DESIGN OF WATER AND WASTEWATER SYSTEMS

FOR RAPID GROWTH AREAS

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IRRIGATION DEVELOPMENT POTENTIAL IN COLORADO

by

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INTRODUCTION

The primary purpose of this report is to project potential crop production levels for irrigated agriculture in Colorado. The projections provide plausible upper limits to new development that could be expected for eight regions of the state by 1990-1995

New development potentials are based primarily on additional water supplies that could be provided by all water development projects that have been proposed for Colorado by the U.S. Bureau of Reclamation. These projects range from the Frying Pan-Arkansas Project,which is actually nearing completion, to the Dotsero Division Project,which was last studied in 1954. Thus, while some of this new development will be realized by 1995, most of it will not. All possible projects in all regions could not be built without exceeding the total supply of water in Colorado. Moreover, many of the projects considered for supplying water to irrigation will never meet criteria for economic feasibility because of extremely high construction costs and the low productive agriculture that would be provided.

This report also estimates the gains in water supply that could be achieved by improving the efficiency of water use on currently irrigated lands. For this purpose, improved irrigation management, ditch lining, and new irrigation systems were considered as means of increasing water use efficiency in agriculture. The gains (losses) in water supply achieved in this manner are stated only in water terms and not related to changes in irrigated acreage which might be effected by such factors.

The state of Colorado was divided into eight regions for purposes of this study. These regions correspond to river subbasins within the state as shown by Figure 1. For the purpose of collecting agricultural acreage and production data, these regions are further delineated along county ines as indicated by Table 1. It is felt that very little distortion of actual river basin data results from the use of county agricultural data.

Figure 1. River Subbasins for the State of Colorado

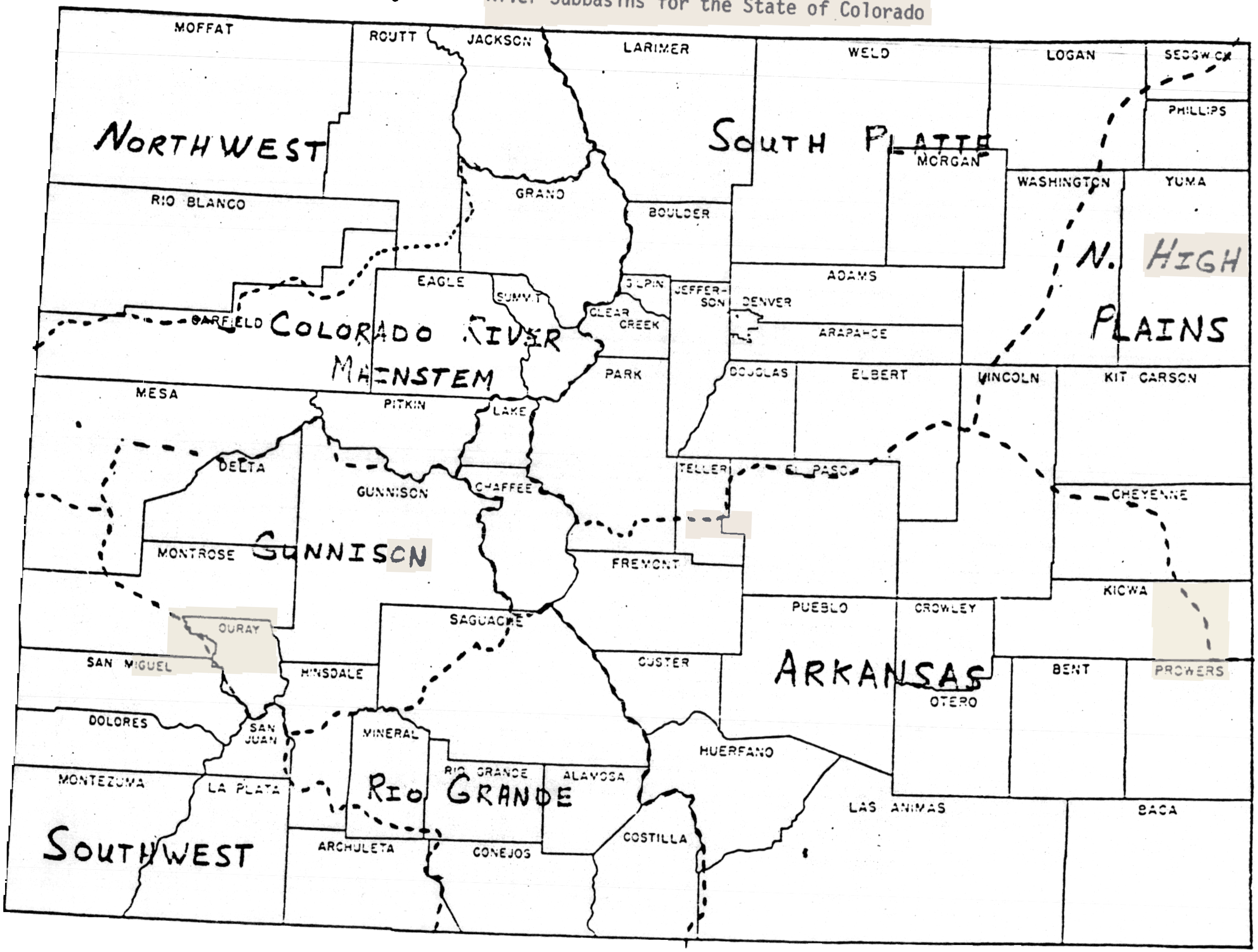


Table 1

COUNTIES IN COLORADO WATER BASIN REGIONS

Northwest

Jackson
Moffat
Rio Blanco
Routt

Gunnison

Delta
Gunnison
Hinsdale
Montrose
Ouray

Rio Grande

Alamosa
Conejos
Costilla
Mineral
Rio Grande
Saguache

Colorado River Mainstem

Eagle
Garfield
Grand
Mesa
Pitkin
Summit

N. High Plains

Cheyenne
Kiowa
Kit Carson
Lincoln
Phillips
Washington
Yuma

Southwest

Archuleta
Dolores
La Plata
Montezuma
San Juan
San Miguel

Arkansas

Baca
Bent
Chaffee
Crowley
Custer
El Paso
Fremont
Huerfano
Lake
Las Animas
Otero
Prowers
Pueblo

South Platte

Adams
Arapahoe
Boulder
Clear Creek
Denver
Douglas
Elbert
Gilpin
Jefferson
Larimer
Logan
Morgan
Park
Sedgwich
Teller
Weld

WATER CONSUMED FOR IRRIGATION

Irrig. Acreage

Estimated current irrigated acreage is shown in Table 2. These data are for the 1974 crop year except for hay, pasture and tree fruits, which are taken from the 1969 Census of Agriculture. These estimates of irrigated acreage form the basis for calculating current levels of water consumption future land use patterns for increased production, and gains in water supply from improved irrigation efficiencies.

Table 3 lists crop consumptive use data for each region of the state. The consumptive use or evapotranspiration needs of an individual crop are stated in terms of acre-feet per year and are net of the effective precipitation for a normal rainfall year. These coefficients do not include water requirements for such things as leaching, germination, or frost protection. Such requirements are accounted for in the on-farm efficiency values.

Irrigation Efficiency

Table 4 shows conveyance and on-farm efficiency coefficients for current methods of irrigation in Colorado. These data are labeled as 1977 The table also shows estimated efficiencies for conditions of improved management with current technology and efficiencies after ditch lining and improved on-farm irrigation systems are applied, labeled as management and technology, respectively. All of the data in this table were adapted from USDA (1976) and then adjusted to reflect the opinion and judgments of many experts interviewed during this investigation.

Definitions

Table 5 is included at this point to provide a clear definition of all terms related to this discussion. Improvements in conveyance efficiences reflected in Table 4 generally assume that all canals and laterals would

Table 2

ESTIMATED CURRENT IRRIGATED CROP PRODUCTION FOR

COLORADO RIVER BASINS [a/]

Crop	Northwest	Gunnison	Rio Grande	Colorado River Mainstem	North High Plains	Southwest	Arkansas	South Platte
	1,000 Acres							
Wheat - Winter	.8	1.8	.5	.8	19.6	1.9	44.1	14.3
Wheat - Spring	.4	2.0	2.9	.8	.9	.4		1.9
Corn - Grain		7.4		7.5	202.0	.1	69.6	171.4
Corn - Silage		8.2		5.2	31.5	1.8	24.3	163.7
Sorghum - Grain					3.7		66.2	1.5
Oats	.5	2.2	4.5	1.6	.6	.4	1.5	6.4
Barley	1.0	12.8	83.0	3.5	2.0	1.4	3.8	42.0
Orchard		6.9		4.3		.7	.01	
Vegetables - Deep		1.0	1.8	.7	.01	.04	7.3	11.9
Hay - Alfalfa	22.3	37.8	85.1	62.7	19.8	29.7	111.9	181.0
Hay - Other	106.8	53.7	82.2	57.1	7.4	16.5	22.7	61.9
Sugar Beets		3.3			18.5		4.42	54.2
Potatoes			34.0					274.4
Dry Beans		5.0		.3	67.9	.7	3.1	39.5
Cropland Pasture	32.5	40.2	62.9	39.1	9.7	44.5	34.5	40.2
Other Pasture	28.8	40.8	53.9	36.2	2.9	30.7	8.1	22.7
	193.0	223.1	411.2	219.8	386.51	128.84	401.53	1,087.0

[a/] All acreages data except for tree fruits, pasture and hay crops are taken from the 1976 Colorado Agricultural Statistics and, hence, are 1974 data. Acreages for tree fruits, pasture and hay crops are taken from the 1969 U.S. Census of Agriculture.

Table 3

CONSUMPTIVE USE IRRIGATION REQUIREMENTS FOR COLORADO CROPS

UNDER NORMAL YEAR PRECIPITATION

Crop	South Platte	High Plains	Arkansas	Rio Grande	North-west	Gunnison	Colorado River Mainstem	South-west
	Acre-Feet/Acre/Year							
Wheat	.70	.70	.80	.70	.70	1.10	1.10	.70
Corn Grain	1.10	1.10	1.30	.80	.90	1.70	1.70	1.10
Corn Silage	1.00	1.00	1.30	.60	.90	1.60	1.60	1.00
Sorghum Grain	1.00	1.00	1.20	.80		1.60	1.60	1.00
Sorghum Silage	1.00	1.00	.80	.60		1.50	1.50	1.00
Oats	.70	.70	.80	.70	.70	1.10	1.10	.70
Barley	.70	.70	.80	.70	.70	1.10	1.10	.70
Orchard (Deciduous)	1.40	1.40	1.60	1.00		1.60	1.60	1.40
Vegetables (Shallow)	.70	1.00	1.10	.70	.70			1.00
Vegetables (Deep)	1.00	1.60	1.30	1.10	.70	1.00	1.40	1.20
Hay (Alfalfa)	1.70	1.70	2.00	1.00	1.50	2.00	2.00	1.70
Hay (Clover-Grass)	1.50	1.50	1.80	1.00	1.40	1.50	2.00	1.50
Hay (Other)	1.40	1.40	1.60	.90	1.30	1.30	1.30	1.40
Hay (Seed)	1.60	1.50	1.90	1.00	1.40	1.60	2.10	1.60
Sugar Beets	1.50	1.50	1.80	1.50		1.50	1.40	
Irish Potatoes	1.30	1.30	1.50	1.00	1.10	1.30	1.60	1.30
Dry Beans	.90	.90	.90	.90		.90	.90	.90
Crop Pasture	1.40	1.40	1.60	.90	1.30	1.30	1.30	1.40
Other Pasture a/	.84	.84	.96	.54	.80	.78	.78	.84
Other Crops	.70	.70	.80	.70	1.40	.70	.80	.70

Source: USDA, 1976

a/ It was assumed that other pasture would be irrigated only to meet 60 percent of seasonal consumptive use requirements. This adjustment is reflected in these coefficients.

Table 4

CONVEYANCE AND ON-FARM EFFICIENCIES FOR IRRIGATION WATER PLUS INCIDENTAL LOSSES UNDER CURRENT AND IMPROVED TECHNOLOGY [a/]

Region	Conveyance Efficiency[e/]		On-Farm Efficiency[e/]			Incidental Loss[e/]			
	1977	Tech.[b/]	1977	Mgmt.[c/]	Tech.[d/]	1977	Mgmt.[c/]	Tech.[f/]	Ditch[g/]
	Percent								
South Platte	73	89	46	52	74	6	8	14	10
High Plains	96	96	58	60	80	10	10	15	10
Arkansas	64	75	52	54	74	12	12	14	14
Rio Grande	68	92	58	60	80	30	30	36	34
Northwest	70	89	32	38	68	8	8	10	9
Gunnison	70	89	38	44	68	12	12	10	11
Colorado River	70	90	35	40	70	10	10	10	10
Southwest	72	88	38	44	68	12	12	12	12

a/ Source: USDA, 1976, as adjusted by expert information. Based on normal yearprecipitation.
b/ Assumes lining of all delivery canals and laterals.
c/ Assumes current technology but improved irrigation management. (See table 5 for definition)
d/ Assumes most modern appropriate technology and improved management.
e/ See appendix for definition.
f/ Assumed to be used for a combination of lined ditches and new on-farm technology.
g/ These coefficients used for a combination of old technology and lined ditches.

Table 5

DEFINITION OF TERMS

Normal Year:

A year in which a 50 percent precipitation level is assumed on the irrigated area; i.e., that precipitation rate which is equaled or exceeded 5 years in 10.

Evapotranspiration:

The combination of evaporation from water surfaces, moist soil and transpiration from plants. It includes three major forms of water loss: (1) transpiration losses and uses by plants: (2) interception losses of precipitation caught by vegetation and evaporated; and (3) direct evaporation from soil, ice and snow surfaces not included in other terms.

Net Depletion (ND):

The total quantity of irrigation water consumed; i.e., that which is irrecoverable. Consumptive loss includes evapotranspiration by the crop and incidental consumptive losses (related to irrigation), but does not include evaporation from irrigation storage reservoirs.

Incidental Consumptive Losses:

Irrecoverable water losses incurred from irrigating crops that are not directly attributable to crop consumptive requirements. It includes evaporation from canals and fields during surface application, evaporation and drift loss from sprinkler systems and consumption by wildlife, flora, phreatophytes and hydrophytes in the irrigated areas. Deep percolation to local groundwater aquifers which is irrecoverable for use is also included. These losses are calculated as a percentage of total diversion requirements (GDR).

Crop Consumptive Irrigation Requirement (CIR):

The consumptive use or evapotranspiration of an individual crop, less the effective precipitation, over a particular period of time (usually monthly or annually). It does not include water requirements for leaching, germination, frost protection, wind erosion protection or plant cooling. (Such requirements are accounted for in the on-farm efficiency values.)

Farm Delivery (FD):

The quantity of water delivered to a farm; this exceeds the CIR due to on-farm application and distribution losses. It is calculated by dividing the CIR by the on-farm efficiency.

Table 5 (continued)

Gross Diversion Requirement (GDR):

The total quantity of water diverted from a stream, lake or reservoir, or removed from the ground in order to irrigate a particular crop. It is determined by dividing the CIR for a crop by the system efficiency for the farm on which that crop is grown. Water diversions or withdrawals cannot be used as a true indicator of total water demands because (1) some of the water diverted can be reused, usually downstream, and (2) the gross diversion requirement for a particular water resource area usually incorporates re-diversion of the same water.

Off-Farm Conveyance Efficiency:

The efficiency of the system that conveys the irrigation water from the diversion point to the boundary of the using farm. The loss of water from such a system includes operational losses and losses due to seepage, evaporation or transpiration by vegetation growing in or near the delivery channel. Each of these will reduce the effective conveyance efficiency. In cases where the water originates on the farm itself, such as from a well, the off-farm conveyance efficiency is assumed to be 100 percent and, consequently, the gross diversion requirement equals the farm delivery.

On-Farm Efficiency:

A combined efficiency that reflects the efficiency of the on-farm distribution system and the on-farm application system. An on-farm distribution system may consist of a series of ditches or pipes, and related appurtenances, which convey the water delivered to the farm to the appropriate field. The application efficiency is the ratio of the volume of water added to the root zone of a soil during irrigation to the total volume of water applied to that soil.

System Efficiency:

The net (combined) efficiency of the entire irrigation system, from the diversion point to the crop root zone. It can be calculated by either of two methods: (1) multiply the off-farm conveyance efficiency by the on-farm efficiency, or (2) divide the CIR by the GDR.

be lined with concrete. Though even higher conveyance efficiences could be achieved in many cases, these figures reflect the assumed practical limits of efficiency that could be achieved without going to completely enclosed pipeline delivery systems.

Current on-farm efficiency coefficients in Table 4 represent those levels of water use efficiency assumed to exist on farms today. It was assumed that 2 to 6 percent improvement could be achieved in current on-farm efficiencies by just improving the irrigation management input. Those areas with relatively high on-farm efficiences now were assumed to have lower gains from increased management inputs than those with currently low on-farm efficiencies

Changing from current irrigation methods to the most modern practical methods of irrigation was assumed to raise on-farm efficiences into the 68-80 percent range. Generally, these changes would entail the substitution of some form of sprinkler irrigation for current rill or flood irrigation methods. Since these efficiency coefficients represent an average for all crops produced throughout a region there is also implied potential for drip irrigation methods on tree fruits and efficient rill or flood irrigation methods where they would be more advantageous than sprinklers

The third set of coefficients in Table 4 represent incidental losses of water that occur in addition to that consumed by crops. Incidental losses are calculated as a percentage of gross diversion requirements (GDR) They represent losses to evaporation, phreatophytes, field borders, unrecovered deep percolation, etc. Thus, total water depletion in any stream is the sum of crop consumptive use or crop irrigation requirement (CIR as defined in Table 5 and incidental losses. Incidental loss coefficients are shown for the current situation, improved management, ditch lining, and new technology which includes ditch lining and new on-farm systems. Further specifying:

Ce = conveyance efficiency

Fe = on-farm efficiency

Se = system efficiency

ND - net depletion

IL = incidental loss

We may then define:

$$GDR = \frac{CIR}{Ce \cdot Fe} \qquad \frac{CIR}{Se}$$

$$IL = GDR\ (\text{percent } IL)\ ,\ \text{and}$$

$$ND = CIR + IL$$

Water Depletion Requirements

The total net depletion of water by agriculture estimated in this analysis is shown in Table 6. These data are based on the above stated procedure and summarized from the information in Appendix Tables A-1 to A-8. Net depletions by agriculture estimated in this study are shown to be 4,938,820 acre-feet per year. These estimates are compared to those provided by the Colorado State Water Plan (USDI, 1974 , which were calculated for the year 1970. After accounting for a difference of High Plains ground water use of about 300,000 acre-feet, the USDI (1974) estimate would be 4,477,000 acre-feet. Thus, this study estimates net water depletions to exceed those of the USDI by 481,000 acre-feet per year. The estimates of net water depletion provided by this study are based upon an assumption of full water supply for all crops except pasture. Hence, it is probable that this assumption leads to excessive estimates of water depletion in some areas of the state. This would be particularly true for parts of the Upper Colorado River Basin where a large share of cropland is devoted to hay crops

Table 6

SUMMARY OF NET DEPLETION OF WATER BY REGION

COMPARED TO ALTERNATIVE ESTIMATES OF SIMILAR DATA

Region	Net Depletions		
	Current Study [a]	Colorado State Water Plan [b]	OBERS [c]
	1,000 Acre-Feet		
South Platte	1,595.57	1,251	1,451.6
High Plains	498.96	220	147.7
Arkansas	795.02	704	866.1
Rio Grande	606.23	617	597.3
Northwest	324.62	221	324.8
Gunnison	431.85		419.0
Colorado River Mainstem	444.76	969 [d]	436.0
Southwest	241.81	195	277.2
Tota	4,938.82	4,177	4,519

[a] These data were estimated in this study by applying the coefficients shown in Tables 2, 3 and 4. They assume full water supply for all crops except pasture.

[b] USDI, Phase I, 1974. These data do not include deep well pumping in the High Plains representing about 300,000 acre-feet of water.

[c] These estimates are based on unpublished OBERS 1975 acreage estimates. They assume a full water supply for all crops and, hence, probably overestimate actual net depletions. Developed by John D. Hedlund, Special Projects Division, S.C.S., USDA as provided by Ivan Wymore, CSU.

[d] Includes the Gunnsion Region

The estimates of this study are also compared to unpublished data calculated from 1975 OBERS acreage data and water use coefficients similar to those used in this study. After accounting for a difference in High Plains groundwater use of 351,000 acre-feet the OBERS data would show a total net depletion for the state equaling 4,870,700 acre-feet, a deviation of only 1 percent from the estimate in this study.

INCREASED WATER SUPPLIES

One major purpose of this study was to estimate the upper limit of agricultural expansion that could be expected by year 1995 The basic assumption underlying the procedure of this analysis was that water is the limiting factor for irrigated agricultural growth throughout the state Water available for growth was estimated from supplies that would be made available by various USBR projects proposed for development throughout the state These projects and their water supply contributions are shown in Table A-9

There were two exceptions to the strict use of water supplied by USBR projects. In the High Plains Region, it was assumed that 500-1500 additional deep wells would be drilled by individual farmers. Each well was assumed to provide 168 acre-feet of water per year of which 153 acre-feet would be available for depletion by agriculture. The second exception resulted from assumed municipal sewage outflow increases to the South Platte River equaling 150,000 acre-feet per year It was assumed that two-thirds or 100,000 acre-feet of this water would be available for depletion by agriculture

Table 7 summarizes the water available for depletion by increased agricultural development. It is specifically assumed that no water is available for expansion of agriculture in the Rio Grande Basin. Further it should be noted that the data in this table are not additive. While some of this development will surely occur, such as in the High Plains Region, it would be impossible to develop all of these water supplies without exceeding the total amount of water available to Colorado. These figures represent upper limits within basins that will have to be

Table 7

SUMMARY OF WATER AVAILABLE FOR IRRIGATION

DEVELOPMENT IN COLORADO

Region [a]	Water Available for Depletion
	Acre-Feet
Northwest	257,600
Gunnison	91,100
Colorado River Mainstem	193,700
Southwest	171,150
South Platte	170,000
Arkansas	66,500
Northern High Plains	
500 new wells	76,500
1,000 new wells	153,000
1,500 new wells	229,500

[a] It is assumed that the Rio Grande Region has no opportunity for expansion from new water supplies. These data are taken from Table A-9.

considered as competitive with development in other regions, particularly for all those regions lying within the Upper Colorado River Basin. Also these water supplies will have to be considered for use by all other competitive water using activities (e.g., energy, M & I, fish and wildlife)

Tables 8 through 14 contain estimates of equivalent full irrigation that could result from increased water supplies in each region. For each region a land use pattern has been projected for potential increased agriculture. In most cases the future pattern of agriculture is assumed to be quite similar to that of the present. In general, there will be increased production of food and feed grains when they are adaptable. Forages, particularly alfalfa hay, are assumed to remain strong competitors for land use. Sugar beets are assumed to have limited markets and are not expanded in proportion to increases in irrigated land. Tree fruits are considered to be generally unadaptable to most of the new lands to be brought under production

The coefficients of water depletion per acre shown in Tables 8 through 14 are taken from Tables A-1 through A-8. A weighted average of these coefficients based on future land use patterns was used to estimate total expansion acreage. (Water for depletion ÷ weighted average water depletion per acre = total acreage for new development.)

A brief discussion of expansion opportunities in each individual region follows

South Platte

It is estimated that an additional 115,646 acres of equivalent full irrigation may be expected in the South Platte Region as shown in Table 8 The source of water for increased development in this region is expected to be the Narrows Project providing 70,000 acre-feet of water, and municipal return flows providing about 100,000 acre-feet of water for depletion

Table 8

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION IN THE SOUTH PLATTE REGION

Crop	1974 [a/] Land Use	Projected for Expansion	Water [b/] Depletion Per Acre	Acreage of New Development
	Percent	Percent	Acre-Feet	Acres
Wheat	1.49	4.00	.82	4,626
Corn Grain	15.77	18.00	1.30	20,816
Corn Silage	15.06	16.00	1.18	18,503
Barley	3.86	4.00	.82	4,626
Sorghum Grain	.14			
Dry Beans	3.63	4.00	1.06	4,626
Sugar Beets	4.99	5.00	1.77	5,782
Oats	.59			
Alfalfa	16.65	20.00	2.00	23,129
Other Hay	5.69	2.00	1.65	2,313
Potatoes	25.25	20.00	1.53	23,129
Pasture	5.79	6.00	1.65	6,939
Vegetables	1.09	1.00	1.18	1,156
	100.00	100.00	1.47 wt. av.	115,646 [c/]

a/ Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data are from the Colorado State Agricultural Statistics.

b/ Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from Tables A1-A8.

c/ Equivalent full irrigation based on available water supply of 170,000 acre-feet.

Table 9

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION

IN THE NORTHERN HIGH PLAINS REGION

Crop	1974 [a/] Land Use	Projected for Expansion	Water [b/] Depletion Per Acre	Acreage of new Development
	Percent	Percent	Acre-Feet	Acres
Wheat	5.31	8.00	.84	9,415
Corn Grain	52.34	50.00	1.31	58,846
Corn Silage	8.16	10.00	1.20	11,769
Barley	.52			
Sorghum Grain	.96	2.00	1.20	2,354
Dry Beans	17.59	17.00	1.08	20,008
Sugar Beets	4.79			
Oats	.16			
Alfalfa	5.13	10.00	2.03	1,769
Other Hay	1.92			
Pasture	3.12	3.00	1.67	3,531
Vegetables				
	100.00	100.00	.30 wt. av.	7,692 [c/]

[a/] Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data are from the Colorado State Agricultural Statistics.

[b/] Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from tables A1-A8.

[c/] Equivalent full irrigation based on available water of 168,000 acre-feet or 1,000 wells of which 9 percent is effective return flow so net depletion would be 153 acre-feet. With 500 wells the acreage would be 58,846. With 1,500 wells the acreage would be 176,538.

Table 10

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION IN THE ARKANSAS REGION

Crop	1974 a/ Land Use	Projected for Expansion	Water b/ Depletion Per Acre	Acreage of New Development
	Percent	Percent	Acre-Feet	Acres
Wheat	10.98	12.00	1.09	4,071
Corn Grain	17.33	20.00	1.77	6,786
Corn Silage	6.05	8.00	1.77	5,714
Barley	.95	1.00	1.09	339
Sorghum Grain	16.49	16.00	1.63	5,428
Dry Beans	.77	2.00	1.22	678
Sugar Beets	1.10			
Oats	.37			
Alfalfa	27.87	28.00	2.72	9,500
Other Hay	5.65			
Tree Fruits				
Pasture	10.62	11.00	2.18	3,732
Vegetables	1.82	2.00	1.77	678
	100.00	100.00	1.96 wt. av.	33,928 c/

a/ Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data are from the Colorado State Agricultural Statistics

b/ Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from Tables A1-A8.

c/ Equivalent full irrigation based on available water of 66,500 acre-feet

Table 11

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION

IN THE NORTHWEST REGION

Crop	1974 [a/] Land Use	Projected for Expansion	Net [b/] Depletion Per Acre	Acreage of New Development
	Percent	Percent	Acre-Feet	Acres
	.62	2.00	.95	2,846
Barley	.52	1.00	.95	1,423
	.25	1.00	.95	1,423
Alfalfa	11.55	30.00	2.04	42,696
Other Hay	55.34	40.00	1.76	56,928
Pasture	31.72	26.00	1.76	37,003
	100.00	100.00	1.81 wt. av.	142,320 [c/]

a/ Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data are from the Colorado State Agricultural Statistics.

b/ Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from Tables A1-A8.

c/ Equivalent full irrigation based on available water of 257,600 acre-feet.

Table 12

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION
IN THE GUNNISON REGION

Crop	1974 a/ Land Use	Projected for Expansion	Water b/ Depletion Per Acre	Acreage of New Development
	Percent	Percent	Acre-Feet	Acres
Wheat	1.71	1.00	1.60	416
Corn Grain	3.34	4.00	2.47	1,664
Corn Silage	3.70	4.00	2.32	1,664
Barley	5.78	6.00	1.60	2,496
Dry Beans	2.26	2.00	1.31	832
Sugar Beets	1.49			
Oats	.99	3.00	1.60	1,248
Alfalfa	17.06	30.00	2.90	12,479
Other Hay	24.03	20.00	1.89	8,320
Tree Fruits	3.11			
Pasture	36.08	30.00	1.89	12,479
Vegetables	.45			
	100.00	100.00	2.19 wt. av.	41,598 c/

a/ Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data and from the Colorado State Agricultural Statistics.

b/ Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from Tables A1-A8.

c/ Equivalent full irrigation based on available water equaling 91,100 acre-feet.

Table 13

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION IN THE COLORADO RIVER MAINSTEM REGION

Crop	1974 [a/] Land Use	Projected for Expansion	Water [b/] Depletion Per Acre	Acreage of new Development
	Percent	Percent	Acre-Feet	Acres
Wheat	.73	1.00	1.55	901
Corn Grain	3.41			
Corn Silage	2.36			
Barley	1.59	4.00	1.55	3,603
Dry Beans	.14			
Oats	.73	3.00	1.55	2,702
Alfalfa	29.51	35.00	2.82	31,532
Other Hay	24.96	20.00	1.83	18,019
Tree Fruits	1.96			
Pasture	34.29	37.00	1.83	33,334
Vegetables	.32			
	100.00	100.00	2.15 wt. av.	90,093 [c/]

a/ Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data and from the Colorado State Agricultural Statistics.

b/ Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from Tables A1-A8.

c/ Equivalent full irrigation based on available water of 193,700 acre-feet.

14

LAND USE PATTERN FOR INCREASED AGRICULTURAL PRODUCTION

IN THE SOUTHWEST REGION

Crop	1974 [a/] Land Use	Projected for Expansion	Water [b/] Depletion Per Acre	Acreage of new Development
	Percent	Percent	Acre-Feet	Acres
Wheat	1.79	2.00	1.01	1,670
Corn Grain	.08			
Corn Silage	1.40	1.00	1.44	835
Barley	1.09	2.00	1.01	1,670
Dry Beans	.54			
Oats	.31	2.00	1.01	1,670
Alfalfa	23.05	25.00	2.44	20,872
Other Hay	12.81	10.00	2.01	8,349
Tree Fruits	.54			
Pasture	58.36	58.00	2.01	48,423
Vegetables	.03			
	100.00	100.00	2.05 wt. av.	83,488 [c/]

a/ Pasture and hay acreage are taken from the 1969 Agricultural Census and all other acreage data and from the Colorado State Agricultural Statistics.

b/ Water depletion equals the sum of consumptive use and incidental loss under current technology and management. These coefficients are taken from Tables A1-A8.

c/ Equivalent full irrigation based on available water of 171,150 acre-feet.

While acreage of new development is shown in terms of equivalent full irrigation, it is probable that most increased irrigation in this region would be supplementa irrigation on lands already receiving some irrigation water. For example, estimates by the Bureau of Reclamation for the Narrows Project indicate that water supplied from this project would be applied to 287,000 acres, all of which would be supplemental irrigation. Cropping patterns for increased development in this region are expected to closely follow those which already exist. Grain and forage crops will continue to occupy the largest share of irrigated acreaged. Potatoes and sugar beets will be the primary cash crops, each continuing with about its current share of total acreage

Northern High Plains

It is estimated that 117,692 acres of additional land could be irrigated in the Northern High Plains through the development of deep wells. This estimate is based on an increase of 1,000 new wells providing 168 acre-feet per well per year. Table 9 shows that the anticipated land use pattern for this region will closely follow that already developed. Wheat will increase slightly with feed grain and forage crops continuing to receive the majority of water. Dry beans will be the primary cash crop produced in this region.

The footnote in Table 9 shows total development acreage under two alternative assumptions--500 wells and 1,500 wells. Land use patterns for these acreages are not shown but they would be directly proportional to those shown for the 1,000 well situation.

Arkansas

It is expected that 66,500 acre-feet of water will become available for new development in the Arkansas Region, as shown in Table 10. Other than the

High Plains Region with a relative certainty of developing new wells, this region is the only one certain of receiving the water supplies indicated for new development herein. The increased water supplies will first become available in 1978 or 1979. It is shown that approximately 34,000 acres of additional land will be irrigated with this quantity of water, shown in equivalent full irrigation terms. The Bureau of Reclamation actually estimates that this water will be applied in supplemental form to 280,000 acres of currently irrigated lands

Table 10 shows the land use pattern projected for this expansion to follow very closely that which is now developed. The reduction of sugar beet acreage is about the only major change from current patterns of land use.

Northwest

Potential water supplies available for new development in the Northwest Region are estimated to be 257,600 acre-feet as shown in Table 1. Based on current consumptive use patterns this water could irrigate an additional 142,000 acres.

The source of new supply in this region is expected to come, if at all, from projects such as the Savory Pothook and Yellow Jacket Projects, which are currently under review by the Carter Administration. Others supplying water would be the Lower Yampa and Upper Yampa Projects.

All of the lands that could be potentially irrigated in this region are at relatively high altitudes with short growing seasons. The productivity of irrigated agriculture in this region is relatively low and of questionable value.

Table 11 shows that current land use patterns are primarily devoted to hay and pasture crops. In 1974 the percentage of total acreage devoted to grain crops was less than 2 percent These have been increased slightly for the projected expansion scenario.

Gunnison

It is expected that an additional 41,598 acres of land could be irrigated in the Gunnison Region if all water supplies currently being considered were fully developed (Table 12). However, these supplies consist of questionable projects such as Fruitland Mesa, Grand Mesa, and Upper Gunnison projects The Dallas Creek Project which is also in this region is a more likely occurrence. Except for the Uncompaghre Improvement Project which would provide supplemental water for lands currently irrigated, projects in this region would largely develop lands which are relatively high in altitude and short in growing season. For this reason land use patterns are expected to trend toward more grain and forage crops and less of the cash crops such as sugar beets, beans and tree fruits.

The Uncompaghre Improvement Project in this region is estimated by the USBR to provide an additional 14,000 acre-feet of water for consumptive use through ditch lining in the Uncompaghre Project. No additional diversions are required and, according to the U.S Bureau of Reclamation, no additional depletions in downstream flow would be required to obtain this increase in water for agriculture. This project is mentioned specifically because throughout the state it was the opinion of experts interviewed in the course of this analysis that very little water could be saved by improved irrigation efficiencies. Thus, the Uncomgaghre Improvement Project, as proposed by the USBR, seems to be in contradiction to the general beliefs of water use experts around the state.

Colorado River Mainstem

The Colorado River Mainstem is estimated to have an additional 193,700 acre-feet of water available for agricultural depletion (Table 13). The projects which would provide this water, however, are all of questionable feasibility. They range from the Basalt Project which was last studied in 1974, to the Dotsero Division and the Middle Park Division of the Cliffs Divide which were only briefly studied in 1954. Most of the land developed through these projects would be in areas of very low agricultural productivity; hence, it would have very little opportunity for repaying the costs of irrigation development. In any case it is estimated that 90,093 acres of new development could be achieved with this increased water supply

The land use pattern for this increased development would be heavily devoted to hay, forage and small grain crops. It is assumed that such crops as corn, dry beans and tree fruits currently produced in the Upper Colorado River Basin would not be increased by new development in these project areas.

Southwest

The new water supplies for the Southwest Region are assumed to become available through the development of the Animas LaPlata Project, Dolores Project, and the San Miguel Project. Of these only the Dolores Project is likely to be developed providing about 76,000 of the 171,150 acre-feet of water assumed to be available within the region. Using the larger figure for setting the boundary on acreage of new development, Table 14 shows that 83,488 acres of new land could be irrigated

In this region as in most of those of the Upper Colorado River Basin, it is assumed that lands to be developed through new water supplies would be of lower productivity than lands currently in production. Thus, the land use patterns projected for expansion move towards more small grain, hay, and forage crops than currently exist within the region. This land use pattern is illustrated in Table 14.

Rio Grande

It was assumed for purposes of this study that no new water supplies could be developed in the Rio Grande Region. Thus, there are no considered projects or increased acreages in this region.

INCREASED EFFICIENCY OF WATER USE

Improving the efficiency of water use in agriculture is often mentioned as a means of increasing the productivity of water currently used for irrigation. Such improvements could be achieved through better management of current on-farm systems, lining conveyance canals and laterals delivering water to farms, and improving the technology of on-farm irrigation systems (e.g., moving from rill or flood irrigation methods to automatic sprinkler systems) Each of these possibilities were considered for their potential of saving water currently wasted for increasing irrigated agriculture

Before going further into this discussion it is necessary to briefly review some of the underlying assumptions and methodology of this analysis. These may best be explained by referring to the coefficients shown in Table 4. Using coefficients in this table for the Gunnison Region under current technology, we may calculate the gross diversion requirement for a crop with a consumptive use requirement of 1.0 acre-feet.

$$GDR = \frac{CIR}{Ce \cdot Fe} = \frac{1.0}{(.70)\ (.38)} \quad 3.75 \text{ acre-feet per year}$$

Incidental loss for irrigating this crop becomes:

$$IL = GDR\ (\%\ IL) = 3.75\ (.12) = .45 \text{ acre-feet}$$

Total net depletion is then shown as:

$$ND = CIR + IL = 1.00 + .45 = 1.45 \text{ acre-feet}$$

It now becomes obvious that if consumptive use requirements remain unchanged, the only water that can be saved through improved efficiency of conveyance or use is the incidental loss, or in this case, .45 acre-feet per acre irrigated.

Increasing the irrigation management only leads to the following:

$$GDR = \frac{1.00}{(.70)\ (.44)} = 3.25 \text{ acre-feet,}$$

$IL = 3.25\ (.12) = .39$ acre-feet, and

$ND = 1.00 + .39 = 1.39$ acre-feet

By only improving management the net savings are .06 acre-feet per acre

Applying improved technology inputs, ditch lining and better management the calculations become:

$$GDR = \frac{1.00}{(.89)\ (.68)} = 1.65 \text{ acre-feet,}$$

$IL = 1.65\ (.10) = .17$ acre-feet, and

$ND = 1.00 + .17 = 1.17$ acre-feet

In this case .28 acre-feet of water per acre is "saved" by investing in lined ditches and new on-farm irrigation systems.

Of course, the quantity of return flow RF = GDR - ND has been reduced from 1.86 acre-feet to .48 acre-feet per acre. The reduction in diversions and, hence, return flows can lead to substantial reductions of salt load for the receiving waters. This improvement in water quality may help to justify improvements in irrigation efficiency in areas where water savings alone are insufficient for this purpose.

Water depletion by irrigation under alternative assumptions of efficiency are summarized in Table 15. The calculations leading to these data are shown in Tables A-1 through A-8. The data in Table 15 are a function of the efficiency coefficients shown in Table 4. A brief discussion of the results shown in Table 15 is provided below.

South Platte

The South Platte Region is relatively unique among Colorado river basins

Table 15

WATER DEPLETION BY COLORADO IRRIGATED AGRICULTURE UNDER ALTERNATIVE ASSUMPTIONS OF IMPROVED EFFICIENCY,[a/] 1974 ACREAGE

Region	Present Conditions	Improved Management	Lined Canals	New Technology [b/]
	1,000 Acre-Feet			
South Platte	1,596	1,638	1,686	1,642
High Plains	499	496	499	504
Arkansas	795	786	794	729
Rio Grande	606	599	564	496
Northwest	325	311	315	279
Gunnison	431	413	394	347
Colorado River Mainstem	445	428	415	366
Southwest	242	232	229	202
Total	4,939	4,903	4,896	4,565

[a/] Derived from Tables A1-A8.

[b/] The new technology assumption includes lined canals, improved management, and new on-farm irrigation systems.

The current pattern and technology of irrigation applied to the South Platte Region has developed over a long period of time and depends heavily upon the physical features of this river basin Primarily these characteristics may be described as a system of irrigation in which return flows are relatively large throughout the system. These return flows are reused many times while flowing the length of the South Platte River before it reaches the Colorado border. The return flows become stored in a shallow aquifer along the river to be pumped out by individual farmers for irrigation upon demand. This shallow aquifer, therefore, becomes a media for water storage and transfer of water from upstream users to downstream users. This method of storage is rather efficient because it is stored in a shallow aquifer requiring little power or energy for removal and it is stored in a manner which removes the possibility of surface evaporation as would be incurred by surface reservoir storage.

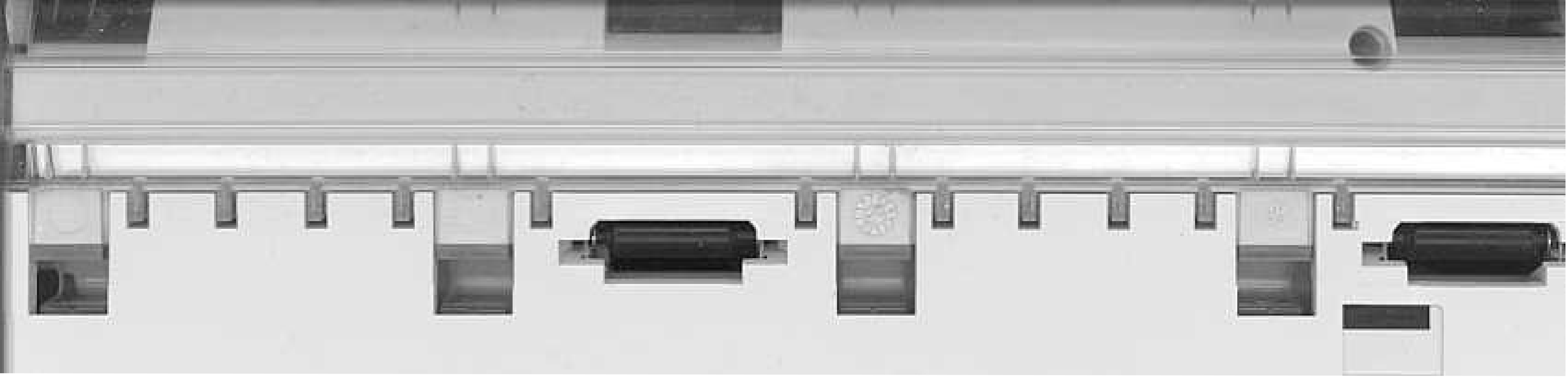
The South Platte Region is, therefore, highly susceptible to disruption through changes in the current irrigation system. To increase the efficiency of water use through lined canals and better on-farm management or irrigation systems among upstream users would require leaving a proportional amount of water in the river for removal for downstream users. To apply this efficiency criteria throughout the river basin would essentially eliminate the use of the shallow aquifer now providing storage for return flow water. This movement of al water to surface systems would not only increase the potential for evaporative losses but would also incur numerous problems of timing with respect to water supply. Downstream users would no longer have the option of pumping water upon demand. Upstream storage would then have to be constructed to provide the time dimension for storage now made available through the use of the groundwater aquifer. Because of the potential of disrupting the current system it was the opinion of experts interviewed in this study that incidental losses as a percentage of gross diversions would actually increase in the South Platte Region if attempts to gain efficiency through better management or higher technology inputs were made.

The results of these calculations are shown in Table 15. Moving from present conditions to improved management increases water depletion by 44,000 acre-feet per year. It will be noted that lining canals or changing on-farm systems also increases water depletion for the South Platte. These figures, while admittedly crude, do depict the assumptions and opinions of experts knowledgeable about irrigation in the South Platte Region. The figures indicate that it would not be wise to attempt to save water through the application of more efficient systems of water use in this region.

While the logic followed in developing this conclusion seems reasonable, it is recommended that further study be given to this subject for the South Platte Region. It is certainly the largest irrigated region of the state and provides the greatest opportunities for gains in efficiency if in fact the conclusions of this study are wrong or, alternatively, it provides the greatest opportunity for potential policy mistakes f the assumptions of this study are correct and decisions are made to improve technology as suggested by some.

High Plains

The region of the High Plains is primarily irrigated by pumping from deep wells at the present It will be noted in Table 4 that conveyance efficiencies are assumed to be 96 percent at the present with no opportunity for improvement. Changing to improved management conditions alone without changing on-farm systems was assumed to decrease water consumption in the region by 4,000 acre-feet per year. Of course, the condition of lining canals is exactly the same as that for current situations since no improvement was assumed to be possible. The application of new technology was



actually assumed to increase the evaporative losses of the system slightly while eliminating potential return flows that now occur through deep percolation. Thus, the application of new technology throughout the region would actually increase water consumption slightly above present conditions. Again, it would be the conclusion of this study that no attempt be made to change irrigation technology in that region

Arkansas

The Arkansas Region has characteristics similar to those of the South Platte. Return flow from irrigation through deep percolation is captured in the shallow aquifer which is pumped or removed upon demand by downstream farmers. The result is that very small gains are possible through improved systems or management of this irrigated region. It was estimated that a small gain could be made by improved management alone. However, lining canals led to virtually no improvement at all. The application of new technology shown in the last column of Table 15 indicates that approximately 65,000 acre-feet of water could be saved annually through the complete revamping of irrigation in that region. This savings would be less than 10 percent of the water now consumed in the region and would be achieved at a relatively high cost. Further, additional upstream storage would probably be required as the use of the current groundwater aquifer was eliminated. This might lead to additional losses not calculated in this analysis and, hence, eliminate those savings indicated in Table 15.

Rio Grande

The Rio Grande Region is also characterized by having a shallow aquifer which provides much of the irrigation water throughout the region. However, it was the opinion of people interviewed in this study that the aquifer was not being used as a means of storing return flow waters. Pumping from this aquifer is being done to eliminate high water tables currently posing a problem within the region. The coefficients in Table 4 show the Rio Grande Region to be relatively inefficient in terms of having a high incidental loss factor. This high incidental loss results from the fact that return flows are directed into a closed basin in which the water becomes virtually unrecoverable.

It is shown in Table 15 that the improvement of management alone would lead to relatively small savings but moving on to the application of new technologies could lead to a savings in excess of 100,000 acre-feet of water per year. It is the opinion of the principal investigator in this study that the coefficients leading to these estimates of water use for the Rio Grande Region are probably more unreliable than for any other region of the state One individual interviewed in the course of this study indicated that deliberate waste occurs in the Rio Grande Region in the following manner The farmers who hold surface rights to upstream diversions allow their water rights to flow through the system annually and into the closed basin in which case the water is totally lost. The same farmers are pumping water from a shallow aquifer to lower the high water problem of their farms and using that water for irrigation. Thus, it would appear that considerable savings of water in the region might be possible if institutional changes were made to require a reduction of surface diversion in proportion to the use of ground water provided by pumping from shallow aquifers. Leaving this water in the stream would prevent a diversion into the closed basin and, hence, provide an opportunity for downstream users to use the same water

Northwest

The Northwest Region is characterized by water diversions for irrigated land that is relatively close to the source of diversion. This results in return flows reaching the streams or river rather quickly and efficiently. Thus, while on-farm efficiencies are currently very low in that region, the lowest in the state, the losses incurred through this inefficiency are relatively small. Table 15 shows that gains in water availability from improved management or lining of canals are both relatively small. The application of improved technologies does lead to savings of about 46,000 acre-feet of water in the region

Because of the very low productivity of agriculture in this region, it is highly unlikely that farmers could be induced to apply the efficiency measures assumed for water savings in this analysis without rather substantial subsidies for capital investments. Thus, while savings indicated by the most extreme measures could reach 14 percent of current consumption, it is improbable that these savings will ever be achieved

Gunnison

The Gunnison Region is similar to that of the Northwest Region and the Upper Colorado Mainstem Region. Water diversions do not venture too far from the source of water or from the potential receiver of return flows.

on-farm efficiency of water use and delivery efficiency may be low, losses to the system above consumptive irrigation requirements of the crops are relatively small. Table 5 indicates that small savings could be achieved by improved management or lined canals and nearly 85,000 acre-feet of water could be saved annually by the application of new technology throughout the system. Again, much of the agriculture in this region is of relatively low productivity and could not support high capital investments for water savings of this magnitude. The Gunnison Region is a large contributor to downstream salinity problems. Thus, the subsidies for alleviation of this problem might eventually be sufficient to provide incentive for movement to water saving technologies.

Colorado River Mainstem

The Colorado River Mainstem, as indicated by coefficients in Table 4, is very similar to the Gunnison Region. The application of improved technologies is, therefore, very similar in effect Agriculture alone could not support the application of capital investment for improved technologies for ditch lining in this area. However, those areas such as the Grand Valley which contribute substantial amounts of salinity to downstream users could be potentially induced through subsidies to higher efficient water using systems.

Southwest

The Southwest Region currently uses the least water of any other region in the state and, therefore, provides the smallest potential for saving water through changing on-farm irrigation practices. Up to 17 percent of total water consumed under current conditions could be saved by movement to the most efficient irrigation systems. Similar to other west slope irrigated regions the savings from improved management and canal linings are relatively small.

It must be noted in conclusion that, while savings from improved management are relatively small throughout the state, these savings could be achieved at the lowest cost to individuals or society. It is therefore recommended that, except for the South Platte and High Plains regions, some effort be given to the improvement of on-farm management of irrigation on farms throughout the state. The water savings as indicated in Table 15 are relatively small but probably understate the total savings that could be achieved in this manner. Beyond the actual water saved it has been shown by several studies that improvement of irrigation management actually leads to higher agricultural productivity while also saving water. Even if no water is saved through higher irrigation management it is possible that the higher productivity of agriculture might justify the application of better management techniques. The additional steps of lining canals and applying new on-farm systems are questionable for the purpose of saving water. Very substantial capital investments would be required and probably could not be justified by agricultural productivity alone

COSTS OF IMPROVING IRRIGATION EFFICIENCY

The previous section has indicated that the quantity of water to be saved through improvement of current irrigation systems in Colorado is rather small While diversion requirements could be substantially reduced in all areas of the state the actual decrease in net depletion by agriculture is relatively much smaller. Of course, decreasing the quantity of return flows could contribute to reductions in downstream salinity problems, particularly in the Colorado River Basin

Total miles of canals and pipelines for conveying water to farms in Colorado are shown in Table 16. About 73 percent of all conveyances are smaller than 50 cubic feet per second in capacity and 95 percent of all present conveyances are unlined. Table 17 shows the average acreage per mile of unlined canal in each region of the state. Throughout the state the average irrigated acreage per mile of unlined canal larger than 50 cfs is 270. For unlined canals smaller than 50 cfs there is an average of 994 acres per mile

Wynn Walker, Assistant Professor of Civil Engineering at Colorado State University, provides the following formulae for estimating canal lining costs For canals larger than 1 m^3/sec

$$Co = 40.1\ Q^{0.56} + 29.70$$

where

$$Q = M^3/sec = 35.3147\ cfs$$

For canals smaller than 1 m^3/sec

$$Co = 40.1\ Q^{0.56}$$

Table 16

IRRIGATED ACRES AND CONVEYANCE DATA FOR COLORADO BY WATER BASIN REGION

	North west	Gunnison	Rio Grande	Colo. River Mainstem	Northern High Plains	South west	Arkansas	South Platte	Total
Irrigation organizations serving farms with no other source of water (acres)	141,242	192,162	207,736	199,852	21,581	92,882	157,111	375,297	1,387,863
Irrigation organizations serving farms with other sources of water (acres)	72,568	61,673	301,978	49,578	80,107	28,727	282,404	557,049	1,434,084
Total Irrigated Acres	213,810	253,835	509,714	249,430	101,688	121,609	439,515	932,346	2,821,947
Conveyance facilities under 50 cubic feet per second capacity (miles)									
Unlined canals (miles)	1,020	1,451	,613	1,519	210	843	1,753	2,040	10,449
Lined canals (miles)	45	27	34	67	10	33	109	99	424
Pipelines (miles)	42	4	12	26		10	63	48	206
Conveyance facilities 50 or more cubic feet per second capacity									
Unlined canals (Miles)	79	289	214	209	94	96	655	1,024	2,840
Lined canals (miles)	9		--	54	8	8	6	48	133
Pipelines (miles)	--			--	--	--	--	--	5

Source: 1969 Census of Agriculture, Irrigation Vol. IV.

[1]The Census data were reported by Water Resource Regions and Subareas of those regions. These divisions cross state boundaries so the following apportionment was applied to obtain the data relevant to Colorado. The bracketed figure following the subarea designation indicates the percent of the SA allocated to Colorado.

1401 (10)	1406 (70)	1025 (30)	1301 (90)
1402 (90)	1407 (50)	1026 (5)	1302 (10)
1404 (100)	1408 (20)	1102 (100)	
1405 (100)	1019 (90)	1104 (10)	
	1018 (15)		

Table 17

IRRIGATED ACREAGE PER MILE OF UNLINED CANAL

Region	Irrigated Acres Per Mile of Unlined Canal	
	Below 50 cfs acres	Above 50 cfs acres
South Platte	774	
High Plains	1,082	
Arkansas	671	
Rio Grande	2,381	
Northwest	2,706	
Gunnison	878	
Colorado River Mainstem	1,193	
Southwest	1,267	
State	994	

Source: 1969 Census of Agriculture, Irrigation, Volume IV he equa we ma

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Table 18

ESTIMATED COSTS FOR ON-FARM IRRIGATION SYSTEMS APPLYING 10 INCHES PER YEAR, 1.8 INCHES PER IRRIGATION AND ZERO FEET PUMPING LIFT

	Initial Cost	Initial Cost	Annual Cost	Annual Energy Use	Annual Energy Cost @ 30 mills/KWH
20 Acres	$	$/A	$/A	KWH/A	$/A
Hand move	3,800	190.00	56.29	1,186	7.24
Drip	4,300	215.00	57.58	462	2.70
Side roll	7,100	355.00	95.67	1,255	11.18
Solid set	16,200	810.00	145.00	1,743	7.28
Permanent	26,500	,325.00	209.72	1,330	7.10
Surface	5,900	295.00	73.88	135	
80 Acres					
Hand move	10,200	127.50	42.95	1,282	8.84
Center pivot	36,100	451.25	125.35	1,440	10.10
Drip	26,200	327.50	55.33	531	3.08
Side roll	25,200	315.00	86.89	2,676	9.20
Solid set	61,800	772.50	142.27	2,189	11.72
Permanent	86,500	1,081.25	173.66	1,620	9.92
Surface	21,700	221.25	54.33	136	
160 Acres					
Hand move	19,700	123.13	41.57	1,307	9.09
Center pivot	40,200	251.25	74.43	1,430	11.07
Drip	32,900	205.63	55.23	509	2.87
Side roll	37,700	235.63	67.11	1,456	11.55
Solid set	125,000	781.25	142.36	2,398	13.41
Permanent	175,600	1,097.50	177.92	1,949	12.59
Surface	26,600	166.25	48.99	124	

Source: Chen, et. al., 1976

Table 19

ESTIMATED COSTS FOR ON-FARM IRRIGATION SYSTEMS APPLYING

30 INCHES PER YEAR, 1.8 INCHES PER IRRIGATION AND ZERO FEET PUMPING LIFT

	Initial Cost	Initial Cost	Annual Cost	Annual Energy Use [a/]	Annual Energy Cost @ 30 mills/KWH
	$	$/A	$/A	KWH/A	$/A
20 Acres					
Hand move	4,000	200.00	100.16	2,735	18.26
Drip	4,500	225.00	80.01	912	6.56
Side roll	7,400	370.00	129.63	3,221	25.98
Solid set	16,200	810.00	166.84	3,226	20.96
Permanent	26,500	1,325.00	226.20	2,776	20.10
Surface	5,900	295.00	117.21	135	
80 Acres					
Hand move	10,500	131.25	82.39	3,066	22.62
Center pivot	36,100	451.25	146.02	3,472	29.21
Drip	16,700	208.75	78.35	1,066	7.86
Side roll	26,000	325.00	116.71	2,869	23.33
Solid set	62,800	785.00	163.66	3,854	26.49
Permanent	87,200	1,090.00	193.46	3,401	18.23
Surface	15,600	195.00	97.76	136	
160 Acres					
Hand move	20,500	128.13	80.54	3,191	23.84
Center pivot	40,200	251.25	96.42	3,693	31.36
Drip	32,900	205.62	78.22	1,146	8.61
Side roll	40,300	251.88	97.42	3,113	18.24
Solid set	125,000	781.25	170.00	5,131	38.01
Permanent	175,600	1,097.50	201.10	4,512	35.64
Surface	26,600	166.25	92.32	12	

Source: Chen, et. al., 1976

[a/] Includes embodied energy in system components.

WATER QUALITY IMPACTS FROM REDUCING RETURN FLOWS

This section is drawn from a Utah State University study (1975) which discusses irrigation efficiency changes as a means of reducing salt loading in the Colorado River System. It is emphasized in that study that irrigation efficiency is related in a critical way to the control of quantity of water used by agriculture. No irrigation technology is inherently more efficient than another. The practical limits are from 70 to 80 percent efficiency for surface, sprinkler and drip systems In actual farm operation, however, water control is usually much better if sprinkler and drip systems are utilized

Most irrigators utilizing sprinklers have an economic incentive, due to energy costs, not to apply more water than is needed for maximum crop growth. Most surface water rights grant the irrigator a proportionate share of the stream or a certain quantity per acre. The physical irrigation system is designed to accommodate that quantity of water. In these circumstances the incremental costs of applying more water than the plant needs by a gravity flow surface system are small and may be close to zero. Hardly any incentive exists to achieve higher irrigation efficiency. The excessive return flows contribute to the salt loads in downstream receiving waters

The costs of installing and operating sprinkler irrigation systems vary greatly, depending on climatic, physical and economic conditions. In arid sections of the country such as the Colorado River Basin, much more water must be applied to a given crop than would be the case if rainfall were more plentiful. The costs of installing and operating the sprinkler irrigation system also depends on the type of system chosen and the scale of the system as shown in Tables 18 and 19. Generally, larger systems are capable of delivering a given quantity of water at lower costs than a smaller system. These and other factors make it difficult to generalize and suggest a set of irrigation sprinkler costs that would apply to the entire state of Colorado.

The benefits to sprinkler irrigation are of two types: (1) the crop yield effects, and (2) the decrease in water diverted. Data on the yield effects are very sparse and the water diversion effects are very complex.

Strong (1962) reports that sugar beet yields in Utah were 10.1 percent higher under sprinkler than with surface irrigation. Better water control was the principal reason for the increase. Hanks, et. al.,(1974) report stated surface or sprinkler systems improved alfalfa yields about 8 percent, oat yields increased by about 14 percent, and corn silage about one-half percent (USU, 1975, p. 249).

One issue that makes water diversion effects through better water control so complex is the disparity that often exists between private and social benefits. "Social benefits" is a term used to describe the benefits that accrue to the entire society, not just the irrigator. If less water can be diverted because of more efficient irrigation techniques, this rerouting in the river system could result in more water being available in the system to be utilized for other purposes. If such other purposes yield beneficial salt concentration as well as salt loading effects on downstream users then someone in the system is made better off by the rerouting of water via increased irrigation efficiency. Whether or not the irrigator who improves his efficiency is himself better off is determined by the nature of his water right restrictions on water transfers to other owners, his land-water ratio, and the vigor of a water rights market. Obviously, some of these factors are interdependent (USU, 1975, p. 249)

If the entitlement of water were in the form of a direct purchase for a certain quantity of water at a given price per unit, then better irrigation efficiency would simply reduce the amount purchased and the irrigator could reduce his water cost. He would have an incentive to invest in more efficient practices so long as the marginal benefits to the investment exceed the cost. Unfortunately, water is seldom allocated to irrigators in this fashion. The practice is for the state to issue a water right, which entitles the irrigator to either a proportionate share of the flow of the stream or to a specified amount of water per acre of irrigated land

Under these allocating rules an irrigator may have no incentive whatever to reduce diversions. His water cost may not depend at all on the amount he uses. He may have an adequate supply of water under his present right to satisfy the needs of his crop at a very low irrigation efficiency. Of course if he needed supplemental water for his crops or if he had additional land that could be irrigated, then the situation would be conducive to irrigating more efficiently. All of these considerations are internal to the farm and come under the management purview of the irrigator (USU, 1975, p. 250).

Alternatively, if the irrigator could sel water not needed on the farm, more incentive would exist for increased irrigation efficiency. In Colorado, however, the water right is generally imited to "beneficial consumptive use" and there are consumptive use restrictions on water right transfers that change the point of diversion. Water rights along a water course are interdependent and some rights are dependent on the return flows of other rights

The USU study estimated the average annual incremental cost of installing and operating a sprinkling system at about $50 per acre, a cost far below those in Tables 18 and 19. If water were valued at $5 per acre-foot the total value of the water by which diversions could be decreased would not even approximate $50 per acre. At a price of $10 per acre-foot, converting to sprinkler systems in the Eagle River and the Uncompaghre River sub-basins was estimated to generate a situation where individual users might wish to sell part of their right to divert to help cover the sprinkler cost.

If the crop yield effects could add $10 to $20 per acre-foot to the value of water per year, the economic feasibility of sprinkling would be more likely. In any case there would almost certainly be legal constraints on changes in place of diversion. The decrease in the return flows might destroy the base on which other water rights depend. The conclusion is that if the social benefits are sufficiently great to warrant increasing irrigation efficiency by adoption of sprinkler irrigation, the change will have to be forced or it will be necessary to subsidize the irrigator to make it financially attractive

The USU study considered the possible universal application of sprinklers throughout the Upper Colorado River Basin as a means of reducing salt load in the Colorado River. It was estimated that investment costs would be approximately $400 per acre. The corresponding average cost per ton of salt removed per year in this fasion ranges from $185 to $308. This is a very high cost compared to other options. Even the desalting complex proposed in connection with the international boundary dispute is scheduled for removal of salt at a cost of about $30 per ton. Howe and Young (1975) have calculated the downstream income impacts (benefits) of removing salt by phasing out the least profitable lands in the Grand Valley and the Uncompaghre Basin at $13.50 to $27 per ton of salt. Shifting to sprinkler irrigation for this purpose is, comparatively, a very expensive and seemingly uneconomic venture

Canal lining is also expensive. A Colorado State University team working in the Grand Valley estimated costs at about $31,600 per mile [1/] (Skogerboe, et. al., 1972, as taken from USU, 1975). These are generally

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[1/] The Bureau of Reclamation indicates for the Grand Valley that the cost would be about $82,500 per mile. (USU, 1975) large canals and laterals which must use major structures such as road crossings, turnouts, etc. The average cost of the canal lining for the whole basin would be about $200 per acre irrigated. The capita costs for salt removal were estimated to range from about $214 per ton to $356 per ton of salt load in the river basin. Converting these to annual costs gives a range from $13.57 to $30.11 per ton of salt removal, depending on cost assumptions, interest rate assumptions, and year of projection.

It is difficult to believe that farmers simply could be required to invest in sprinkler systems or canal lining without sacrificing much of the agricultural production in the state. Some farmers would be forced out of business. Agriculture is a very competitive industry and existing profits at best are only nominal. Any unexpected increase in cost of obtaining irrigation water may reduce land rents to some extent without driving agriculture land out of production. If costs rise sharply relative to other competing agricultural areas, long-run adjustments must occur and some agricultural production will undoubtedly be sacrificed.

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Table 20

LAND BASE NEEDED TO ACCOMMODATE VARIOUS POPULATION INCREASES AT ALTERNATIVE RATES OF OCCUPANCY PER CAPITA

	Land Needed to Supply Population			
	Low	Low-Med	High-Med	High
South Platte				
Pop. Change (number)	240,664	503,765	766,866	1,013,411
.1 A/cap.[a] (acres)	24,066	50,376	76,687	101,341
.158 A/cap. (acres)	38,025	79,595	121,165	160,119
.052 A/cap. (acres)	12,515	16,196	39,877	52,697
High Plains				
Pop. change (number)	1,574	3,060	4,546	6,031
.5 A/cap.[a] (acres)	787	1,530	2,273	3,015
.158 A/cap. (acres)	249	483	718	953
Arkansas				
Pop. Change (number)	120,664	175,892	231,120	279,539
.1 A/cap.[a] (acres)	12,066	17,589	23,112	27,594
.158 A/cap. (acres)	19,065	27,791	36,517	44,167
.052 A/cap. (acres)	6,274	9,146	12,018	14,536
Rio Grande				
Pop. Change (number)	11,831	14,115	16,399	18,683
.5 A/cap[a] (acres)	5,915	7,057	8,200	9,392
.158 A/cap. (acres)	1,869	2,230	2,591	2,952
Southwest				
Pop. Change (number)	9,167	11,993	14,819	17,645
.5 A/cap.[a] (acres)	4,584	5,996	7,410	8,822
.158 A/cap. (acres)	1,448	1,895	2,341	2,788
Gunnison				
Pop. Change (number)	1,910	5,841	9,772	13,702
.5 A/cap.[a] (acres)	955	2,920	4,886	6,851
.158 A/cap. (acres)	301	923	1,544	2,165
Colorado River Mainstem				
Pop. Change (number)	26,178	56,254	86,330	116,905
.1 A/cap.[a] (acres)	2,618	5,625	8,633	11,640
.158 A/cap. (acres)	4,136	8,888	13,640	18,392
.052 A/cap. (acres)	1,361	2,925	4,489	6,065
Northwest				
Pop. Change (number)	3,554	16,395	29,236	42,076
.1 A/cap.[a] (acres)	355	1,640	2,924	4,208
.158 A/cap. (acres)	562	2,590	4,619	6,648

Source: Dr. Raymond Anderson, ERS, USDA, Fort Collins, Colorado.

[a]These acreage estimates are deemed to be the most likely of those shown.

High Plains

Total growth in the High Plains Region is expected to be small. Most will be near small towns. Space will not be constraining and large lots equaling .5 acre/capita will be used for new development.

Arkansas River

Pueblo, Colorado Springs and Arkansas Valley towns will dominate growth in the Arkansas Region. Hence, urban density of .1 acre per capita is assumed

Rio Grande

It is expected that growth in the Rio Grande Region wi be small and concentrated in rura areas. Hence, large space per capita equaling .5 acre per capita is assumed.

Southwest

The Southwest Region is expected to have a growth pattern similar to that of the Rio Grande. Large lots wil be typical equaling .5 acre per capita.

Gunnison

Growth in the Gunnison Region will also be similar to that of the Rio Grande. Large lots will be typical equaling .5 acre per capita

Colorado River

The Colorado River Mainstem region has a possibility of fairly intense energy development. Urban type towns primarily with rapid growth and development for workers will prevail. Hence, fairly dense population centers will develop. The nature of topography and availability of water, sewer, etc., will cause most development to occur on irrigated lands on valley floors resulting in .1 acre per capita increase.

Northwest

Energy development will cause most of the growth in the Northwest Region. Therefore, development will be similar to the Colorado River Mainstem Region with fast growing company towns accommodating most of the growth. Land use will equal .1 acre per capita. In the early period, very dense trailer park development is likely to dominate development and standard housing will probably develop later

These estimates include only the land needed to actually accommodate the population increase. It does not account for any unused land that may now be idle or underutilized in the urban areas. Most importantly, it also does not include land that may prematurely and speculatively be subdivided for urban development. Given the permissive attitude of most county governments toward zoning and subdivision location, it is likely that much land will be subdivided into unneeded urban type land use

Table 2 shows estimates of water requirements for population growth. Again, it must be noted that demands for water will be a function of many factors and, hence, will probably be highly variable. For the purpose of planning at this point, it is recommended that the water supply based on 200 gallons per capita per day be used. In some areas where water is plentiful or where the land-population ratio is large, it would be more appropriate to use the data based on 250 gallons per capita per day

As an alternative method of estimating water needs, the data in Table 22 are based on water use per land area. For most concentrated urban developments where land is restricted to about .1 acre per capita the water consumption data based on 1-1.5 acre-feet per acre might be the most applicable. The South Platte, Arkansas, and Colorado River Mainstem Regions are examples of this rate. These estimates might also be appropriate for growth that occurs on

Table 21

ESTIMATED WATER WITHDRAWALS NEEDED TO SUPPLY POPULATION INCREASES

	Gal./cap. day	Low	Low-Med.	Hig-Med.	High
			Acre-Feet		
South Platte	150	40,437	84,643	128,850	170,275
	200	53,916	112,858	171,800	227,033
	250	67,394	141,072	214,750	283,792
High Plains	150	264	514	764	1,013
	200	353	686	1,018	1,351
	250	441	857	1,273	1,689
Arkansas	150	20,274	29,554	38,833	46,968
	200	27,032	39,405	51,778	62,625
	250	33,790	49,256	64,722	78,281
Rio Grande	150	1,988	2,372	2,755	3,139
	200	2,650	3,162	3,674	4,186
	250	3,313	3,953	4,592	5,232
Southwest	150	1,540	2,015	2,490	2,965
	200	2.054	2,687	3,320	3,953
	250	2,567	3,358	4,150	4,941
Gunnison	150	321	981	1,642	2,302
	200	428	1,308	2,189	3,070
	250	535	1,636	2,737	3,837
Colorado River	150	4,398	9,452	14,505	19,558
	200	5,865	12,602	19,340	26,078
	250	7,331	15,753	24,176	32,598
Northwest	150	597	2,755	4,912	7,070
	200	796	3,673	6,550	9,426
	250	995	4,591	8,187	11,783

Source: Dr. Raymond Anderson, ERS, USDA, Fort Collins.

Table 22

WATER WITHDRAWALS NEEDED ON BASIS OF ACRES CONVERTED TO URBAN USE

	Low	Low-Med.	High-Med.	High
	Acre-feet			
South Platte (.1 A/cap.)				
1. AF/A	24,066	50,376	76,687	101,341
1.5 AF/A	36,099	75,564	115,030	152,012
2. AF/A	48,132	100,752	153,374	202,682
High Plains (.5 A/Cap.)				
1 AF/A	787	1,530	2,273	3,015
1.5 AF/A	1,180	2,295	3,410	4,522
2 AF/A	1,574	3,060	4,546	6,030
Arkansas (.1 A/cap.)				
1 AF/A	12,066	17,589	23,112	27,954
1.5 AF/A	18,099	26,384	34,668	41,931
2 AF/A	24,132	35,178	46,224	55,908
Rio Grande (.5 A/cap.)				
1 AF/A	5,915	7,057	8,200	9,342
1.5 AF/A	8,872	10,586	12,300	14,013
2 AF/A	11,830	14,114	16,400	18,684
Southwest (.5 A cap.)				
1 AF/A	4,584	5,996	7,410	8,822
1.5 AF/A	6,876	8,994	11,115	13,233
2 AF/A	9,168	11,992	14,820	17,644
Gunnison (.5 A/cap.)				
1 AF/A	955	2,920	4,886	6,851
1.5 AF/A	1,432	4,380	7,329	10,276
2 AF/A	1,910	5,840	9,772	13,702
Colorado River (.1 A/cap.)				
1 AF/A	2,618	5,625	8,633	11,640
1.5 AF/A	3,927	8,438	12,950	17,460
2 AF/A	5,236	11,250	17,266	23,280
Northwest (.1 A/cap.)				
1 AF/A	355	1,640	2,924	4,208
1.5 AF/A	532	2,460	4,386	6,312
2 AF/A	710	3,280	5,848	8,416

Source: Dr. Raymond Anderson, ERS, USDA, Fort Collins previously irrigated land even though the land-population ratio exceeds .1 acre per capita. The Roaring Fork River Valley and the Grand Valley areas are examples of this type of growth. For most other situations where the land-population ratio exceeds .1, these estimates of water use could be excessive.

CONCLUSIONS AND RECOMMENDATIONS

There are few concrete conclusions that can be drawn from this study Primarily this occurs because the study was designed to collect and present specific data without subjecting the data to much analysis or policy discrimination. Briefly, some interpretive observations are provided below

The methodology used to estimate current water depletion by agriculture throughout the state was deemed to be the best available given the time and resources devoted to the project. Until additional resources in rather large amounts can be given to research for improving data on such things as hydrology, crop consumptive use, and irrigation management in each region of the state, it is unlikely that significantly better estimates of water use can be developed

In general, it is felt that estimates of current water consumption by irrigation developed in this study probably exceed actual consumption by a small amount. This error occurs because it was assumed that full consumptive use requirements of irrigated crops were met in all regions, except for pasture crops. In fact, some crops are known to be under-irrigated because of limited water supplies in several regions. The water that would be supplied by most proposed USBR projects is expected to be applied supplementally to lands already irrigated, as evidence of this phenomenon.

It is also possible that this study has underestimated the potential water savings from the application of better management or improved irrigation systems. However, until more evidence is collected on specific areas of the state these estimates should be sufficiently accurate for policy planning purposes.

It is recommended that additional research be devoted to the estimation of coefficients representing the efficiency and depletion of water use for major irrigation systems throughout the state. Such estimates will become more valuable as future concerns for water supplies and water quality become more acute

The energy component of new irrigation systems should be analyzed in further depth. Recommendations to change irrigation systems to improve water use efficiency or to abate downstream water quality problems should be made with a full awareness of the direct and embodied energy that would be required to achieve desired results.

More research should be devoted to the measurement of economic impacts from groundwater mining by irrigation. Is the aquifer being managed to allow all investments in well and irrigation equipment to be depreciated over periods of normal life, or is the declining water level requiring equipment replacement schedules to be accelerated and thus increasing costs of operation? Is the distribution of income from well irrigation equitable or do institutional factors allow some individuals to capture a disproportionate share of the value created from the water? These and other questions should be analyzed in order to develop more rational groundwater management policies.

Finally, it is recommended that serious thought be given to measurement of the genuine economic benefits to be derived from additional agricultura development in this state. Is the water deriving more social benefit in its present uses than it would if diverted for agriculture? Could and should the water be more productively devoted to energy or municipal uses? The current fears of many people in the West regarding the doubtful future of planned irrigation projects is difficult to justify. It should be remembered that a decision not to develop more irrigation today is not necessarily an irreversible decision. If future economic conditions warrant more irrigation than now exists, it should be possible to provide for such reallocations of water when the need arises.

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PEOPLE CONTACTED

The following is a partial list of people contacted for data and opinions in the course of this research project. Their assistance in this endeavour is gratefully acknowledged. However, the principal investigator of this project accepts full responsibility for any errors of omission or commission in the use of information provided by these people.

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APPENDIX TABLES

Table A-1

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, SOUTH PLATTE REGION

(acre-feet per acre)

Crop	Acres Harvested	Consumptive Use (CU)	1977			With Improved Management			High Efficiency			Improved Conveyance		
			Diversion	Incidental Loss (IL)	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL
	(000 acres)													
Wheat (winter)	14.3	.70	2.08	.12	.82	1.84	.15	.85	1.06	.15	.85	1.71	.17	.87
Wheat (spring)	1.9	.70	2.08	.12	.82	1.84	.15	.85	1.06	.15	.85	1.71	.17	.87
Corn (grain)	171.4	1.10	3.27	.20	1.30	2.89	.23	1.33	1.67	.23	1.33	2.69	.27	1.37
Corn (silage)	163.7	1.00	2.98	.18	1.18	2.63	.21	1.21	1.52	.21	1.21	2.44	.24	1.24
Sorghum (grain)	1.5	1.00	2.98	.18	1.18	2.63	.21	1.21	1.52	.21	1.21	2.44	.24	1.24
Oats	6.4	.70	2.08	.12	.82	1.84	.15	.85	1.06	.15	.85	1.71	.17	.87
Barley	42.0	.70	2.08	.12	.82	1.84	.15	.85	1.06	.15	.85	1.71	.17	.87
Orchard (deciduous)														
Vegetables (deep)	11.9	1.00	2.98	.18	1.18	2.63	.21	1.21	1.52	.21	1.21	2.44	.24	1.24
Hay (alfalfa)	181.0	1.70	5.06	.30	2.00	4.47	.36	2.06	2.58	.36	2.06	4.16	.42	2.12
Hay (other)	61.9	1.40	4.17	.25	1.65	3.68	.29	1.69	2.12	.30	1.70	3.42	.34	1.74
Sugar Beets	54.2	1.50	4.46	.27	1.77	3.94	.32	1.82	2.28	.32	1.82	3.67	.37	1.87
Irish Potatoes	274.4	1.30	3.87	.23	1.53	3.42	.27	1.57	1.97	.28	1.58	3.18	.32	1.62
Dry Beans	39.5	.90	2.68	.16	1.06	2.37	.19	1.09	1.37	.19	1.09	2.20	.22	1.12
Crop Pasture	40.2	1.40	4.16	.25	1.65	3.68	.29	1.69	2.12	.30	1.70	3.42	.34	1.74
Other Pasture	22.7	.85	2.53	.15	1.00	2.24	.18	1.03	1.29	.18	1.03	2.08	.21	1.06
Total a/	1,087.0	1,354,365	4,030,770	241,206	1,595,570	3,561,240	284,095	1,638,460	2,054,880	287,860	1,642,220	3,311,420	331,817	1,686,180
Weighted Average Depletion Per Acre		1.25	3.71	22	1.47	3.28	.26	51	1.89	.26	1.51	3.05		55

a/ Water figures in this row represent aggregate acre-feet for the entire region.

Table A-2

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, NORTHERN HIGH PLAINS REGION

(acre-feet per acre)

Crop	Acres Harvested	Consumptive Use (CU)	Diversion	Incidental Loss (IL)	CU + IL	With Improved Management: Diversion	IL	CU + IL	High Efficiency: Diversion	IL	CU + IL	With Improved Conveyance: Diversion	IL	CU + IL
	(000 acres)													
Wheat (winter)	19.6	.70	1.26	.13	.83	1.22	.12	.82	.91	.14	.84	1.26	.13	.83
Wheat (spring)	.9	.70	1.26	.13	.83	1.22	.12	.82	.91	.14	.84	1.26	.13	.83
Corn (grain)	202.0	1.10	1.97	.20	1.30	1.91	.19	1.29	1.43	.21	1.31	1.97	.20	1.30
Corn (silage)	31.5	1.00	1.80	.18	1.18	1.74	.17	1.17	1.30	.20	1.20	1.80	.18	1.18
Sorghum (grain)	3.7	1.00	1.80	.18	1.18	1.74	.17	1.17	1.30	.20	1.20	1.80	.18	1.18
Oats	.6	.70	1.26	.13	.83	1.22	.12	.82	.91	.14	.84	1.26	.13	.83
Barley	2.0	.70	1.26	.13	.83	1.22	.12	.82	.91	.14	.84	1.26	.13	.83
Orchard (deciduous)														
Vegetables (deep)	.01	1.60	2.87	.29	1.89	2.78	.28	1.88	2.08	.31	1.91	2.87	.29	1.89
Hay (alfalfa)	19.8	1.70	3.05	.31	2.01	2.95	.30	2.00	2.21	.33	2.03	3.05	.31	2.01
Hay (other)	7.4	1.40	2.51	.25	1.65	2.43	.24	1.64	1.82	.27	1.67	2.51	.25	1.65
Sugar Beets	18.5	1.50	2.69	.27	1.77	2.60	.26	1.76	1.95	.29	1.79	2.69	.27	1.77
Irish Potatoes														
Dry Beans	67.9	.90	52	16	1.06	1.56	.16	1.06	.17	.18	1.08	1.62	.16	1.06
Crop Pasture	9.7	1.40	51	25	1.65	2.43	.24	1.64	.82	.27	1.67	2.51	.25	1.65
Other Pasture	2.9	.85	53	15	1.00	1.48	.15	1.00	.11	.17	1.02	1.53	.15	1.00
Total [a/]	386.51	422,510	,946	76,719	498,960	733,557	73,292	495,803	549,279	81,928	504,439	757,946	76,449	498,960
Weighted Average Depletion Per Acre		.09	1.96	20	.29	1.90	19	1.28	.42	21	.30	.96		1.29

a/ Water figures in this row represent aggregate acre-feet for the entire region.

Table A-3

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, ARKANSAS REGION

(acre-feet per acre)

			1977			With Improved Management			High Efficiency			With Improved Conveyance		
Crop	Acres Harvested	Consumptive Use (CU)	Diversion	Incidental Loss (IL)	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL
	(000 acres)	acre-feet												
Wheat (winter)	44.1	.80	2.40	.29	1.09	2.31	.28	.08	.42	.20	1.00	2.05	.29	.09
Wheat (spring)														
Corn (grain)	69.6	1.30	3.90	.47	1.77	3.76	.45	1.75	2.31	.32	1.62	3.33	.47	1.77
Corn (silage)	24.3	1.30	3.90	.47	1.77	3.76	.45	1.75	2.31	.32	1.62	3.33	.47	1.77
Sorghum (grain)	66.2	1.20	3.60	.43	1.63	3.47	.42	1.62	2.13	.30	1.50	3.08	.43	1.63
Oats	1.5	.80	2.40	.29	1.09	2.31	.28	1.08	1.42	.20	1.00	2.05	.29	1.09
Barley	3.8	.80	2.40	.29	1.09	2.31	.28	1.08	1.42	.20	1.00	2.05	.29	1.09
Orchard (deciduous)	.01	1.60	4.80	.58	2.18	4.62	.55	2.15	2.84	.40	2.00	4.10	.57	2.17
Vegetables (deep)	7.3	1.30	3.90	.47	1.77	3.76	.45	1.75	2.31	.32	1.62	3.33	.47	1.77
Hay (alfalfa)	111.9	2.00	6.01	.72	2.72	5.78	.69	2.69	3.55	.50	2.50	5.13	.72	2.72
Hay (other)	22.7	1.60	4.80	.58	2.18	4.62	.55	2.15	2.84	.40	2.00	4.10	.57	2.17
Sugar Beets	4.42	1.80	5.41	.65	2.45	5.20	.62	2.42	3.20	.45	2.25	4.62	.65	2.45
Irish Potatoes														
Dry Beans	3.1	.90	2.70	.32	1.22	2.60	.31	1.21	1.60	.22	1.12	2.31	.32	1.22
Crop Pasture	34.5	1.60	4.80	.58	2.18	4.62	.55	2.15	2.84	.40	2.00	4.10	.57	2.17
Other Pasture	8.1	.95	2.85	.34	1.29	2.75	.33	1.28	1.69	.24	1.19	2.44	.34	1.29
Total [a]	401.53	584,297	,754,054	210,725	795,020	1,688,751	202,227	786,520	,037,440	145,573	729,870	1,498,115	210,153	794,450
Weighted Average Depletion Per Acre		1.46	4.37	.52	1.98	4.21	.50	.96	2.58	.36	1.82	3.73	.52	.98

[a] Water figures in this row represent aggregate acre-feet for the entire region.

Table A-4

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGEMENT AND TECHNOLOGICAL INPUT LEVELS, RIO GRANDE REGION

(acre-feet per acre)

			Current Methods			Improved Management			High Efficiency Technology			Improved Conveyance		
Crop	Acres Harvested	Consumptive Use (CU)	Diversion	Incidental Loss (IL)	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL
	(000 acres)	AF/A	AF/A											
Wheat (winter)	.5	.70	1.78	.53	1.23	1.72	52	1.22	85	31	1.01	1.31	45	1.15
Wheat (spring)	2.9	.70	1.78	.53	1.23	1.72	52	1.22	85	31	1.01	1.31	45	1.15
Corn (grain)														
Corn (silage)														
Sorghum (grain)														
Oats	4.5	70	1.78	53	1.23	1.72	52	1.22	85	31	1.01	1.31	45	1.15
Barley	83.0	70	1.78	53	1.23	1.72	52	1.22	85	31	1.01	1.31	45	1.15
Orchard (deciduous)														
Vegetables (deep)	1.8	1.10	2.79	84	1.94	2.70	81	1.91	1.33	48	1.58	2.06	70	1.80
Hay (alfalfa)	85.1	1.00	2.54	77	1.77	2.45	74	1.74	1.21	44	1.44	1.87	64	1.64
Hay (other)	82.2	.90	2.28	68	1.58	2.21	66	1.56	1.09	39	1.29	1.69	57	1.47
Sugar Beets														
Irish Potatoes	34.0	1.00	2.54	76	1.76	2.45	74	74	1.21	44	1.44	1.87	64	1.64
Dry Beans														
Crop Pasture	62.9	.90	2.28	.68	1.58	2.21	.66	1.56	1.09	.39	1.29	1.69	.57	1.47
Other Pasture	53.9	.55	1.40	.40	.95	1.34	.40	.95	.66	.24	.79	1.03	.35	.90
Total [a/]	410.8	344,945	875,630	261,284	606,230	[illegible]45,900	[illegible]54,186	599,130	417,500	150,972	495,910	646,240	219,961	564,910
Weighted Average Depletion Per Acre		84	2.13	64	1.48	2.07	62	1.46	1.03	37	21	1.59	54	1.38

[a/] Water figures in this row represent aggregate acre-feet for the entire region.

Table A-5

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, NORTHWEST REGION

(acre-feet per acre)

Crop	Acres Harvested	Consumptive USE (CU)	Current Method			Improved Management			High Efficiency Technology			Improved Conveyance		
			Diversion	Incidental Loss (IL)	CU + IL	Diversion	IL	CU + IL	Diversion	IL	IL + CU	Diversion	IL	IL + CU
	(000 acres)	acre-feet												
Wheat (winter)	.8	.70	3.13	.25	.95	2.63	.21	.91	1.16	.12	.82	2.46	.22	.92
Wheat (spring)	.4	.70	3.13	.25	.95	2.63	.21	.91	1.16	.12	.82	2.46	.22	.92
Corn (grain)														
Corn (silage)														
Sorghum (grain)														
Oats	.5	.70	3.13	.25	.95	2.63	.21	.91	1.16	.12	.82	2.46	.22	.92
Barley	1.0	.70	3.13	.25	.95	2.63	.21	.91	1.16	.12	.82	2.46	.22	.92
Orchard (deciduous)														
Vegetables (deep)														
Hay (alfalfa)	22.3	1.50	6.70	.54	2.04	5.64	.45	1.95	2.48	.25	1.75	5.26	.47	1.97
Hay (other)	106.8	1.30	5.80	.46	1.76	4.89	.39	1.69	2.15	.22	1.52	4.56	.41	1.71
Sugar Beets														
Irish Potatoes														
Dry Beans														
Crop Pasture	32.5	1.30	5.80	.46	1.76	4.89	.39	1.69	2.15	.22	1.52	4.56	.41	1.71
Other Pasture	28.8	.80	3.57	.29	1.09	3.01	.24	1.04	1.32	.13	.93	2.81	.25	1.05
Total [a/]	193.1	239,470	1,068,620	85,147	324,620	900,740	71,841	311,320	395,950	40,289	279,750	840,080	75,388	314,860
Weighted Average Depletion Per Acre		1.24	5.53	.44	1.68	4.66	.37	1.61	2.05	.21	1.45	4.35	.39	1.63

a/ Water figures in this row represent aggregate acre-feet for the entire region.

Table A-6

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, GUNNISON REGION

(acre-feet per acre)

Crop	Acres Harvested	Consumptive Use (CU)	Current Method			Improved Management			High-Efficiency Technology			Improved Conveyance		
			Diversion	Incidental Loss (IL)	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL
	(000 acres)	acre-feet												
Wheat (winter)	1.8	1.10	4.14	.50	1.60	3.57	.43	1.53	1.82	.18	1.28	3.25	.36	1.46
Wheat (spring)	2.0	.70	2.63	.32	1.02	2.27	.27	.97	1.16	.12	.82	2.07	.23	.93
Corn (grain)	7.4	1.70	6.39	.77	2.47	5.52	.66	2.36	2.81	.28	1.98	5.03	.55	2.25
Corn (silage)	8.2	1.60	6.02	.72	2.32	5.19	.62	2.22	2.64	.26	1.86	4.73	.52	2.12
Sorghum (grain)														
Oats	2.2	1.10	4.14	.50	1.60	3.57	.43	1.53	1.82	.18	1.28	3.25	.36	1.46
Barley	12.8	1.10	4.14	.50	1.60	3.57	.43	1.53	1.82	.18	1.28	3.25	.36	1.46
Orchard (deciduous)	6.9	1.60	6.02	.72	2.32	5.19	.62	2.22	2.64	.26	1.86	4.73	.52	2.12
Vegetables (deep)	1.0	1.00	3.76	.45	1.45	3.25	.39	1.39	1.65	.17	1.17	2.96	.33	1.33
Hay (alfalfa)	37.8	2.00	7.52	.90	2.90	6.49	.78	2.78	3.31	.33	2.33	5.92	.65	2.65
Hay (other)	53.7	1.30	4.89	.59	1.89	4.22	.51	1.81	2.15	.22	1.52	3.85	.42	1.72
Sugar Beets	3.3	1.50	5.64	.68	2.18	4.87	.58	2.08	2.48	.25	1.75	4.44	.49	1.99
Irish Potatoes														
Dry Beans	5.0	.90	3.38	.41	1.31	2.92	.35	1.25	1.49	.15	1.05	2.66	.29	1.19
Crop Pasture	40.2	1.30	4.89	.59	1.89	4.22	.51	1.81	2.15	.22	1.52	3.85	.42	1.72
Other Pasture	40.8	.80	3.01	.36	1.16	2.60	.31	1.11	1.32	.13	.93	2.37	.26	1.06
Total [a/]	223.10	297,380	,118,507	134,463	431,850	965,310	115,741	413,460	491,697	49,443	346,820	880,280	96,443	393,820
Weighted Average Depletion Per Acre		1.33	5.01	.60	94	4.33		.85	2.20	.22	.55	3.95	43	1.77

a/ Water figures in this row represent aggregate acre-feet for the entire region.

Table A-7

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, COLORADO RIVER MAINSTEM REGION

(acre-feet per acre)

Crop	Acres Harvested (000 acres)	Consumptive Use (CU)	Current Method			Improved Management			High-Efficiency Technology			Improved Conveyance		
			Diversion	Incidental Loss (IL)	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL	Diversion	IL	CU + IL
Wheat (winter)	.8	1.10	4.49	.45	1.55	3.92	.39	1.49	1.75	.18	1.28	3.49	.35	1.45
Wheat (spring)	.8	.70	2.86	.29	.99	2.50	.25	.95	1.11	.11	.81	2.22	.22	.92
Corn (grain)	7.5	1.70	6.94	.69	2.39	6.07	.61	2.31	2.70	.27	1.97	5.40	.54	2.24
Corn (silage)	5.2	1.60	6.53	.65	2.25	5.71	.57	2.17	2.54	.25	1.85	5.08	.51	2.11
Sorghum (grain)														
Oats	1.6	1.10	4.49	.45	1.55	3.92	.39	1.49	1.75	.18	1.28	3.49	.35	1.45
Barley	3.5	1.10	4.49	.45	1.55	3.92	.39	1.49	1.75	.18	1.28	3.49	.35	1.45
Orchard (deciduous)	4.3	1.60	6.53	.65	2.25	5.71	.57	2.17	2.54	.25	1.85	5.08	.51	2.11
Vegetables (deep)	.7	1.40	5.71	.57	1.97	5.00	.50	1.90	2.22	.22	1.62	4.44	.44	1.84
Hay (alfalfa)	62.7	2.00	8.16	.82	2.82	7.14	.71	2.71	3.17	.32	2.32	6.34	.63	2.63
Hay (other)	57.1	1.30	5.31	.53	1.83	4.64	.46	1.76	2.06	.21	1.51	4.13	.41	1.71
Sugar Beets														
Irish Potatoes														
Dry Beans	.3	.90	3.67	.37	1.27	3.21	.32	1.22	1.43	.14	1.04	2.86	.29	1.19
Crop Pasture	39.1	1.30	5.31	.53	1.83	4.64	.46	1.76	2.06	.21	1.51	4.13	.41	1.71
Other Pasture	36.2	.80	3.27	.33	1.13	2.86	.29	1.09	1.27	.13	.93	2.54	.25	1.05
Total a/	219.80	315,670	1,289,980	129,093	444,760	1,126,940	112,204	427,870	500,480	48,828	366,390	,001,870	99,524	415,190
Weighted Average Depletion Per Acre		.44	5.87	59	2.02	5.13	.51	95	2.28	22	1.67	4.56	.45	1.89

a/ Water figures in this row represent aggregate acre-feet for the entire region.

Table A-8

ESTIMATED WATER DIVERSION AND DEPLETION FOR ALTERNATIVE MANAGERIAL AND TECHNOLOGICAL INPUT LEVELS, SOUTHWEST REGION

(acre-feet per acre)

Crop	Acres Harvested	Consumptive Use (CU)	1977 Diversion	1977 Incidental Loss (IL)	1977 CU + IL	With Improved Management Diversion	With Improved Management IL	With Improved Management CU + IL	High Efficiency Diversion	High Efficiency IL	High Efficiency CU + IL	With Improved Conveyance Diversion	With Improved Conveyance IL	With Improved Conveyance CU + IL
	(000 acres)													
Wheat (winter)	.9	.70	2.55	31	1.01	2.21	27	97	1.17	.14	.84	2.10	.25	.95
Wheat (spring)	.4	.70	2.55	31	1.01	2.21	27	97	1.17	.14	.84	2.10	.25	.95
Corn (grain)		1.10	4.01	48	1.58	3.47	42	52	1.84	.22	1.32	3.29	.39	1.49
Corn (silage)	1.8	1.00	3.64	44	1.44	3.15	38	38	1.67	.20	1.30	2.99	.36	1.36
Sorghum (grain)														
Oats	.4	.70	2.55	.31	1.01	2.21	.27	.97	1.17	.14	.84	2.10	.25	.95
Barley	1.4	.70	2.55	.31	1.01	2.21	.27	.97	1.17	.14	.84	2.10	.25	.95
Orchard (deciduous)	.7	1.40	5.11	.61	2.01	4.42	.53	1.93	2.34	.28	1.68	4.19	.50	1.90
Vegetables (deep)	.04	1.20	4.38	.53	1.73	3.79	.45	1.65	2.01	.24	1.44	3.59	.43	1.63
Hay (alfalfa)	29.7	1.70	6.20	.74	2.44	5.36	.64	2.34	2.84	.34	2.04	5.09	.61	2.31
Hay (other)	16.5	1.40	5.11	.61	2.01	4.42	.53	1.93	2.34	.28	1.68	4.19	.50	1.90
Sugar Beets														
Irish Potatoes														
Dry Beans	.7	.90	3.28	.39	1.29	2.84	.34	1.24	1.51	.18	1.08	2.69	.32	1.22
Crop Pasture	44.5	1.40	5.11	.61	2.01	4.42	.53	1.93	2.34	.28	1.68	4.19	.50	1.90
Other Pasture	30.7	.85	3.10	.37	1.22	2.68	.32	1.17	1.42	.17	1.02	2.54	.30	1.15
Total [a/]	128.84	168,420	614,476	73,379	241,810	531,400	63,622	232,050	281,444	33,685	202,280	504,022	60,130	228,550
Weighted Average Depletion Per Acre		1.31	4.78	.57	88	4.12		1.80	2.18	.26	1.57	3.91	47	1.77

[a/] Water figures in this row represent aggregate acre-feet for the entire region.

Table A-9.

ESTIMATED WATER AVAILABLE FOR IRRIGATION DEVELOPMENT IN COLORADO

Region--Project	Year Planned	Acres Irrigated: Full Acres	Acres Irrigated: Sup. Acres	Water Supply for Irrigation Acre-feet	Water Depletion Acre-feet
Northwest[a]					
Lower Yampa	1963	101,280		308,900	163,000
	1977		1,780	2,600	1,800
Upper Yampa	1957	36,740	3,610	114,050	41,100
Savory Pothook	1959	21,920	13,345	63,600	38,000
	1977	14,410	14,330	53,600	22,400
Yellow Jacket	1972	10,500	3,690	30,080	15,500
	1977	8,900	1,600	22,600	10,700
Subtotal[b]		170,440	22,425	516,630	257,600
Gunnison[a]					
Dallas Creek	1966	14,900	8,720	60,300	31,700
	1976		2,850	11,200[c]	5,100
Fruitland Mesa	1967	15,870	7,010	52,900	28,000
	1977	11,940	6,310	45,400	21,300
Grand Mesa	1973	7,430	20,840	52,100	25,300
Upper Gunnison	1973	2,170	18,250	21,700	6,100
Uncompaghre Improvement			83,300	14,000[d]	[d]
Subtotal[b]		40,370	138,120	206,000	91,100
Colorado River Mainstem[a]					
Basalt	1974	2,860	4,660	15,500	5,300
Bluestone	1971	750	1,880	4,250	2,100
Battlement Mesa	1967	6,340	3,130	24,600	15,300
Dotsero Div.	1954	32,750	15,880	108,000	49,100
Middle Park Div. of Cliffs Divide	1954	58,880	17,225	167,210	72,100
West Divide	1966	18,890	21,030	115,600	49,800
	1977	12,190	20,110	76,400	39,000
Subtotal[b]		120,470	63,805	435,190	193,700
Southwest[e]					
Animas LaPlata	[f]	41,700	17,600	98,600	62,600
Dolores	[f]	40,300	26,300	90,900	76,550
San Miguel	[f]	11,500	12,500	38,000	32,000
Subtotal		93,500	56,400	227,500	171,150
South Platte[g]					
Narrows	1977		287,000	102,000	95,000[k]
Municipal Outflow[h]				150,000	100,000
Subtotal			287,000	102,000	170,000[k]
Arkansas[g]					
Frying Pan-Ark.	1977		280,000	79,500	79,500[m]
Subtotal			280,000	79,500	66,500[m]
N. High Plains[j]					
Deep wells				153,000	153,000
Subtotal				153,000	153,000

a/ Source: Richard Pond, USBR, Grand Junction.

b/ Total of largest individual project figures.

c/ 10,700 acre feet of total are to be supplied to Uncompaghre project.

d/ The source of new supply for the Uncompaghre project is improved efficiency and, hence, no new depletion is anticipated.

e/ Source: Glade Barney, USBR, Durango

f/ Date of study unknown.

g/ Source: Kent Schuyler, USBR, Denver.

h/ It is assumed that municipal outflows to the South Platte will increase by 150,000 AF of which one-third will be lost in transit and storage prior to agricultural use.

j/ Source: Bill McDonald, DNR, Denver. Based on an additional 1,000 wells at 168 acre feet per well per year of which 153 acre feet are available for agricultural depletion.

k/ 25,000 acre feet of total depletion is due to reservoir evaporation.

m/ 43,727 acre feet are used by M&I and 13,000 acre feet depleted before it is available to agriculture.