expenditures, flood protection not required.
(7,058 net acres; Arizona)

Increment 8 - Undeveloped acres requiring flood protection
(7,806 net acres; Arizona)

on. Development of new lands were evaluated on the assumption that recommended system improvements have been implemented on existing irrigated lands. New lands were assigned by Increment according to the likelihood of their development based on estimated off-farm system development costs by parcel. Other factors such as existing lease agreement, parcel size and suitability for agriculture were also considered.[1]

Variable Adjustments by Model

Selected variables were adjusted by Increment model to reflect investments in land treatment and water management. Variable adjustments involved 1) RTA transfer alternatives, 2) new land development, 3) water supply, 4) acres in level basin systems, 5) acres in irrigation water management, and 6) acreage ranges by RTA/soil (Tables 12 through 16).

Production alternatives involving irrigation system development include RTA transfers and new land transfers. RTA transfers represent system improvements on existing irrigated acres. New land transfers represent system development on previously undeveloped acres. Production alternatives by Increment model represent selected categories of system improvements on existing lands (Table 12) and system development on new lands (Table 13).

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1. Selection of an optimal level of irrigation development based on total net returns is not affected by the order in which system improvements are evaluated. Estimated (marginal) net returns by category of system improvement may be affected by the order in which they are evaluated; i.e., returns to IWM are a function of the management potentials of physical systems, returns to new land development are dependant to a certain extent on the level of water savings on existing developed lands.

Table 12. RTA Transfer Alternatives by Increment Model[a]

RTA Transfer		Soils Applicable[b]			INCREMENT[c]			
					0	1	2	3-8
					Base Year	IWM Transfers	IWM Transfers Level Basin Transfers - semi-improved systems	IWM Transfers Level Basin Transfers - semi-improved system - poor systems
RTA from	RTA to	Fine	Medium	Coarse				
1	3	x	x			—	—	x
	4			x	—	—	—	x
	5	x	x		—	—	—	x
	6			x	—	—	—	x
	7	x	x		—	—	—	x
	8			x	—	—	—	x
	9	x	x		—	—	—	x
	10			x	—	—	—	x
2	3	x	x		—	—	—	x
	4			x	—	—	—	x
	5	x	x		—	—	—	x
	6			x	—	—	—	x
	7	x	x		—	—	—	x
	8			x	—	—	—	x
	9	x	x		—	—	—	x
	10			x	—	—	—	x
3	5	x	x		—	x	x	x
	6			x	—	—	—	x
	7	x	x		—	—	x	x
	8			x	—	—	—	x
	9	x	x		—	—	x	x
	10			x	—	—	—	x
4	6	x	x	x	—	x	x	x
	8	x	x	x	—	—	x	x
	10	x	x	x	—	—	x	x
5	7	x	x		—	—	x	x
	9	x	x		—	—	x	x
6	8	x	x	x	—	—	x	x
	10	x	x	x	—	—	x	x
7	9	x	x		—	x	x	x
8	10	x	x	x	—	x	x	x
11	13	x	x		—	x	x	x
12	14			x	—	x	x	x
15	16		x	x	—	x	x	x

Table 12, Continued

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[a]RTA transfers represent the upgrading of on-farm irrigation systems resulting from physical system improvements and/or improved water management. RTA transfer alternatives were defined by soil for each Increment model evaluated.

[b]RTA transfers applicable by soil are indicated with a (X).

[c]RTA transfer alternatives included by Increment model are indicated with an (X). RTA transfer alternatives which do not apply by Increment model are indicated with an (--).

Table 13. Upper Bound on New Land Development by Increment Model[a]

New Land Parcels	Net Acres	INCREMENT[b] 0-4	5	6	7	8
AZ 4	4,127	--	X	X	X	X
AZ 7	141	--	X	X	X	X
AZ 8	378	--	X	X	X	X
AZ 13	97	--	X	X	X	X
AZ 15	163	--	X	X	X	X
AZ 16	16	--	X	X	X	X
AZ 19	37	--	X	X	X	X
CR 8	103	--	X	X	X	X
AZ 1	942	--	--	X	X	X
AZ 5	44	--	--	X	X	X
AZ 12	28	--	--	X	X	X
AZ 17	53	--	--	X	X	X
AZ 10	92	--	--	X	X	X
AZ 11	1,509	--	--	X	X	X
AZ 15B	994	--	--	X	X	X
AZ 20	6,300	--	--	--	X	X
CR 8	72	--	--	--	X	X
CR 9	85	--	--	--	X	X
BOUSE	601	--	--	--	X	X
AZ 2	504	--	--	--	--	X
AZ 3	352	--	--	--	--	X
AZ 14	200	--	--	--	--	X
AZ 18	422	--	--	--	--	X
AZ 6	5,078	--	--	--	--	X
CR 12	106	--	--	--	--	X
CR 13	100	--	--	--	--	X
Total Acres[c]	23,588	0	5,062	8,724	15,782	23,588

[a]Potential new land development was defined by increment model evaluated. New land parcels and acreage by parcel are listed on the left.

[b]New land parcels evaluated by increment model are indicated with a (x). New land parcels not applying by increment model are indicated with a (--).

[c]Total acres shown by increment represents the upper bound on total new land development by increment model.

Table 14. Upper Bound on Total Potential Farm Delivery by Incremental Model[a]

	INCREMENT 0	1	2	3	4	5	6	7	8
(1) Total Water Entitlement, AZ Valley	662,000	662,000	662,000	662,000	662,000	662,000	662,000	662,000	662,000
(2) River and Well Pumping	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
(3) Total Water Subject to Canal Losses and Regulating Waste (1)-(2)	642,000	642,000	642,000	642,000	642,000	642,000	642,000	642,000	642,000
(4) Off-Farm System Efficiency, % of (3)[b]	81.0	85.3	85.3	85.3	93.1	93.1	93.1	93.1	93.1
(5) - System Losses, % of (3)									
Canal Seepage	9.8	9.8	9.8	9.8	2.0	2.0	2.0	2.0	2.0
Canal Evaporation	.6	.6	.6	.6	.6	.6	.6	.6	.6
Regulating Waste	8.6	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
(6) - Reduction in System Losses, % of base year level									
Canal Seepage	—	0.	0.	0.	80.	80.	80.	80.	80.
Regulatory Waste	—	50.	50.	50.	50.	50.	50.	50.	50.
(7) Adjusted Total Water Subject to Canal Losses and Regulatory Waste (3)x(4)	520,000	548,000	548,000	548,000	598,000	598,000	598,000	598,000	598,000
(8) Total Potential Farm Delivery (7)+(2)[c]	540,000	568,000	568,000	568,000	618,000	618,000	618,000	618,000	618,000

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[a]Total potential farm delivery was defined for each increment model evaluated. Total potential farm delivery represents the CRIR Arizona water entitlement adjusted for off-farm system losses. Line items (1) through (8) outline procedures followed in computing total potential farm delivery by increment.

[b]Off-farm system efficiency was calculated based on assumed percent reductions in system loses with improvements in off-farm management and off-farm physical delivery systems.

[c]Total potential farm delivery serves as the upper bound on water available for farm use by increment.

Table 15. Upper Bound on Total Net Acres Level Basin Irrigation Systems by Increment[a]

	INCREMENT								
	0	1	2	3	4	5	6	7	8
(1) Total acres in level basin systems, base year	11,256	11,256	11,256	11,256	11,256	11,256	11,256	11,256	11,256
(2) Total potential level basin transfers, existing developed acreage	0	0	28,326	60,284	60,284	60,284	60,284	60,284	60,284
(3) Total potential level basin transfers, new lands	0	0	0	0	0	2,342	5,721	5,806	12,368
(4) Total potential acres, level basin systems (1)+(2)+(3)[b]	11,256	11,256	39,285	71,540	71,540	73,882	77,261	77,346	83,908

[a]Acres permitted in level basin systems were adjusted by Increment model evaluated. Acres in level basin systems were increased with categories of on-farm physical improvements introduced by Increment. Line items (1) through (4) outline procedures followed in computing upper bounds for total acres in level basin systems.

[b]Total potential acres in level basin systems serve as the upper bound on level basin acreage by Increment.

Table 16. Upper Bound on Total Net Acres Under Irrigation Water Management (IWM) by Increment, Incremental Analysis[1]

	INCREMENT								
	0	1	2	3	4	5	6	7	8
(1) Total acres with IWM, base year	11,475	11,475	11,475	11,475	11,475	11,475	11,475	11,475	11,475
(2) Total acres without IWM, but with on-farm physical systems permitting IWM[b]	40,627	40,672	40,627	61,155	61,155	61,155	61,155	61,155	61,155
(3) Percent total acres subject to problems involving irrigation delivery[c]	40.	30.	30.	30.	0.	0.	0.	0.	0.
Off-farm structural	30.	30.	30.	30.	0.	0.	0.	0.	0.
Off-farm system management	10.	0.	0.	0.	0.	0.	0.	0.	0.
(4) Total acres subject to problems involving irrigation delivery (2)x(3)	16,269	12,202	12,202	18,346	0	0	0	0	0
(5) Total potential IWM transfers, existing developed acres (2)-(4)	—	28,470	28,470	42,809	61,155	61,155	61,155	61,155	61,166
(6) Total acres of new land developed	—	0	0	0	0	5,062	8,724	15,782	23,588
(7) Total acres with IWM potential (1)+(5)+(6)	—	39,945	39,945	54,284	72,630	77,692	81,354	88,412	96,218
(8) Percent total IWM acres achievable[d]	—	90.	90.	90.	90.	90.	90.	90.	90.
(9) Total IWM acres achievable (7)x(8)[e]	11,475	35,950	35,950	48,856	65,367	69,923	73,219	79,571	86,596

[a] Acres permitted under irrigation water management (IWM) were adjusted by increment model evaluated. Acres with IWM potential are assumed to increase with categories of on-farm and off-farm irrigation improvements introduced by increment. Line items (1) through (9) outline procedures followed in computing upper bounds for total acres under irrigation water management.

[b] Total unmanaged acres with on-farm physical systems permitting IWM include acres in RTA 3 (fine and medium soil), 4, 5, and 6.

[c] Percent of acres subject to problems involving off-farm management and off-farm structural system were based on judgment estimates of SCS field personnel.

[d] It was assumed that IWM was achievable on 90% of acres with potential for water management.

[e] Total IWM acres achievable serves as the upper bound on acres with water management by increment.

Total water supply refers to acre-feet of water available at the farm level for crop production. Total farm delivery available was based on total acre-feet of potential diversion and estimated off-farm delivery system efficiency by Increment. Off-farm system efficiencies were adjusted from the base year level to reflect reduced water losses due to canal spills and canal seepage with improvements in the off-farm system (Table 14).

Level basin transfers represent the upgrading of existing irrigation systems to level basin systems with land leveling. Level basin transfers were adjusted to reflect assumed levels of physical system development by Increment. Acres transferring to level basin systems were limited by fixing an upper bound on total acres under level basin systems, i.e. acres in RTA 7 through 14 (Table 15).

IWM transfers represent the upgrading of existing irrigation systems through improvements in water management. Acres of on-farm IWM by Increment represent potential levels of water management achievable, based on on-farm and off-farm physical system development by Increment. On-farm IWM potentials are assumed to increase with physical improvements installed on existing irrigated lands. Acres transferring from unmanaged to managed on-farm systems were limited by fixing an upper bound on total acres under IWM; that is, acres in RTA 5, 6, 9, 10, 13, 14 and 16 (Table 16).

Upper and lower bounds on acres by RTA/soil define the range within which acres may fluctuate in the model solution for a given irrigation system and soil combination. Acreage ranges may be closed or open-ended. The use of acreage ranges ensure that a specific minimum or maximum amount of acres remain for a given RTA/soil in the model solution. Range constraints were used in the base year models to fix acres by RTA/soil combination.[1]

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1. Upper and lower bounds by RTA/soil combination were used more extensively in evaluating alternate implementation rates of system improvements under a subsequent phase of the CRIR economic analysis.

CHAPTER 4

RESULTS

Base Year Model

The Base Year reflects agricultural production and resource use on the Reservation under existing conditions in the base year, 1981. Acres by RTA/soil and total water use in the base year model were set equal to actual estimates for 1981. Crop acres and production levels reflect an approximate average by crop for years 1977-1981. Total on-farm costs and returns were computed in the base year model. Summary data for the base year model solution are displayed in Tables 17 through 20.

Irrigated Acreage

By 1981, an estimated 72,630 net irrigable acres had been developed in the Arizona valley. Surface irrigation systems accounted for 71,540 acres, or approximately 98% of total cropland acres. The remaining 1,090 developed acres were under sprinkler irrigation systems.

Level basin systems accounted for 11,256 acres (16%) of total acres in surface systems. Uniform sloped systems accounted for 53,747 acres (75%) and rough sloped system accounted for 6,537 acres (9%). An estimated 51,712 acres (72%) were in fields with 1,320' water runs, while 19,828 acres (28%) were in fields with 660' water runs. Approximately 41,761 acres (58%) were in fields serviced by lined on-farm ditches.

Table 17. Irrigated Acreage Summary, Base Year Analysis

Total Net Developed Acres	72,630
Net Developed Acres by RTA[a]	
RTA 1	6,531
RTA 2	23,242
RTA 3	12,347
RTA 4	10,168
RTA 5	3,632
RTA 6	4,358
RTA 7	3,632
RTA 8	2,905
RTA 9	1,451
RTA 10	1,453
RTA 11	726
RTA 12	726
RTA 13	145
RTA 14	218
RTA 15	872
RTA 16	218
Net Developed Acres by RTA Component	
Flood Irrigation System	71,540
Rough Slope	6,537
Uniform Slope	53,747
Level Basin	11,256
1,320 Runs	51,712
660 Runs	19,828
Unlined Ditches	29,779
Lined Ditches	41,761
Water not Pumped	69,725
Water Pumped	1,815
Sprinkler Irrigation System	1,090
Irrigation Water, Managed	11,475
Unmanaged	61,155

[a]For RTA's defined, See Table 2.

Table 18. Crop Production Summary, Base Year Analysis

Net Developed Acres by Crop		
Cotton		30,591
Alfalfa		26,483
Small Grain		6,995
Lettuce		2,504
Melon		2,504
Idle		3,592
Net Developed Acres by Crop Sequence Type		
Continuous Cotton		28,616
Continuous Alfalfa		14,308
Alfalfa/Cotton		9,300
Cotton/Small Grain		9,300
Lettuce/Small Grain		5,008
Melon/Small Grain		5,000
Alfalfa/Small Grain		1,090
Total Production by Crop		
Cotton	(Bales)	66,400
Alfalfa	(Tons)	203,200
Small Grain	(Tons)	15,700
Lettuce	(CWT)	651,000
Melon	(CWT)	400,600
Average Per Acre Yield by Crop		
Cotton	(Bales)	2.2
Alfalfa	(Tons)	7.7
Small Grain	(Tons)	2.3
Lettuce	(CWT)	260.0
Melon	(CWT)	160.0

Table 19. Cost and Return Summary, Base Year Analysis

	$1000
Total Net Return[a]	17,450.4
Total Gross Return	60,237.4
Total Cost	42,787.0
On-Farm:	
Total Variable Cost	30,622.1
Return to Management (TVC x .10)	3,062.2
Fixed Machine Cost	9,102.7
Land Rent	4,957.2
Development Cost Physical Systems	
Existing Developed Acreage	0.0
New Land Acreage	0.0
Off-Farm:	
Development Cost Physical Systems	
Delivery System	0.0
Flood Protection	0.0
Delivery System Management (BIA)	0.0
Technical Assistance (SCS On-Farm)	0.0

[a]Total net return is defined as gross return minus variable cost, minus return to management, minus fixed machine cost minus irrigation development cost. Land rent was not reflected in total net return, as rent is regarded as a transfer between target groups within the study area (i.e., farmers and tribal landholders). Costs associated with irrigation development (installation cost, additional off-farm system management and additional technical assistance) were assumed to be zero in the base year model.

Table 20. Water Use Summary, Base Year Analysis.

Total Water Use (AF)	
Water Entitlement, Arizona	662,402
Total Diversion[a]	632,099
Total Farm Delivery[b]	512,000
Total Irrigation Requirement[c]	278,531
Total Potential Farm Delivery[d]	540,000
Average Water Use per Developed Acre (AF)	
Water Entitlement, Arizona	9.1
Total Diversion	8.7
Total Farm Delivery	7.0
Total Irrigation Requirement	3.8
Irrigation System Efficiency (%)	
On-Farm Systems[e]	54.0
Off-Farm Delivery Systems[f]	81.0
Irrigation Water Expenditure[g]	
Total ($ million)	2.0
Average per Developed Acre ($)	27.3
Marginal Value of Water Supply ($)[h]	0.0
Average Value of Water ($)[i]	
(GR - (TVC))/AF	57.8
(GR - (TVC, Rent, Dev Cost))/AF	48.2
(GR - (TVC, Rent, Dev Cost, Mach Cost))/AF	30.4

Table 20, Continued.

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[a]Estimated diversion represents the diversion necessary to meet farm delivery requirements, based on the efficiency of the off-farm delivery system.

[b]Farm Delivery represents the total water required at the farm level, based on cropping patterns and on-farm irrigation system efficiences.

[c]Irrigation requirements represents total crop consumptive use, plus leaching and 'special requirements' minus effective rainfall.

[d]Potential farm delivery represents total water available for farm delivery, based on total water entitlement and efficiency of the off-farm delivery system.

[e]On-farm system efficiency was computed as the total irrigation requirement divided by total farm delivery.

[f]Off-farm delivery system efficiency was computed of total farm delivery divided by total diversion.

[g]Irrigation water expenditures are based on (BIA) water charges per acre-foot diverted; pumping costs are not included.

[h]Marginal value of water supply represents the net value to agriculture of one additional acre-foot of water available for farm delivery.

[i]Average value of water represents net return divided by total acre-feet of farm delivery. Average value of water was computed for three different measures of net return; (1) gross return above variable cost, (2) gross returns above variable cost, land rent and development cost, and (3) gross return above variable cost, land rent, development cost and fixed machine cost.

A high level of on-farm irrigation water management was practiced on an estimated 11,475 acres (16%) of total irrigated acreage in the Arizona valley. The level of irrigation water management was considered low on the remaining 61,155 acres (84%).

Crop Acres

Cotton accounted for 30,591 acres (44%) of total cropped acres in the Arizona valley. Alfalfa accounted for 26,483 acres (38%) while 6,955 acres (10%) were planted to small grains. Specialty crops, lettuce and melon, accounted for a combined 5,008 acres (8%). An estimated 3,592 acres were assumed uncropped in the base year.

On-Farm Cost and Return

Total net return in the base year was estimated at $17.5 million where net return is defined as gross return minus variable cost, fixed machine cost and return to management. Total gross value of production was estimated at $60.2 million. Total variable production cost was estimated at $30.6 million. Total fixed machine cost was estimated at $9.1 million. Return to management was computed as 10% of total variable cost, or $3.1 million. Total land rent on acreage leased in the base year was estimated at $5.0 million.

Water Use

Potential water diversion in the Arizona portion of the Reservation was 662,402 acre-feet (1964 Decree). An estimated 632,099 acre-feet was diverted in the base year (river water plus wells) to provide approximately 512,000 acre-feet of farm delivery. Total irrigation requirements for crops produced (i.e., total consumptive use, leaching and special requirements, minus effective rainfall) was estimated at 278,531 acre-feet.

System efficiency for the off-farm delivery system (i.e. total farm delivery divided by total diversion) was estimated at 81%. Average water use efficiency for on-farm irrigation systems (i.e. total irrigation requirement divided by total farm delivery) was estimated at 54%.

Total expenditures for surface water delivered in the base year was estimated at $2.0 million. Average expenditure per developed acre was approximately $27.00/acre.

Incremental Models

Development costs by Increment are displayed in Table 21. Irrigation system development includes on-farm physical system development and improved on-farm water management, off-farm physical system development, improved off-farm (BIA) delivery system management, and additional (SCS) technical assistance.

Acreage levels for on-farm irrigation systems by Increment are displayed in Table 22. Upper bounds on acreage in level basin systems and acreage under IWM were fixed exogenously in the model (Tables 15 and 16); on-farm system transfers occurred in the model solution subject to acreage constraints specified. Off-farm system development required to achieve levels of on-farm irrigation development by Increment were estimated outside the model.

Table 21. Irrigation Development and Development Costs by Increment, Incremental Analysis[a]

System Improvements	Increment 1		Increment 2		Increment 3		Increment 4		Increment 5		Increment 6		Increment 7		Increment 8	
	Initial Cost	Annual Cost	Initial Cost	Annual Cost	Initial Cost	Annual Cost	Initial Cost	Annual Cost	Initial Cost	Annual Cost	Initial Cost	Annual Cost	Initial Cost	Annual Cost	Initial Cost	Annual Cost
	($1000)															
On-Farm System Development																
Existing Developed Acres																
On-Farm Structural																
Leveling	0.0	0.0	4,782.9	396.6	10,443.4	866.0	10,443.4	866.0	10,443.4	866.0	10,443.4	866.0	10,443.4	866.0	10,443.4	866.0
Ditch Lining/Construction	0.0	0.0	0.0	0.0	13,120.3	1,087.9	13,120.3	1,087.9	13,120.3	1,087.9	13,120.3	1,087.9	13,120.3	1,087.9	13,120.3	1,087.9
Measuring Flumes	28.1	2.7	32.2	3.0	49.2	4.7	70.9	6.7	70.9	6.9	70.9	6.7	70.9	6.7	70.9	6.7
New Land Acres																
On-Farm Structural																
Clearing and Leveling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5,704.4	473.0	9,042.3	749.8	17,980.8	1,491.0	25,492.5	2,113.8
Ditch Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2,356.4	195.4	4,230.8	350.8	8,300.0	688.2	11,461.2	950.4
Measuring Flumes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	.6	10.3	1.0	18.7	1.8	27.9	2.7
Irrigation Water Management	--	149.5	--	171.3	--	261.7	--	377.2	--	409.1	--	432.2	--	476.7	--	525.8
Off-Farm System Development																
Existing Developed Acres																
Off-Farm Structural																
Canal Lining/Reconstruction	0.0	0.0	0.0	0.0	0.0	0.0	6,582.4	680.9	6,582.4	680.9	6,582.4	680.9	6,582.4	680.9	6,582.4	680.9
Lateral Turnouts w/ Measuring Devices	0.0	0.0	0.0	0.0	0.0	0.0	725.8	75.1	725.8	75.1	725.8	75.1	725.8	75.1	725.8	75.1
Farm Turnouts w/ Measuring Devices	0.0	0.0	0.0	0.0	447.2	40.9	2,261.8	228.6	2,261.8	228.6	2,261.8	228.6	2,261.8	228.6	2,261.8	228.6
Check Gates	67.4	6.2	67.4	6.2	67.4	6.2	67.4	6.2	67.4	6.2	67.4	6.2	67.4	6.2	67.4	6.2
Road Crossings	0.0	0.0	0.0	0.0	0.0	0.0	85.0	8.8	85.0	8.8	85.0	8.8	85.0	8.8	85.0	8.8
New Lands																
Off-Farm Structural																
Canal Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	456.2	47.2	601.1	62.1	618.4	63.9	2,158.1	223.2
Lateral Turnouts w/ Measuring Devices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.6	2.0	43.9	4.6	43.9	4.6	85.1	8.8
Farm Turnouts w/ Measuring Devices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	348.4	36.1	603.2	62.5	611.5	63.4	1,173.1	121.5
Check Gates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.6	2.3
Road Crossings	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.6	5.0	0.6	71.2	7.5
Pumping Stations, Distribution Pipe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,432.9	768.8	7,572.9	783.3
Wells	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	284.4	29.4	284.4	29.4
Flood Protection	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7,000.4	790.5
Management Off-farm Delivery System	--	100.0	--	150.0	--	200.0	--	200.0	--	200.0	--	230.6	--	270.0	--	300.0
Technical Assistance																
IWM Transfers	160.2	6.4	183.6	7.3	280.4	11.2	404.2	16.2	438.4	17.5	463.1	18.5	510.7	20.4	563.4	22.5
Leveling Transfers	0.0	0.0	424.9	17.0	904.3	36.2	904.3	36.2	980.2	39.2	1,035.1	41.4	1,141.0	45.6	1,258.1	50.3
Total Annual Cost	--	264.8	--	751.4	--	2514.8	--	3589.8	--	4380.3	--	4914.3	--	6884.6	--	8892.0

Table 21, Continued

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[a]Irrigation development costs include physical development costs plus various annual costs, i.e., on-farm IWM, off-farm delivery system management (BIA) and on-farm technical assistance (SCS). Physical development costs include initial installation costs plus amortized costs (@ 8.125%, 50 year amortization period).

[b]The symbol (--) indicates that 'initial installation cost' does not apply.

Table 22. Irrigated Acreage Summary, Incremental Analysis

	INCREMENT								
	0	1	2	3	4	5	6	7	8
Total Net Developed Acres	72,630	72,630	72,630	72,630	72,630	81,354	81,354	88,412	96,223
New Land Acres Developed	0	0	0	0	0	5,062	8,724	15,782	23,588
Net Developed Acres by RTA[a]									
RTA 1	6,537	6,537	6,537	0	0	0	0	0	0
RTA 2	23,242	23,242	23,242	0	0	0	0	0	0
RTA 3	12,347	5,808	2,179	0	0	0	0	0	0
RTA 4	10,168	1,845	0	0	0	0	0	0	0
RTA 5	3,632	10,171	0	0	0	0	0	0	0
RTA 6	4,358	13,223	0	0	0	0	0	0	0
RTA 7	3,632	0	1,816	5,006	4,358	4,864	5,230	5,382	6,302
RTA 8	2,905	2,179	2,179	17,897	2,179	2,179	2,179	2,733	2,449
RTA 9	1,451	5,083	17,067	32,761	33,409	34,576	35,158	35,006	39,341
RTA 10	1,453	2,179	16,705	14,061	29,779	30,448	32,855	32,301	34,936
RTA 11	726	0	0	145	0	0	0	0	0
RTA 12	726	726	726	726	726	726	726	726	726
RTA 13	145	871	871	726	871	871	883	968	823
RTA 14	218	218	218	218	218	218	230	230	230
RTA 15	872	0	0	0	0	0	0	0	0
RTA 16	218	1,090	1,090	1,090	1,090	3,810	4,093	11,066	11,266
Net Developed Acres by RTA Component									
Flood Irrigation System	71,540	71,540	71,540	71,540	71,540	73,882	77,261	77,346	84,592
Rough Slope	6,537	6,537	6,537	0	0	0	0	0	0
Uniform Slope	53,747	53,747	25,421	0	0	0	0	0	0
Level Basin	11,256	11,256	39,582	71,540	71,540	73,882	77,261	77,346	84,952
1,320 Runs	51,712	51,712	51,712	38,638	38,638	40,311	41,271	41,356	46,611
660 Runs	19,828	19,828	19,828	32,902	32,902	33,571	35,990	35,990	38,341
Unlined Ditches	29,779	29,779	0	0	0	0	0	0	0
Lined Ditches	41,761	41,761	41,761	71,540	71,540	73,882	77,261	77,346	84,952
Water not Pumped	69,725	69,725	69,725	69,725	69,725	72,067	75,422	75,422	83,028
Water Pumped	1,815	1,815	1,815	1,815	1,815	1,815	8,839	1,924	1,924
Sprinkler Irrigation System	1,090	1,090	1,090	1,090	1,090	3,810	4,093	11,066	11,266
Irrigation Water, Managed	11,475	32,835	35,951	48,856	65,367	69,923	73,219	79,571	86,596
Unmanaged	61,155	39,795	36,679	23,774	7,263	7,769	8,135	8,841	9,622

[a] For RTA's defined, refer to Table 2.

Crop acres and crop production levels by Increment are displayed in Table 23. Cropping patterns were fixed in the models through acreage constraints applied by crop sequence. Cropping patterns by Increment were roughly equivalent to cropping patterns in the base year. Acres by crop sequence are constant for Increments 1 through 4; acres are increased proportionately for Increments 5 through 8 to reflect alternate levels of new land development.[1] Total production and average yield by crop were computed from the model solutions.

Costs and returns by Increment are displayed in Table 24. Total net return was based on on-farm net return derived from the Increment model solution and associated system development costs computed outside the model. Total net return was defined as (annualized) gross return minus (annualized) variable costs, minus fixed (annual) machine cost, minus (annual) on-farm irrigation development cost, minus (annual) off-farm irrigation development cost. Total net return represents the annualized stream of costs and returns over a fifty year period, resulting from irrigation improvements introduced in year 1 (Figure 3).

Marginal net returns and marginal benefit/cost ratios by Increment are displayed in Table 25. Marginal net returns were computed based on the change in total net return from one Increment to the next. The marginal net return by Increment represents the contribution to

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1. Cropping patterns were assumed constant in order to isolate the impact of irrigation improvements on net returns and resource use on the Reservation. Further, limited computer funds precluded the development of additional models required to test alternate assumptions on future cropping patterns by Increment.

Table 23. Crop Production Summary by Increment, Incremental Analysis

		INCREMENT								
		0	1	2	3	4	5	6	7	8
Net Developed Acres by Crop										
Cotton		28,787	29,921	30,845	32,084	32,155	33,115	34,501	34,536	37,712
Alfalfa		25,339	25,437	25,339	26,393	26,251	29,265	30,701	36,310	38,909
Small Grain		6,900	6,900	6,900	7,032	7,067	7,836	8,217	9,620	10,598
Lettuce		2,504	2,504	2,504	2,504	2,504	2,586	2,704	2,707	2,974
Melon		2,504	2,504	2,504	2,504	2,504	2,586	2,704	2,707	2,973
Idle		6,596	5,364	4,538	2,113	2,149	2,304	2,527	2,532	3,053
Net Developed Acres by Crop Sequence Type										
Continuous Cotton		28,616	28,616	28,616	28,616	28,616	29,553	30,905	30,939	33,981
Continuous Alfalfa		14,308	14,308	14,308	14,308	14,308	14,776	15,452	15,469	16,900
Alfalfa/Cotton		9,300	9,300	9,300	9,300	9,300	9,605	10,044	10,055	11,044
Cotton/Small Grain		9,300	9,300	9,300	9,300	9,300	9,604	10,044	10,055	11,044
Lettuce/Small Grain		5,008	5,008	5,008	5,008	5,008	5,172	5,408	5,414	5,947
Melon/Small Grain		5,008	5,008	5,008	5,008	5,008	5,172	5,408	5,414	5,946
Alfalfa/Small Grain		1,090	1,090	1,090	1,090	1,090	3,810	4,093	11,066	11,266
Total Production by Crop (000)										
Cotton	(Bales)	67.3	70.6	86.9	103.2	99.6	102.4	106.1	106.2	115.8
Alfalfa	(Tons)	179.2	188.8	197.1	245.5	271.4	300.0	314.2	366.4	393.7
Small Grain	(Tons)	16.0	17.5	19.5	19.4	20.5	22.5	23.6	26.9	29.8
Lettuce	(CWT)	651.0	651.8	701.1	701.1	701.1	724.1	757.1	758.0	832.6
Melon	(CWT)	400.6	400.6	400.6	400.6	400.6	413.8	432.6	433.1	475.1
Average Per Acre Yield by Crop										
Cotton	(Bales)	2.3	2.4	2.8	3.2	3.1	3.1	3.1	3.1	3.1
Alfalfa	(Tons)	7.1	7.4	7.8	9.3	10.3	10.3	10.2	10.1	10.1
Small Grain	(Tons)	2.3	2.5	2.8	2.8	2.9	2.9	2.7	2.8	2.8
Lettuce	(CWTT)	260.0	260.3	280.0	280.0	280.0	280.0	280.0	280.0	280.0
Melon	(CWT)	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0	160.0

Table 24. Cost and Return Summary by Increment, Incremental Analysis

	INCREMENT								
	0	1	2	3	4	5	6	7	8
Total Net Return[a]	17,724.9	19,253.0	26,554.1	34,174.3	34,214.3	35,915.4	36,850.6	37,275.4	38,686.9
Total Gross Return	58,494.3	60,950.7	69,105.3	80,031.9	81,077.7	85,536.4	89,090.0	94,346.8	102,518.6
Total Cost	40,769.4	41,697.7	42,551.2	45,857.6	46,343.2	49,621.2	52,239.4	57,071.4	63,831.7
On-Farm:									
Total Variable Cost	29,061.0	29,688.0	29,966.4	31,230.8	30,803.5	32,620.4	34,165.2	36,201.1	39,778.3
Return to Management (TVC x .10)	2,906.1	2,968.8	2,996.6	3,123.1	3,080.3	3,262.0	3,416.5	3,620.1	3,977.8
Fixed Machine Cost	8,802.3	8,925.6	9,008.1	9,250.6	9,247.0	9,767.4	10,176.2	10,842.2	11,709.2
Land Rent	9,953.0	9,953.0	9,159.8	8,326.8	8,326.8	8,393.6	8,438.7	8,516.8	8,628.9
Development Cost, Physical Systems									
Existing Developed Acreage	0.0	2.7	399.6	1,958.6	1,960.6	1,960.6	1,960.6	1,960.6	1,960.6
New Land Acreage	0.0	0.0	0.0	0.0	0.0	669.0	1,101.6	2,181.0	3,066.8
Off-Farm:									
Development Costs, Physical Systems									
Delivery System	0.0	6.2	6.2	47.1	99.5	1,084.9	1,129.4	1,930.3	2,175.6
Flood Protection	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	790.5
Delivery System Mgmt. (BIA)	0.0	100.0	150.0	200.0	200.0	200.0	230.0	270.0	300.0
Technical Assistance (SCS On-Farm)	0.0	6.4	24.3	47.4	52.3	56.7	59.9	66.1	72.9

[a]Total net return is defined as gross return minus variable cost, minus return to management, minus fixed machine cost, minus irrigation development cost.

Table 25. Marginal Cost, Marginal Return and Marginal Benefit/Cost Ratio by Increment, Incremental Analysis

Increment	Irrigation Development Cost($1000)[a]	Marginal Development Cost($1000)[b]	Return Above Total Cost Excluding Devl. Cost ($1000)[b]	Marginal Return Above Total Cost, Excl. Devl. Cost ($1000)	Return Above Total Cost ($1000)	Marginal Return Above Total Cost ($1000)	MB/MC Ratio[c]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	0.0		17,724.9		17,724.9		
		264.8		1,792.9 (1,402.5)[d]		1,528.1	6.8 (5.2)[d]
1	264.8		19,517.8 (19,127.4)[d]		19,253.0		
		486.6		7,787.7 (7,358.9)		7,301.1	16.0 (15.1)
2	751.4		27,305.5 (26,486.3)		26,554.1		
		1,763.4		9,383.6 (8,001.5)		7,620.2	5.3 (4.5)
3	2,514.8		36,689.1 (34,487.8		34,174.3		
		1,075.0		1,635.0 (1,536.9)		560.0	1.5 (1.4)
4	3,589.8		38,324.1 (36,024.7)		34,734.3		
		790.5		1,971.6		1,181.1	2.5
5	4,380.3		40,295.7		35,915.4		
		534.0		1,468.6		934.6	2.8
6	4,914.3		41,764.3		36,850.0		
		1,970.3		2,395.8		425.5	1.2
7	6,884.6		44,160.1		37,275.5		
		2,007.6		3,419.0		1,411.4	1.7
8	8,892.2		47,579.1		38,686.9		

Table 25, Continued

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[a]Irrigation development costs by Increment are displayed in Table 21.

[b]Marginal Development Cost was comuted as the change in Irrigation Development Cost (column 2) from one Increment to the next.

[c]"Return above Total Cost, Excluding Development Cost' represents Gross Return minus Total Variable Cost, minus Return to Management, Minus Fixed Machine Cost (Table 24). Increased IWM charge was deducted from total Variable Cost, to be included as a development cost (Table 21).

[d]"Marginal Benefit/Cost Ratio' represents the change in Total Return above Total Cost, excluding Development Cost' (Column 5) relative to the change in Irrigation Development Cost by Increment (column 3).

[e]Marginal net returns associated with Increments 1-4 reflect increases in per-acre returns with system improvements as well as increased returns resulting from assumed reductions in idle acreage. Values in parantheses represent returns and benefit/cost ratios due to increases in per acre returns alone.

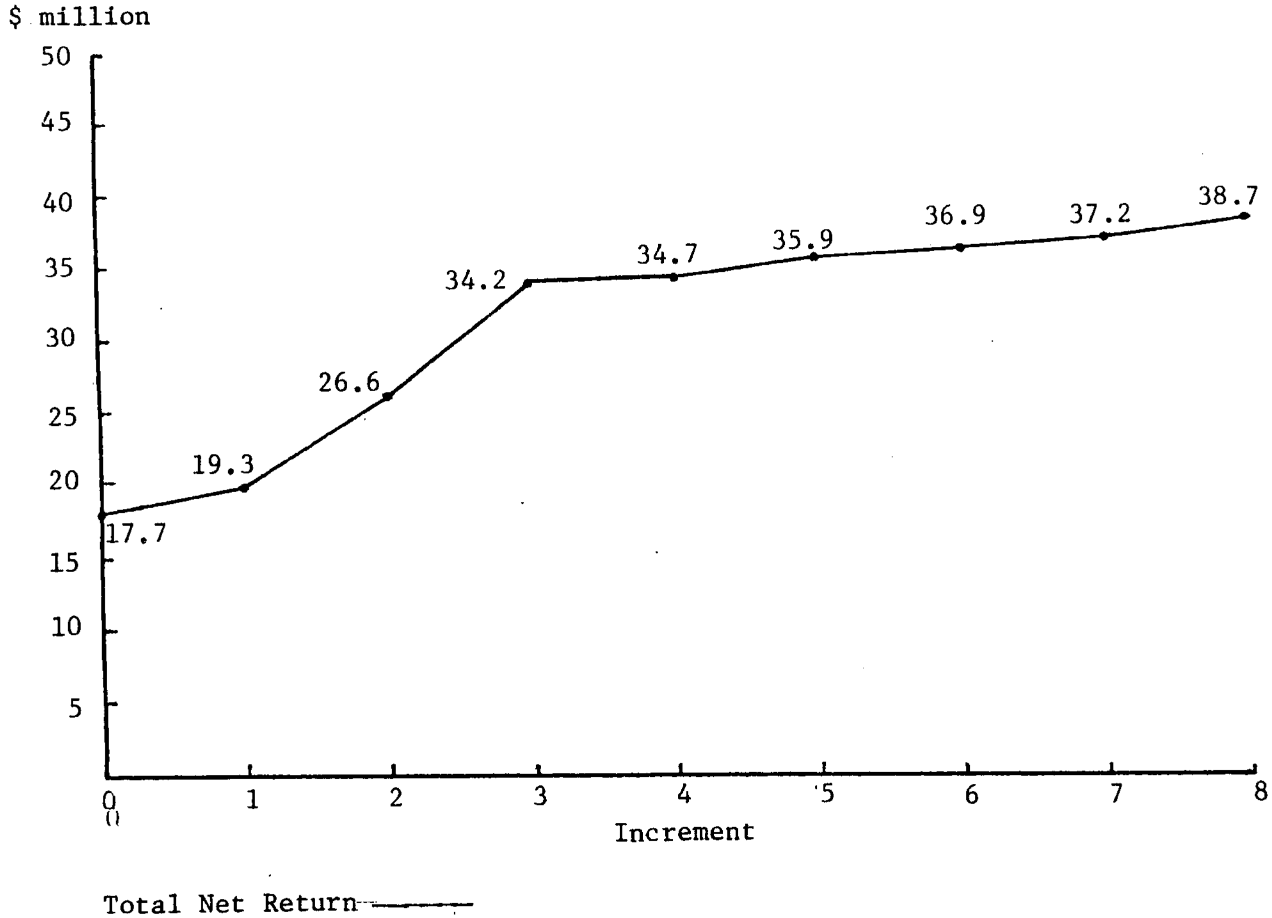

Figure 3. Total Net Return by Increment

total net return resulting from additional irrigation improvements introduced by Increments.[1] (Figure 4).

Marginal benefit/cost ratios were computed for categories of irrigation development introduced by Increment. Marginal benefit/cost ratios represent the change in total net return over production cost relative to the change in total irrigation development cost.[2] The marginal benefit/cost ratio may be interpreted as the long-term return to dollars invested by category of irrigation system development[3] (Figure 5).

Water use efficiency and total water use by Increment are displayed in Table 26. Adjustments in on-farm water use efficiency reflect reduced water application requirements on improved irrigation systems. Adjustments in off-farm system efficiencies reflect reduced on-farm water losses due to canal seepage and spills.

Estimated acre-feet of water delivery required for crop production was computed from the model solutions, based on assumed cropping patterns and on-farm water use efficiencies. Total potential farm

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1. Marginal net returns by Increment include increased returns attributed directly to improvements in irrigation systems well as increased returns resulting from reductions in idle acreage associated with system development (Table 25, Footnote e).

2. Return above production cost represents return above total cost, excluding development cost.

3. Benefit/cost estimates for physical system improvements reflect a long-term period of fifty years and (social) discount rate of 8.125% as required for federal water projects under Principles and Guidelines. Estimated benefit/cost ratios do not necessarily reflect private returns to investments in irrigation system development.

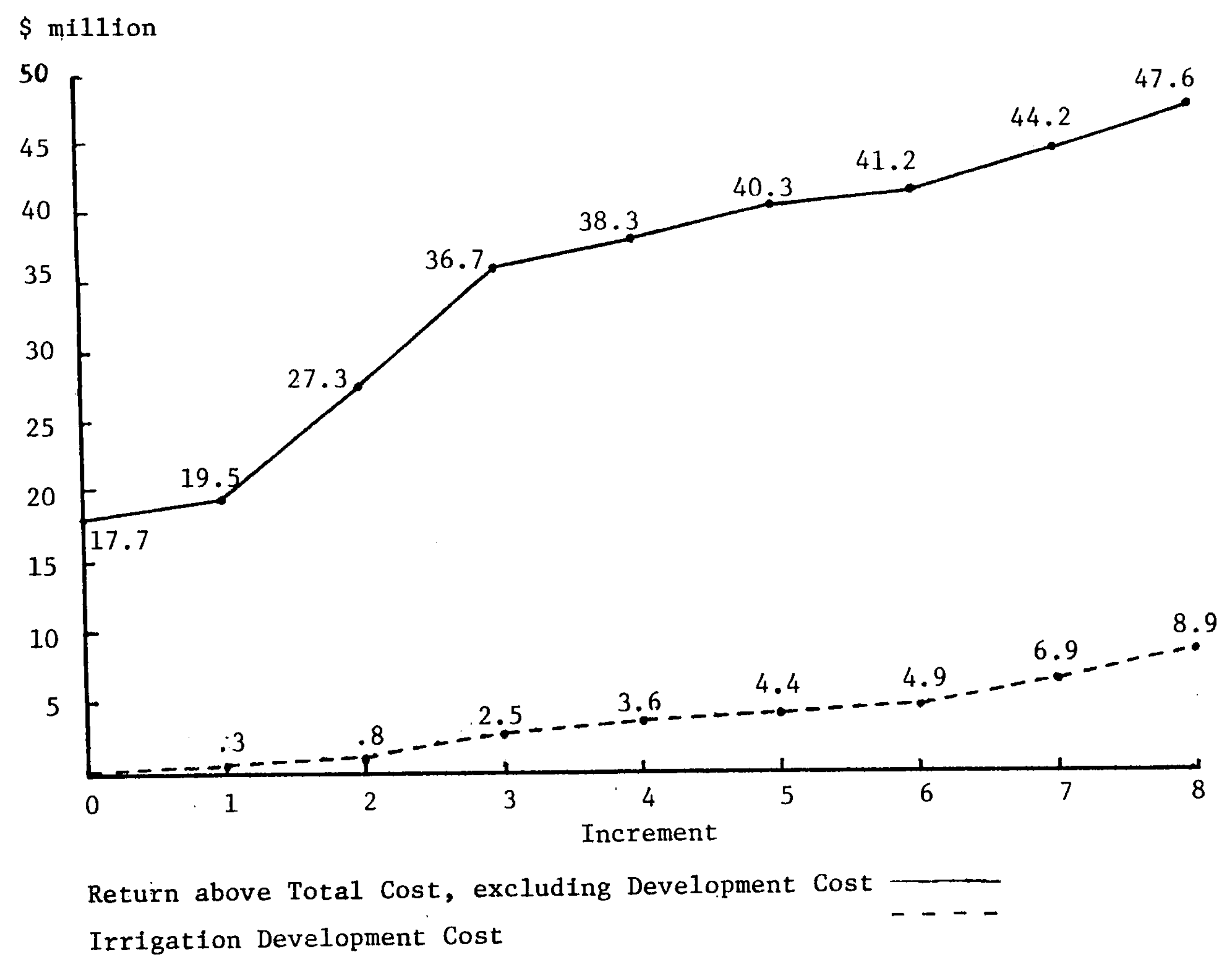

Figure 4. Irrigation Development Cost and Return above Total Cost excluding Development Cost by Increment

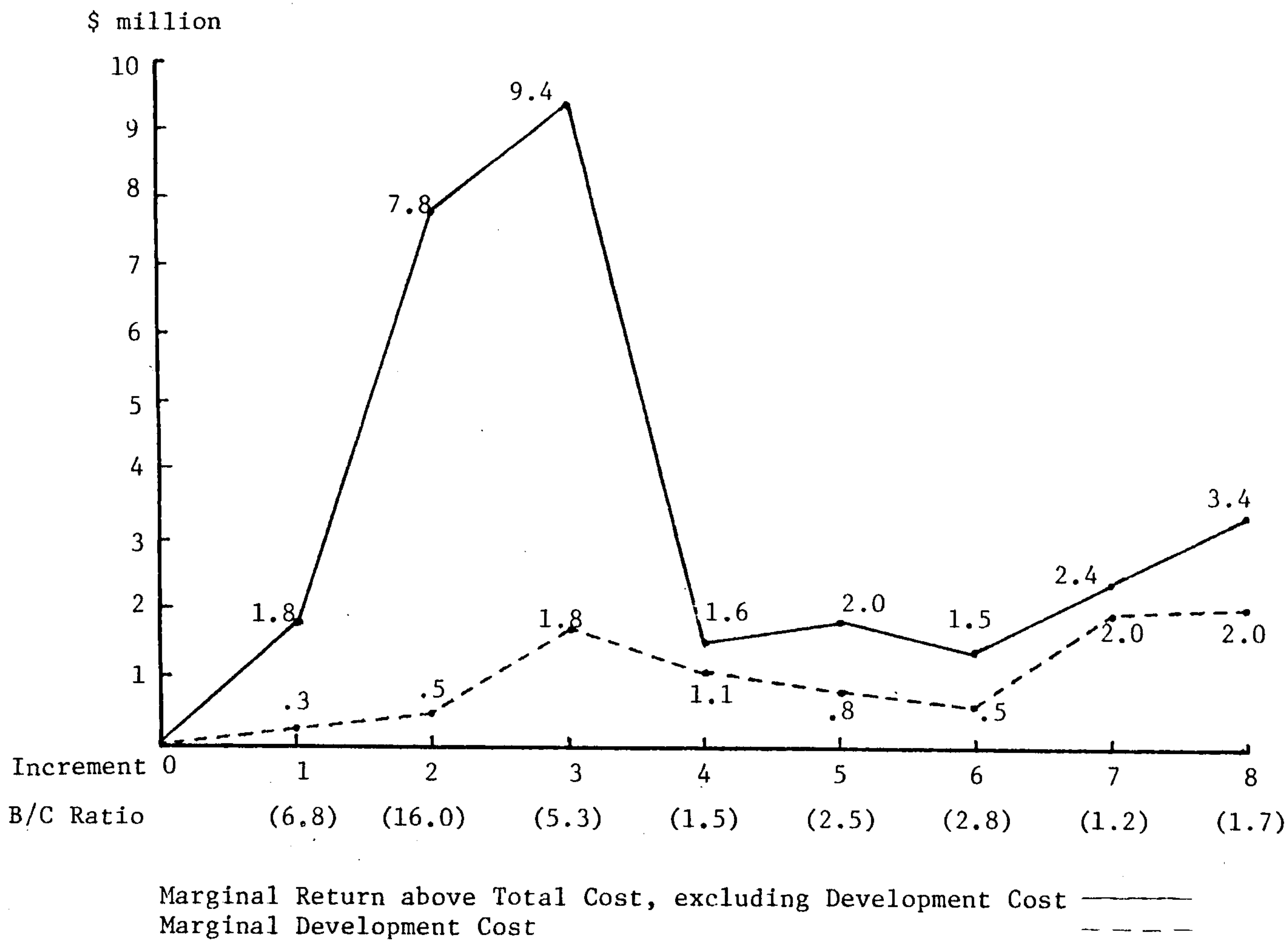

Figure 5. Marginal Development Cost, Marginal Return above Total Cost excluding Development Cost, and Marginal B/C Ratio by Increment

Table 26. Cost and Return Summary by Increment, Incremental Analysis

	INCREMENT								
	0	1	2	3	4	5	6	7	8
Total Water (AF)									
Water Entitlement, Arizona	662,402	662,402	662,402	662,402	662,402	662,402	662,402	662,402	662,402
Total Diversion[a]	629,543	574,355	517,512	447,030	386,375	417,240	438,439	492,754	531,213
Total Farm Delivery[b]	509,930	499,689	450,236	388,916	356,539	388,033	407,748	458,261	494,028
Total Irrigation Requirement[c]	266,458	270,621	273,062	283,124	282,730	305,121	319,263	354,365	383,463
Total Potential Farm Delivery[d]	540,000	568,000	568,000	568,000	618,000	618,000	618,000	618,000	618,000
Average per Developed Acre (AF)									
Water Entitlement, Arizona	9.1	9.1	9.1	9.1	9.1	8.5	8.1	7.5	6.9
Total Diversion	8.7	7.9	7.1	6.2	5.3	5.4	5.4	5.6	5.5
Total Farm Delivery	7.0	6.9	6.2	5.4	4.9	5.0	5.0	5.2	5.1
Total Irrigation Requirement	3.7	3.7	3.8	3.9	3.9	3.9	3.9	4.0	4.0
Irrigation System Efficiency (%)									
On-Farm Systems[e]	52.3	54.2	60.7	72.8	79.3	78.6	78.3	77.3	77.6
Off-Farm Delivery System[f]	81.0	85.0	85.0	85.0	93.0	93.0	93.0	93.0	93.0
Irrigation Water Expenditures[g]									
Total ($ million)	1,988.3	1,940.1	1,705.5	1,392.1	1,206.4	1,310.0	1,376.7	1,571.2	1,681.5
Average per Developed Acre ($)	27.4	26.7	23.5	19.2	16.6	16.9	16.9	17.8	17.5
Marginal Value of Water Supply ($)[h]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average Value of Water ($)									
(GR - (TVC))/AF	57.7	62.6	86.9	125.5	141.0	136.4	134.7	126.9	127.0
(GR - (TVC, Rent, Dev Cost))/AF	38.2	42.6	65.7	99.0	112.2	108.0	106.5	99.3	99.4
(GR - (TVC, Rent, Dev Cost, Mach Cost))/AF	20.9	24.8	45.7	75.3	86.2	82.8	81.6	75.6	75.7

Table 26, Continued.

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[a]Estimated diversion represents the diversion necessary to meet farm delivery requirements, based on the efficiency of the off-farm delivery system.

[b]Farm Delivery represents the total water required at the farm level, based on cropping patterns and on-farm irrigation system efficiences.

[c]Irrigation requirements represents total crop consumptive use, plus leaching and 'special requirements' minus effective rainfall.

[d]Potential farm delivery represents total water available for farm delivery, based on total water entitlement and efficiency of the off-farm delivery system.

[e]On-farm system efficiency was computed as the total irrigation requirement divided by total farm delivery.

[f]Off-farm delivery system efficiency was computed of total farm delivery divided by total diversion.

[g]Irrigation water expenditures are based on (BIA) water charges per acre-foot diverted; pumping costs are not included.

[h]Marginal value of water supply represents the net value to agriculture of one additional acre-foot of water available for farm delivery.

[i]Average value of water represents net return divided by total acre-feet of farm delivery. Average value of water was computed for three different measures of net return; (1) gross return above variable cost, (2) gross returns above variable cost, land rent and development cost, and (3) gross return above variable cost, land rent, development cost and fixed machine cost.

delivery (i.e., water entitlement divided by off-farm system efficiency) was computed outside the model. The difference between total potential farm delivery and farm delivery represents unused potential farm delivery available for (additional) new land development (Figure 6).

Water savings computed for categories of irrigation improvements by Increment are displayed in Table 27. Water savings reflect both improved on-farm water use efficiencies and improved off-farm delivery system efficiency. Water savings by Increment were based on the change in unused potential farm delivery resulting from irrigation improvements introduced. Water savings per dollar of irrigation development were estimated by category of improvements on existing irrigated lands.

Acreage, cost and returns, and water use by new land Increment are displayed in Table 28. Average net returns and average water use per new land acre were estimated for categories of new land evaluated.

Increment 0

Increment 0 represents the base year condition, modified for comparion purposes in the Increment Analysis. Acreage distribution by irrigation system under Increment 0 is indentical to that given in the initial base year model. Increment 0 differs from the initial base year model with respect to the water supply constraints and land lease scenarios specified.[1]

---

1. Under the initial base year model, the water supply constraint was fixed at the actual estimated total farm delivery in the base year. Under Increments 0 through 8, the water suppply constraint represents estimated total potential farm delivery, i.e. total water entitlement divided by estimated off-farm system efficiency.

Table 27. Farm Delivery, Marginal Water Savings and Water Savings per Dollar of Marginal Cost by Increment, Incremental Analysis

Increment (1)	Total Acres (2)	Total New Land Acres (3)	Total Potential Farm Delivery (AF)[a] (4)	Estimated Farm Delivery (AF)[a] (5)	Total Unused Potential Farm Delivery (AF) (6)[b]	Marginal Benefit, Water Saved (AF) (7)[c]	Marginal Development Cost ($1,000) (8)[d]	Water Savings (AF) per dollar of Marginal Cost, (9)[e]
0	72,630	0	540,000	509,930	30,070			
						38,241	264.8	.14
1	72,630	0	568,000	499,689	68,311			
						49,453	486.6	.10
2	72,630	0	568,000	450,236	117,764			
						61,330	1,763.4	.03
3	72,630	0	568,000	388,916	179,084			
						82,377	1,075.0	.08
4	72,630	0	618,000	356,539	261,461			
						-31,494	730.5	—
5	72,630	5,062	618,000	388,033	229,967			
						-19,715	534.0	—
6	72,630	8,724	618,000	407,748	210,252			
						-50,513	1,970.3	—
7	72,630	15,782	618,000	458,261	159,739			
						-35,767	2,007.6	—
8	72,630	23,588	618,000	494,028	123,972			

[a]Total Potential Farm Delivery and estimated Farm Delivery by increment are displayed in Table 26.

[b]Total unused Potential Farm Delivery was computed as the difference between total Potential Farm Delivery (column 4) and estimated farm delivery (column 5).

[c]Marginal benefit, Water Saved was computed as the change in total Unused Potential Farm Delivery (Column 6) from one increment to the next.

[d]Marginal Development Cost (Table 25, column 3).

[e]Water Savings (AF) per dolair of Marginal Cost was computed as Marginal Benefit, Water Saved (column 7) divided by Water Savings at Marginal cost (column 9).

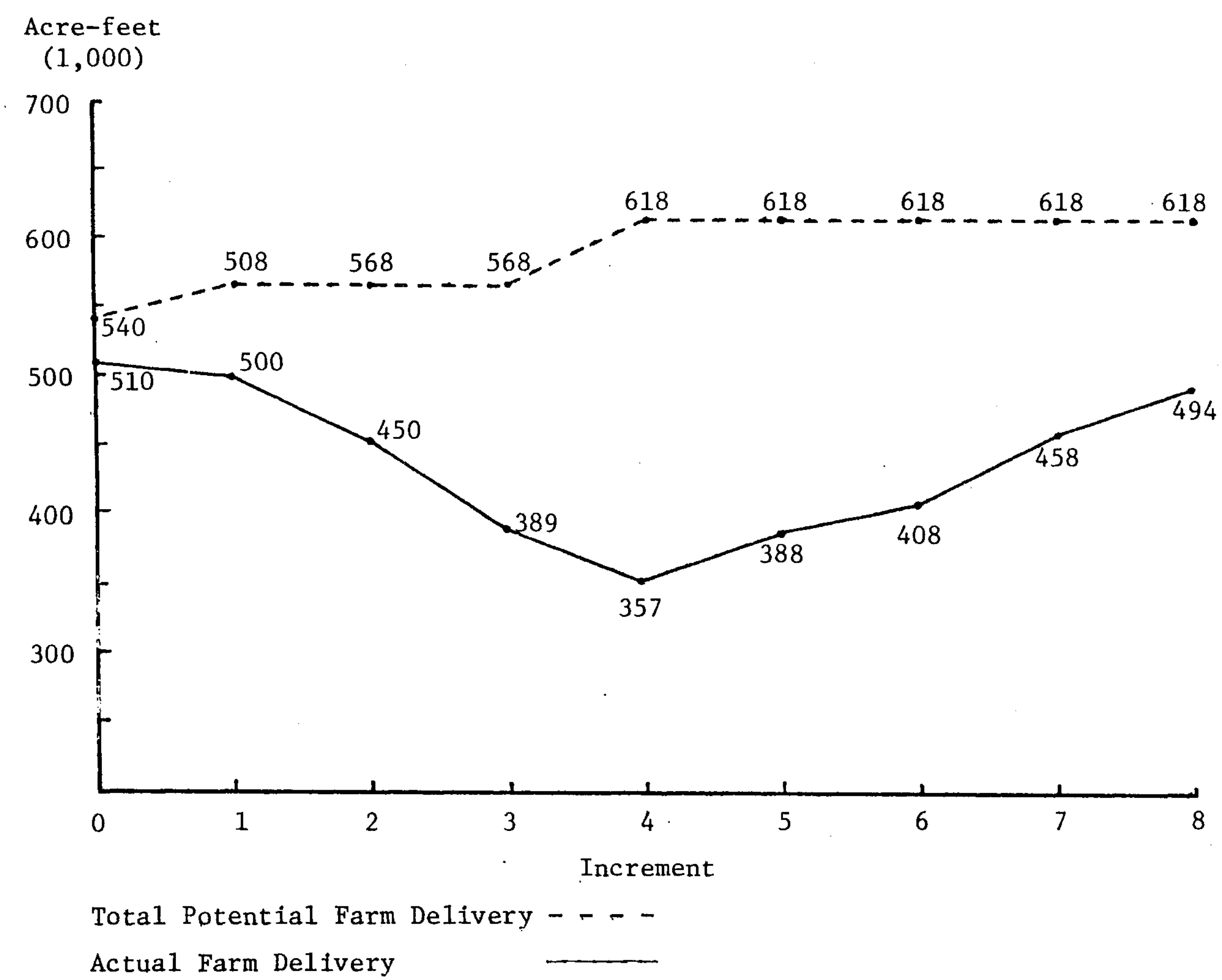

Figure 6. Acre-feet of Total Potential Farm Delivery and Actual Farm Delivery by Increment

Table 28. Cost, Return and Water Use by New Land Increment, Incremental Analysis[a]

	INCREMENT				
	4	5	6	7	8
Acreage					
Total Net Acres	72,630	77,692	81,354	88,412	96,128
New Land Acres Developed	—	5,062	3,662	7,058	7,806
New Land Acres, Cumulative Total	—	5,062	8,724	15,782	23,588
Costs and Returns					
Total Net Return ($ million)	34.7	35.9	36.9	37.3	38.7
Marginal Net Return, New Lands ($ million)	—	1.2	.9	.4	1.4
Marginal Net Return per New Land Acre ($)	—	232.	255.	61.	181.
Total Gross Return ($ million)	81.1	85.5	89.1	94.3	102.5
Marginal Gross Return New Lands ($ million)	—	4.5	3.6	5.3	8.2
Marginal Gross Return per New Land Acre ($)	—	881.	970.	745.	1,047.
Total Development ($ million)	3.6	4.4	4.9	6.9	8.9
Marginal Dev. Cost, New Lands ($ million)	—	.8	.5	2.0	2.0
Marginal Dev. Cost per New Land Acre ($)	—	156.	146.	279.	257.
Water Use (AF)					
Total Farm Delivery	356,539	388,033	407,748	458,261	494,028
Marginal Farm Delivery, New Lands	—	31,494	19,715	50,513	35,767
Farm Delivery on New Lands, Cumulative Total	—	31,494	51,209	101,722	137,489
Farm Delivery per New Land Acre	—	6.2	5.4	7.2	4.6

[a]New Land Increments include those increments in which new lands are evaluated (Increments 5-8). Data are displayed for Increment 4 as these values were used in computing marginal estimates for Increment 5.

Increment 1

Under Increment 1, improvements in on-farm and off-farm irrigation water management (IWM) were introduced on existing physical irrigation systems. Improvements in on-farm water management involve soil moisture monitoring, irrigation scheduling and measurement of water applications. Improvements in off-farm water management involve scheduling of water deliveries and regulation of water flows. Improved levels of water management reflect increased and better qualified on-farm and off-farm system personnel, plus installation of portable measuring devices and small-scale structures such as check gates and on-farm measuring flumes.

With improved water management practices on existing systems under Increment 1, acreage under water management increased from 11,475 acres (16%) to 32,835 acres (45%). Improvements in on-farm water management were limited to physical irrigation systems with capacity for high levels of management.[1] Improvements in IWM were further limited to 70% of existing developed acres which are not affected by structural limitations of the off-farm delivery system.

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1. Under the initial base year model, significant acreage is assigned to existing long term leases in which no additional physical improvements would be installed. Under Increments 0 through 8, this category of lease is removed to model further physical irrigation improvements on all existing developed acres.

Modifications in the base year condition under Increment 0 resulted in a model solution which differs slightly from the initial base year model solution (i.e., crop acres, crop production, water use efficiency, total net returns).

Irrigation systems with capacity for high levels of water management include RTA's 4 through 16, plus RTA 3 (fine and medium soils).

Total net return under Increment 1 was estimated at $19.3 million. The change in net return from Increment 0 to Increment 1, or the marginal return associated with Increment 1, was $1.5 million.

Total irrigation development cost under Increment 1 was estimated at $0.3 million. The change in return above production cost resulting from system improvements was estimated at $1.8 million. The marginal benefit/cost ratio for Increment 1 was 6.8.

With improved levels of off-farm delivery system management under Increment 1, off-farm system efficiency was increased from 81.0% to 85.0%. With improved levels of on-farm irrigation management, on-farm system efficiency was increased from 52.3% to 54.2%.

Total farm delivery requirements were decreased from 509,930 to 499,689 acre-feet with improved on-farm system efficiency under Increment 1. Potential farm delivery was increased to 568,000 acre-feet with improved off-farm system efficiency. Water savings resulting from system improvements introduced were estimated at 38,241 acre-feet. Water savings would provide for the irrigation needs of an estimated 6,593 acres of new land.[1] Approximately .14 acre-feet of water was saved per dollar of marginal system development cost under Increment 1.

---

1. Irrigation needs for new land acres were based on average estimated per-acre farm delivery requirements for 23,588 acres of new land evaluated, i.e. 5.8 acre-feet/acre. Farm delivery requirements were based on the assumption that highest efficiency systems (possible) are installed, and appropriate levels of water management are practiced.

Increment 2

Under Increment 2, on-farm physical system improvements were introduced on medium efficiency irrigation systems. Medium efficiency systems refer to semi-improved sloping irrigation systems with uniform field slope, recommended water run lengths and lined ditches.[1] Recommended system improvements involve land levelling and soil swapping.

With on-farm physical improvements introduced under Increment 2, acreage in level basin systems increased from 11,256 acres (16% surface systems) to 39,582 acres (55%). Acreage under water management increased from 32,835 acres (45%) to 35,950 acres (49%).

Total net return under Increment 2 was estimated at $26.6 million. The change in total net return from Increment 1 to Increment 2, or the marginal return associated with Increment 2, was $7.3 million.

Total irrigation development cost under Increment 2 was estimated at $0.8 million. Development cost associated with additional system improvements introduced under Increment 2 was $0.5 million. The change in total return over production cost resulting from system improvements was estimated at $7.8 million. The marginal benefit/cost ratio for Increment 2 was 16.0.

With physical improvements on medium-efficiency irrigation systems under Increment 2, on-farm system efficiency was increased from 54.2% to 60.7%. Off-farm system efficiency was assumed constant at 85.0%.

---

1. Medium efficiency irrigation systems include RTA's 4 through 6, plus RTA 3 (fine and medium soils).

Total farm delivery requirements under Increment 2 were decreased to 450,236 acre-feet with improved on-farm efficiencies. Water savings resulting from system improvements introduced under Increment 2 were estimated at 49,453 acre-feet. Water savings would provide for the irrigation needs of an estimated 8,526 acres of new land. Approximately .10 acre-feet of additional water was saved per dollar of marginal development cost under Increment 2.

Increment 3

Under Increment 3, on-farm physical system improvements were introduced on low efficiency irrigation systems. Low efficiency systems refer to poor irrigation systems with field slope (uniform and non-uniform), unlined ditches, and/or excessive water run lengths.[1] Recommended system improvements involve leveling and soil swapping, ditch-lining, and field reorganization.

With on-farm physical improvements introduced under Increment 3, acreage in level basin systems increased from 39,582 acres (55%) under Increment 2 to 71,540 acres (100%). Acreage served by lined ditches was increased from 41,761 acres (58%, surface systems) to 71,540 acres (100%). Field reorganization involving reduced water runs and additional ditch construction was implemented on 13,074 acres.

As a result of increased management potentials due to physical improvements on low efficiency systems, acreage under water management increased from 35,950 acres (49%) to 48,856 acres (67%).

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1. Low efficiency irrigation systems include RTA 1 and 2, plus RTA 3 (coarse soil).

Total net return under Increment 3 was estimated at $34.2 million. The change in total net return from Increment 2 to Increment 3, or the marginal return associated with Increment 3, was $7.6 million.

Total irrigation system development cost under Increment 3 was estimated at $2.5 million. Development cost associated with additional system improvements introduced under Increment 3 was $1.8 million. The change in total return over production cost resulting from system improvements was estimated at $9.4 million. The marginal benefit/cost ratio for Increment 3 was 5.3.

With physical improvements on low efficiency irrigation systems under Increment 3, on-farm system efficiency was increased from 60.7% to 72.8%. Off-farm system efficiency was assumed constant at 85.0%.

Total farm delivery requirements under Increment 3 were decreased to 388,916 acre-feet with improved on-farm efficiencies. Water savings resulting from system improvements introduced under Increment 3 were estimated at 61,320 acre-feet. Water savings would provide for the irrigation needs of an estimated 10,572 acres of new land. Approximately .03 acre-feet of additional water was saved per dollar of marginal development cost under Increment 3.

Increment 4

Under Increment 4, structural improvements were introduced on selected portions of the off-farm delivery system. Structural improvements include canal widening, canal lining and construction of farm and lateral turnouts with measuring flumes.

With structural improvements introduced under Increment 4, limitations on on-farm water management due to the off-farm physical system were removed. The level of acreage under water management increased from 48,856 acres (67%) under Increment 3 to 65,367 acres (90%).

Total net return under Increment 4 was estimated at $34.7 million. The change in total net return from Increment 3 to Increment 4, or the marginal return associated with Increment 4, was $0.6 million.

Total irrigation system development cost under Increment 4 was estimated at $3.6 million. Development cost associated with additional system improvements introduced under Increment 4 was $1.1 million. The change in total return over production cost resulting from system improvements was estimated at $1.7 million. The marginal benefit/cost ratio for Increment 4 was 1.5.

With structural improvements specified under Increment 4, off-farm system efficiency was increased from 85% to 93%. Improved levels of on-farm water management resulted in an increase in on-farm system efficiency from 72.8% to 79.3%.

Total farm delivery requirements under Increment 4 were decreased to 356,539 acre-feet with improved on-farm system efficiencies. Potential farm delivery was increased to 618,000 acre-feet with improved off-farm system efficiency. Water savings resulting from system improvements introduced under Increment 4 were estimated at 82,377 acre-feet. Water savings would provide for the irrigation needs of an estimated 14,203 acres of new land. Approximately .08 acre-feet of additional water was saved per dollar of marginal development cost under Increment 4.

Increment 5

Under Increment 5, 5,062 acres of new land development were introduced. New lands include acreage currently under development as well as acreage contracted for future development under existing long term lease arrangements.

Total net return under Increment 5 was estimated at $35.9 million. The change in total net return from Increment 4 to Increment 5, or the marginal return associated with Increment 5, was $1.2 million. Average net return per new land acre developed was estimated at $233/acre.

Total irrigation development cost under Increment 5 (existing plus new lands) was estimated at $4.4 million. Development cost associated with 5,062 acres of new land under Increment 5 was $.8 million. The change in total return over production cost resulting from new lands introduced was $2.0 million. The marginal benefit/cost ratio for Increment 5 was 2.5.

Total farm delivery requirements associated with 5,062 acres of new land under Increment 5 was 31,494 acre-feet. Average farm delivery requirement per new land acre was approximately 6.2 acre-feet.

Increment 6

Under Increment 6, an additional 3,662 acres of new land were introduced, resulting in 8,724 total acres of new land development. Additional new lands include acreage which may be developed with minimal to moderate expenditures in off-farm delivery system development.

Total net return under Increment 6 was estimated at $36.9 million. The change in total net return from Increment 5 to Increment 6, or the marginal return associated with Increment 6, was $.9 million. Average net return per additional new land acre developed was estimated at $255/acre.

Total irrigation development cost under Increment 6 was estimated at $4.9 million. Development cost associated with 3,662 additional acres of new land under Increment 6 was $.5 million. The change in total return over production cost resulting from new lands introduced was $1.5 million. The marginal benefit/cost ratio for Increment 6 was 2.8.

Total farm delivery requirements associated with 3,662 acres of additional new land under Increment 6 was 19,715 acre-feet. Average farm delivery requirement per new land acre was approximately 5.4 acre-feet.

Increment 7

Under Increment 7, an additional 7,058 acres of new land were introduced, resulting in 15,782 total acres of new land development. Additional new lands include acreage which may be developed only with heavy expenditures on off-farm delivery system development, excluding acres requiring flood protection. The majority of acreage in this category are outlying mesa lands proposed for development in sprinkler irrigation systems.

Total net return under Increment 7 was estimated at $37.3 million. The change in total net return from Increment 6 to Increment

7, or the marginal return associated with Increment 7, was $.4 million. Average net return per additional new land acre developed was estimated at $61/acre.

Total irrigation development cost under Increment 7 was estimated at $6.9 million. Development cost associated with 7,058 additional acres of new land under Increment 7 was $2.0 million. The change in total return over production cost resulting from new lands introduced was $2.4 million. The marginal benefit/cost ratio for Increment 7 was 1.2.

Total farm delivery requirements associated with 7,058 acres of additional new land under Increment 7 was 50,513 acre-feet. Average farm delivery requiremenmt per new land acre was approximately 7.2 acre-feet.

<u>Increment 8</u>

Under Increment 8, an additional 7,806 acres of new land were introduced, resulting in 23,588 total acres of new land development. Additional new lands include undeveloped acreage requiring flood protection.

Total net return under Increment 8 was estimated at $38.7 million. The change in total net return from Increment 7 to Increment 8, or the marginal return associated with Increment 8, was $1.4 million. Average net return per additional new land acre developed was estimated at $181/acre.

Total irrigation system development cost under Increment 8 was estimated at $8.9 million. Development cost associated with 7,806 additional acres of new land under Increment 8 was $2.0 million. The change in total return over production cost resulting from new lands introduced was $3.4 million. The marginal benefit/cost ratio for Increment 8 was 1.7.

Total farm delivery requirements associated with 7,806 acres of additional new land under Increment 8 was 35,767 acre-feet. Average farm delivery requiremenmt per new land acre was approximately 4.6 acre-feet.

CHAPTER 5

RECOMMENDATIONS FOR IRRIGATION SYSTEM DEVELOPMENT

Recommendations for irrigation system development on the CRIR are based on an analysis of costs and returns by Increment, as defined under the Incremental Analysis. The recommended level of irrigation system development is that which maximizes total annual net returns. Marginal net returns and water use associated with each Increment reflect the relative contribution of various categories of irrigation improvements evaluated.

Implementation of recommended system improvements will involve decisions by those involved in irrigation development on the CRIR--the farmers, the tribal landholders, and the federal government. Observations on the potential role of each group in the development process are discussed below. A more thorough analysis of how costs should be shared among groups concerned is beyond the scope of this thesis.

System Improvements on Existing Developed Acreage

Irrigation Water Management

Improved levels of water management on existing on-farm and off-farm physical irrigation systems involve increased and better qualified system personnel, plus installation of measuring devices and small-scale structures such as off-farm check gates and on-farm measuring flumes.

Improvements in irrigation water management are recommended based on the analysis (Increment 1). Improved levels of water management resulted in a substantial increase in net returns to agriculture on the CRIR.[1] Increased net returns reflect higher yields and reduced production costs with water management on existing systems. The benefit/cost ratio computed for improved water management supports the generally held notion that dollar returns are high.

Improved water management resulted in improved efficiencies in on-farm and off-farm systems. Water savings reflect improved efficiencies both on existing on-farm irrigation systems and on the off-farm delivery system. Investments in water management represent the most efficient means of saving water (acre-feet saved per dollar invested) among categories of irrigation system improvements evaluated.

Prospects for the implementation of improved water management are favorable. Outlays for improvements in water management--training of qualified system personnel plus related structures and equipment--are small relative to outlays for large scale physical system improvements. The majority of on-farm expenses could be covered by farm-operators without federal assistance. Government outlays would be limited to improvements in off-farm delivery system management and increased on-farm technical assistance.[2]

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1. See Footnote to Table 19, p. 65 for definition of net return.

2. On-farm technical assistance is considered essential to help farmers understand the advantages of IWM and to assist them in implementing improved management practices.

Substantial improvements in water management may be achieved with existing physical irrigation systems on the Reservation. However, levels of water management are limited by low management potentials on many existing systems. More significant increases in water management levels on the Reservation will be achieved only in conjunction with physical improvements in on-farm and off-farm irrigation systems.

Physical Improvements---Medium-efficiency Irrigation Systems

Physical improvements on medium efficiency on-farm irrigation systems involve land leveling with soil swapping as required.

The upgrading of semi-improved irrigation systems to high efficiency level basin systems is recommended based on the analysis (Increment 2). Physical improvements on semi-improved irrigation systems resulted in a large increase in net returns to agriculture. Increased net returns reflect higher yields and reduced production costs associated with level basin systems. The benefit/cost ratio computed for physical improvements on semi-improved systems was the highest among categories of irrigation improvements evaluated.

Further, physical improvements on semi-improved irrigation systems resulted in significant water savings. Water savings reflect improved efficiencies with level basin systems. Physical improvements on semi-improved systems represent an efficient means of saving water relative to other categories of physical irrigation improvements evaluated.

Although computed returns were significant, farmers may be somewhat reluctant to enter ten-year improvement leases in which physical improvements are required of the lessee. An improvement lease is acceptable to the farmer only if investments in system improvements can reasonably be recovered during the lease term. High market interest rates, cash-flow considerations, and concerns for investment risk may limit the farmers willingness to assume costly system improvements.[1] Further, farmers accustomed to more traditional sloping irrigation systems may be reluctant to invest in less familiar level basin systems.

Efforts to upgrade existing physical irrigation systems, on the other hand, may not have the full support of all tribal landholders. Under the terms of an improvement lease, landholders typically accept a reduced land rent over ten years in return for system improvements installed by the farmer. Private tribal landholders who depend on lease revenues as an important source of income may be reluctant to accept significant short-term reductions in rent under improvement leases.

Physical improvements on semi-improved irrigation systems may result in increased rental value of the land over the long term. Earning potentials with level basin systems under improved water management are likely to be reflected in future rental bids. However, rents paid for existing level basin systems were not significantly higher than rents paid for semi-improved sloping systems in 1981.

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1. Amortized development costs specified in the model were based on a fifty year amortization period and a discount rate of 8.125 percent, as required for use in federal water projects. Amortized costs faced by farmers would be more accurately based on a reduced amortization period equivalent to the duration of the lease and a discount rate approximating market interest rates for capital improvement loans.

Prospects for the implementation of recommended improvements on semi-improved irrigation systems are fairly good. Outlays for leveling and required soil swapping per acre are low relative to other categories of physical improvements evaluated. Further, the upgrading of on-farm physical irrigation systems on the Reservation currently has the support of the tribal council. As administrator of communal lands which comprise the majority of farmed acreage, the tribal council maintains considerable leverage over the implementation of physical improvements through stipulations defined in the lease contract.

An accelerated rate of farmer participation in improvement leases may depend on levels of federal assistance available in the form of cost-sharing for on-farm system improvements and associated technical assistance. Rates of farmer participation may also depend on the willingness of tribal landholders to assume short-term reductions in lease revenue in return for system improvements installed.

Physical Improvements---Low-efficiency Irrigation Systems

Physical improvements on low-efficiency on-farm irrigation systems include land leveling and soil swapping, ditchlining, and ditch construction with field reorganization. Levels of on-farm water management were increased as a result of increased management potentials associated with level basin systems.

The upgrading of poorly designed, low efficiency irrigation systems to high efficiency level basin systems is recommended based on the analysis (Increment 3). Physical improvements on low efficiency systems resulted in an additional increase in net returns to agriculture. Increased net returns reflect higher yields and reduced production costs associated with level basin systems and improved levels of on-farm water management. The benefit/cost ratio computed for improvements in low efficiency irrigation systems was significant, although lower than that for improvements in semi-improved systems. The reduced benefit/cost ratio for low efficiency systems reflects heavy outlays associated with ditch construction.

Further, improvements in low efficiency systems resulted in significant water savings. Water savings reflect substantially improved efficiencies with level basin systems and improved levels of water management. However, physical improvements on low efficiency systems represent the least efficient means of saving water among categories of irrigation improvements evaluated.

Prospects for the implementation of recommended improvements on low efficiency irrigation systems are fair. Increases in rental value with physical system improvements are substantial. Outlays for recommended improvements are high however relative to improvements on semi-improved systems. Although the upgrading of low-efficiency systems is supported by the tribal government, significant acreage in poor systems is controlled by private landholders who may not be interested in improvement leases. An accelerated rate of physical improvements on poor systems may require federal cost-sharing or significant short-term rental concessions on the part of tribal landholders.

Off-Farm Structural Improvements

Structural improvements in the off-farm delivery system include canal widening, canal lining and construction of farm and lateral turn-outs with measuring flumes. Levels of on-farm water management were increased as a result of improvements in off-farm delivery.

Upgrading of selected portions of the off-farm delivery system is recommended based on the analysis (Increment 4). Structural improvements in the off-farm delivery system resulted in a positive, although comparatively small increase in total net returns to agriculture. Increased net returns reflect higher yields and reduced production costs with improved on-farm water management. The benefit/cost ratio computed for off-farm structural improvements is low relative to other categories of system improvements evaluated for existing developed lands.

Off-farm structural improvements resulted however in substantial water savings. Water savings reflect reduced canal seepage losses as well as improved on-farm water management. Investments in off-farm structural systems represent a moderately efficient means of saving water relative to other categories of irrigation improvements evaluated.

Structural improvements in the off-farm delivery system are generally installed by the Bureau of Indian Affairs on behalf of the Tribe. Outlays for off-farm structural improvements are heavy. Implementation of recommended off-farm improvements will depend largely on levels of federal financing available through the Bureau of Indian Affairs.

New Land Development

Four levels of new land development were evaluated in the study. These include acreage under development or contracted for development under existing leases (Increment 5), unleased acreage requiring minimal off-farm development (Increment 6), acreage requiring heavy expenditures in off-farm development, excluding flood protection (Increment 7), and acreage requiring flood protection (Increment 8). Development of 23,588 acres of new land is recommended based on the analysis. Each Increment of new land evaluated resulted in an additional positive increase in net return to agriculture. Returns associated with investments in new land were low however relative to investments in existing (on-farm) irrigation systems.

Benefit/cost ratios for new land development were highest for lands requiring minimal off-farm development (Increment 5) and moderate off-farm development (Increment 6). The benefit/cost ratio for valley lands requiring flood protection (Increment 8) was somewhat lower. The benefit/cost ratio was the lowest for new lands on the mesa requiring heavy off-farm delivery system development (Increment 7).

Average irrigation requirements were moderate for lands requiring minimal off-farm development (Increment 5) and moderate off-farm development (Increment 6). Average irrigation requirement was highest for lands requiring heavy off-farm delivery system development (Increment 7), reflecting the comparatively low irrigation efficiences for mesa lands under sprinkler. Average irrigation requirement was lowest for lands requiring flood protection (Increment 8). Much of this land is prime valley land under heavier soils which has not been developed to date due to flooding.

The Tribe is actively seeking to expand its irrigated acreage base. New lands are offered at reduced rents under long-term lease arrangements in exchange for capital improvements installed by the farmer. Capital costs associated with on-farm system installation on new lands are high however, and new land development would not qualify for funding under proposed federal cost-share programs. Extensive off-farm development is also required for much of the proposed new land development, particularly for those parcels requiring heavy outlays in delivery system development and/or flood protection. Further, total water use on the Reservation is approaching the Tribe's total legal water entitlement. Levels of new land development may be limited for lack of irrigation water available.

The rate of irrigation system expansion on the CRIR will depend on a number of factors. Future water supplies for the irrigation of additional new land acreage depend on the increase in water use efficiency associated with improvements on existing irrigated systems. Federal funding through the Bureau of Indian Affairs of off-farm structural improvements may be required to open certain areas of the Reservation for irrigation development. Farmer participation in long-term development leases will depend on the attractiveness of lease terms offered by the Tribe as well as the availability of moderate cost capital improvement loans through government and private lending agencies. The level of external demand for farm cropland on the Reservation will ultimately depend on regional adjustments in land and water resource conditions, and future returns to irrigated agriculture.

Recommended Level of Irrigation System Development

All categories of irrigation development evaluated in the analysis resulted in a positive net return to agriculture. Total annual net returns to agriculture were maximized with levels of irrigation system development identified under Increment 8. Level of system development recommended include improvements evaluated for existing irrigated systems (Increments 1-4) as well as 23,588 acres of proposed new land development (Increment 5-8).

With recommended levels of irrigation system development, total annualized net returns increased from $17.5 million (base year) to $38.7 million. System improvements on existing irrigated acres accounted for an increase of $17.2 million. New land development accounted for an increase of $4.0 million.

Total cost for recommended levels of physical irrigation system development was estimated at $88.7 (unamortized). Physical system improvements on existing irrigated acres accounted for $33.3 million. This includes $23.6 million for on-farm system development and $9.7 million for related off-farm system development. Physical system improvements on new land acres accounted for $55.4 million. This includes $37.0 million for on-farm system development and $18.4 million for related off-farm system development.

Total annual cost of improved on-farm water management--existing and new lands--was estimated at $526,000. Total annual costs of improved off-farm (BIA) delivery system management--existing and new lands--was estimated at $300,000. Total cost of (SCS) technical assistance associated with on-farm system development was estimated at $73,000.

With recommended on-farm system improvements, on-farm irrigation efficiency was increased from 54% (base year) to 79%. With recommended off-farm system improvements, off-farm delivery system efficiency was increased from 81% (base year) to 93%. New land development resulted in an increase of 137,489 acre-feet of farm delivery required. However, improvements on existing irrigation systems resulted in a reduction of 153,391 acre-feet of farm delivery required on existing lands.

Average cotton yields on the Reservation were increased from 2.2 bales/acre (base year) to 3.1 bales/acre (Increment 4) with improvements on existing irrigated acres. Average alfalfa yields increased from 7.7 tons/acre to 10.3 tons/acre. Average yields for small grains increased from 2.3 tons/acre to 2.9 tons/acre. Average lettuce yields increased from 260 CWT/acre to 280 CWT/acre. Average melon yields held constant at 160 CWT/acre.

Total cotton production increased from 66,400 bales (base year) to 99,600 bales (Increment 4) with improvements on existing irrigated acres. Cotton production increased to 115,800 bales with proposed development on new lands (Increment 8). Alfalfa production increased from 203,200 tons to 271,400 tons with improvements on existing irrigated acres; production increased to 393,700 tons with new land development. Small grain production increased from 15,700 tons to 20,500 tons with improvements on existing systems; production increased to 29,800 tons with new land development. Lettuce production increased from 651,000 CWT to 701,000 CWT with improvements on existing systems; production increased to 832,600 CWT with new land development. Melon production held constant at 400,600 CWT with improvements on existing systems; production increased to 475,700 CWT with new land development.

Concluding Observations

With projected increases in on-farm and off-farm irrigation efficiencies under existing program levels (on-farm cost-sharing, on-farm SCS technical assistance and off-farm BIA system development) irrigation expansion on the CRIR would be substantially limited due to a lack of water available (12,400 acres). With recommended improvements on existing irrigation systems and highest efficiency systems installed on new lands, sufficient irrigation water would be available for development of all 23,588 acres of new land identified plus additional new lands (not yet identified). The actual amount of water available for new land development will depend on the extent to which irrigation efficiences are increased on existing developed lands.

Based on findings in the study, investments in existing irrigation systems have a generally higher return per dollar invested than investments in new land development. Improvements in irrigation water management and on-farm physical irrigation systems show the highest dollar return. Structural improvements in the off-farm delivery system have a comparatively low dollar return, although these result in substantial water savings. Irrigation system development programs should emphasize improving the productive capacity and water use efficiency levels of existing developed systems.

New land parcels requiring minimal or moderate off-farm system development (Increment 5 and Increment 6) are recommended for early development, based on estimated net returns and irrigation requirements per acre. New land parcels in the valley requiring flood protection (Increment 8) are recommended for development prior to new land parcels requiring heavy off-farm delivery system development--i.e., principally irrigated mesa lands proposed for sprinkler systems (Increment 7). Per acre net returns for new lands requiring flood protection exceed net returns for mesa lands requiring heavy off-farm development. Further, the per acre irrigation requirement for lands requiring flood protection was substantially lower than that for mesa lands under sprinkler irrigation.

Although the estimated long term net returns to irrigation system development were positive, implementation of recommended improvements are not likely to occur in the immediate future under on-going program levels. Low levels of irrigation management expertise, limitations on financial resources available for system development and institutional constraints involving restricted leasing terms discourage farmers from investing heavily in irrigation system development. Inducements may be required to increase the implementation rate of recommended system improvements. Inducements may be in the form of federal cost-sharing for on-farm system improvements and/or increased rental concessions from the Tribe.

Summary of Conclusions

1. All categories of irrigation development introduced in the analysis (Increments 1 through 8) resulted in a positive net return to agriculture. This includes proposed improvements for existing systems plus 23,588 acres of new land development. The recommended level of system development is that given under Increment 8.

2. With projected levels of irrigation development under on-going program levels, total water would be limiting on the amount of (identified) new land acreage which could be developed. Total water supply would not be a limiting factor of production on the CRIR, assuming levels of irrigation system development specified under Increment 8.

3. Improvements in existing irrigation systems have a generally higher return per dollar invested than new land development. Irrigation development programs should emphasize improving the productive capacity and water use efficiency of existing irrigation systems.

4. Development of new lands should be directed toward those parcels with the highest return per dollar invested. New lands requiring minimal and moderate off-farm system development are recommended for early development; valley lands requiring flood

protection (Increment 8) are recommended for development prior to mesa lands requiring heavy off-farm delivery system development (Increment 7).

5. In order to bring about a rapid implementation of irrigation system development on the CRIR, farmers may have to be induced to invest in recommended system improvements. Inducements may be in the form of federal cost-sharing and/or rental concessions from the Tribe.

Suggestions for Further Research

1. Changes in yields, water use requirements and other input requirements by on-farm irrigation system improvement were based on available field data and best judgement estimates. Additional field data is needed to increase the reliability of costs and returns associated with proposed system improvements on the CRIR. Field data is also needed to evaluate new irrigation technologies currently under development which may have applications on the CRIR, i.e., drip systems, drop-tube systems, surge-flow systems, etc.

2. The Colorado River Indian Tribes seek to have a more active role in determining the direction of development on the Reservation. Further research is needed to evaluate tribal management options with respect to irrigation system development. Tribal management options might involve such areas as agricultural leasing policy,

water allocation/pricing policy and tribal development of irrigation systems.

3. The CRIR water entitlement is institutionally locked into agriculture use on the Reservation. Thus water is fixed in a relatively low valued use and economic incentives to conserve on water use are lessened. Research is needed on the development and impact of water markets in the Southwest which would provide for the transfer of water into such uses as market forces dictate.

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