Upper Colorado Region

Comprehensive Framework Study

Appendix XI
Municipal and Industrial Water

Upper Colorado Region State-Federal Inter-Agency Group / Pacific Southwest
Inter-Agency Committee / Water Resources Council
June 1971

This appendix prepared by the
MUNICIPAL AND INDUSTRIAL WATER SUPPLY WORKGROUP
of the
UPPER COLORADO REGION STATE-FEDERAL INTERAGENCY GROUP
for the
PACIFIC SOUTHWEST INTERAGENCY COMMITTEE
WATER RESOURCES COUNCIL

WORK GROUP MEMBERS

Name	Agency
Robert H. Hagen, Chairman	Environmental Protection Agency
Roger E. Frenette (Chairman November 1968-September 1970)	Environmental Protection Agency
Gordon Goodsell	Bureau of Reclamation
Graham Atkins	Corps of Engineers
Jerry Key (Alt.)	Corps of Engineers
Ralph B. Armstrong	Bureau of Indian Affairs
Wendell M. Doty, Jr.	Forest Service
Grant Seaman (Alt.)	Forest Service
George Bjerke	Soil Conservation Service
S. Gene Day	Bureau of Land Management
David P. Hale	New Mexico
Carl Slingerland (Alt.)	New Mexico
James G. Christensen	Utah
Albert V. Soukup	Environmental Protection Agency
Art Williamson	Wyoming
Laren D. Morrill	Colorado
Thomas C. Clark	Arizona
Robert E. Farrer (Alt.)	Arizona
Homer C. Stewart	Bureau of Mines
John H. Davidson	Economic Development Administration

Other contributors:

George G. Collins, Environmental Protection Agency
Patrick J. Godsil, Environmental Protection Agency
J. William Geise, Environmental Protection Agency
Ray D. Eicher, Bureau of Indian Affairs
Delbert Boyer, Wyoming

UPPER COLORADO REGION

COMPREHENSIVE FRAMEWORK STUDY

APPENDIX XI

MUNICIPAL AND INDUSTRIAL WATER SUPPLY

JUNE 1971

This report of the Upper Colorado Region State-Federal Interagency Group was prepared at field level and presents a framework program for the development and management of the water and related land resources of the Upper Colorado Region. This report is subject to review by the interested federal agencies at the departmental level, by the Governors of the affected states, and by the Water Resources Council prior to its transmittal to the Congress for its consideration.

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UPPER COLORADO REGION

COMPREHENSIVE FRAMEWORK STUDY

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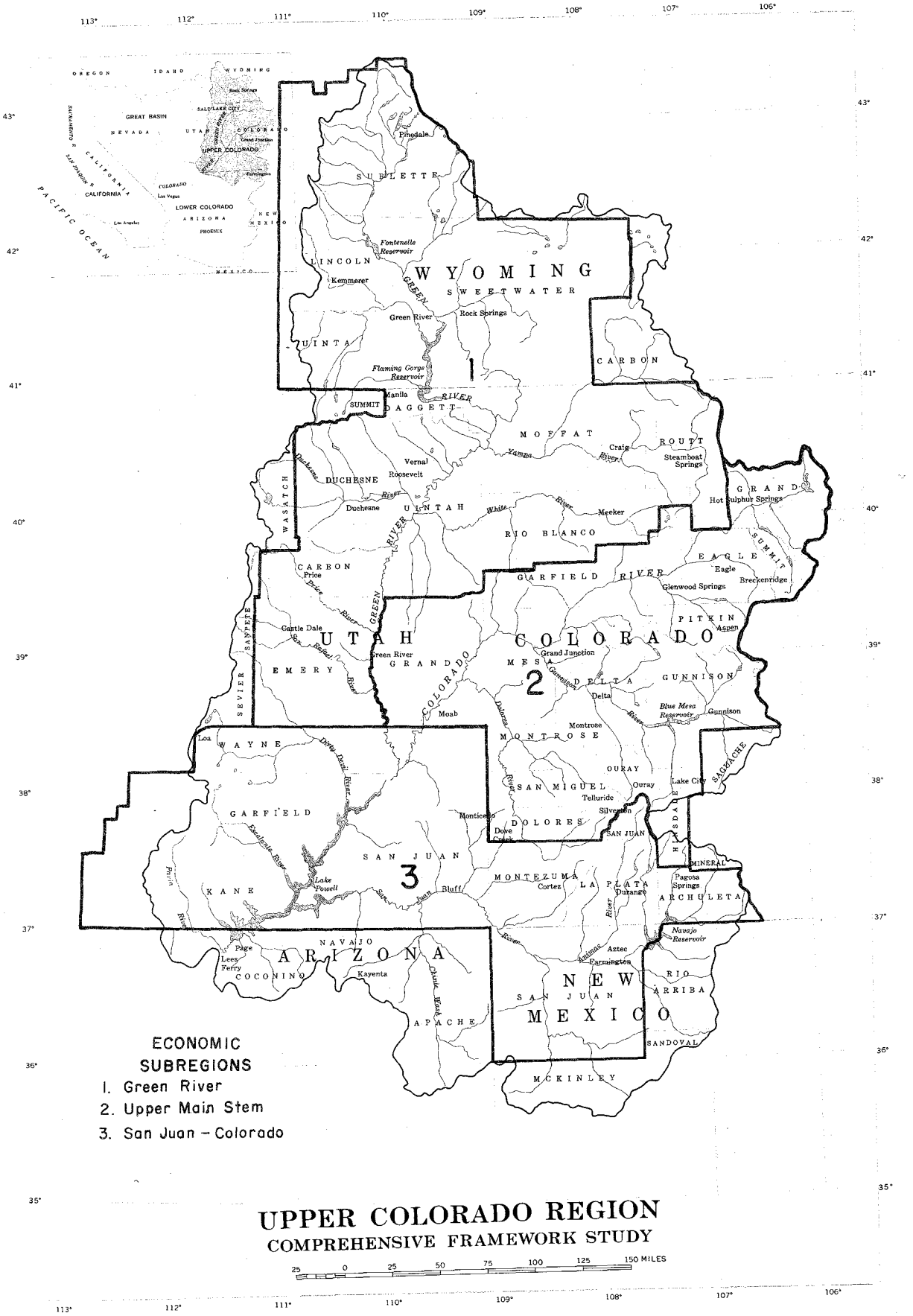

UPPER COLORADO REGION

COMPREHENSIVE FRAMEWORK STUDY

SUMMARY

Water withdrawal requirements for municipal and industrial water uses in the Upper Colorado Region amounted to 123,900 acre-feet in 1965. Water depletion requirements totaled 62,300 acre-feet, amounting to 50 percent of the withdrawals. Domestic water use amounted to 42 percent of the Regional withdrawal, and livestock used about 30 percent.

The Upper Main Stem subregion, which has the largest population, accounted for the largest subregional withdrawals (45,600 acre-feet) and depletions (23,500 acre-feet). The San Juan-Colorado Subregion had the smallest withdrawal (29,400 acre-feet) and depletion (17,600 acre-feet), although its population was larger than the Green River Subregion. The relatively low water use in the San Juan-Colorado Subregion can be attributed to a large Indian population within the subregion and a lack of adequate water distributions facilities in the Indian communities.

Seventy-five percent of the Regional municipal and industrial withdrawal requirements were supplied by surface water sources and the remainder by ground water sources. An estimated population of 260,800, or 78 percent of the Regional population within the hydrologic boundaries, was served by 192 municipal systems in 1965. Inadequate municipal water source protection and treatment is prevalent in the Region, with chlorination the major improvement required.

The 2020 municipal and industrial withdrawals and depletions are estimated to be 347,900 and 169,100 acre-feet per year, respectively, representing more than a two-fold increase from 1965. Municipal and industrial water depletions accounted for only 1.8 percent of the total regional water use in 1965, and are expected to account for about 2.6 percent by 2020. Withdrawals for commercial uses will be largest (94,000 acre-feet) with domestic uses following (88,000 acre-feet). A projected 86 percent increase in population (includes hydrologic acre of Arizona), more than eight-fold increase in the ecomonic activity in the commercial category, and an increased water-use rate by the Region's Indian and rural residents are the major reasons for the growth of municipal and industrial water demands.

Future municipal and industrial needs will be met by developing additional surface and limited groundwater supplies and by converting some agricultural water to municipal and industrial uses.

The non-federal investment costs for development and treatment are projected to be $2.6, $6.5 and $9.0 million for the 1966-1980, 1981-2000 and 2001-2020 time frames, respectively. These totals represent the single-purpose costs of developing 20 to 30 percent of the future needs and costs of treating all future municipal and industrial requirements. Costs of distribution systems from the treatment plant to the consumer are not included. Costs of federal multi-purpose projects that have a

municipal and industrial water supply allocation are also not included. Multi-purpose project costs are given in the General Program and Alternatives Appendix.

Three alternatives in addition to the regional interpretation of OBE-ERS have been suggested and incorporated in the General Program and Alternatives Appendix. The alternatives are defined as 1) States' Alternative at 6.5 million acre-feet (m.a.f.), 2) States' Alternative at 8:16 m.a.f., and 3) States' Alternative for Water Available at Site. In each case these alternative levels are a reapportionment of water among the various industrial uses as agreed to by all states of the Upper Colorado Region. By 2020 municipal and industrial water depletions, excluding stock-pond evaporation and livestock use, will amont to 147,600 acre-feet per year for States' Alternative at 6.5 m.a.f., 191,800 acre-feet for States'Alternative at 8.16 m.a.f., and 201,800 acre-feet for States' Alternative for Water Available at Site. The percentage increase over water depletions at the OBE-ERS projected level by 2020, therefore, is 34, 74 and 83 percent, respectively.

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PART I

INTRODUCTION

Purpose and Scope

The purpose of the Municipal and Industrial Water Supply Appendix is to:

(1) Summarize the water volumes withdrawn and depleted for municipal and industrial (including livestock) purposes in the base year (1965);

(2) Based on projections of the Office of Business Economics (OBE) of the Department of Commerce and the Economic Research Service (ERS) of the Department of Agriculture, determine the water required to meet the corresponding future demands in the target years 1980, 2000, and 2020;

(3) Compare future demands with the available water supplies and determine the opportunities and means available to satisfy these demands; and

(4) List the water required to meet the future demands in the target years 1980, 2000, and 2020 for alternative levels of development.

This appendix summarizes the water use for domestic, manufacturing, livestock, governmental, and commercial and other related purposes in the Upper Colorado Region.

The Present Status section is based on the 1965 level of development, compiled from existing information and estimations in areas where data were lacking or inadequate. In comparing projected demands with the potential water supplies, areas requiring additional water supplies are designated as well as the magnitude of the required supply. Suggested means of satisfying future demands are general. A few specific projects or developments are presented. Research needs and additional data requirements are also presented.

Municipal and industrial water requirements are based on the level of economic projections identified as OBE-ERS projections in the

Economic Base and Projections Appendix. Subsequent to computation of the water requirements presented in this appendix, a different level of ecomonic projections was established for use in the study. This level, the Regional Interpretation of OBE-ERS, contained upward revisions for population (2020 Regional total 660,000 compared to 616,000) and economic activity. Use of the Regional Interpretation of OBE-ERS would result in somewhat higher water requirements than presented herein. A discussion of the different projection levels and a comparison of water depletions for the OBE-ERS Projection and Regionally Interpreted levels is presented in the Economic Base and Projections Appendix.

Water uses and demands are presented on a subregional basis. The subregions are delineated on the maps preceding the summary. The two population centers of Grand Junction, Colorado and Farmington, New Mexico are discussed with respect to future demands and special problems.

The water requirements for the three regional alternatives given at the end of this report were compiled by the Upper Colorado Region Staff from data submitted by State representatives. The General Program and Alternatives Appendix lists the background data and justifications.

Relationship to Other Appendixes

The Municipal and Industrial Water Supply Appendix is one of several technical appendixes dealing with a particular phase of water development. Water requirements developed in the Municipal and Industrial Water Supply Appendix are summarized along with all other Regional water requirements in the Water Resources Appendix.

Water required for mineral extraction is summarized in the Mineral Resources Appendix, and water required for power generation is summarized in the Electric Power Appendix. Wildlife water needs are included in the Fish and Wildlife Appendix.

The major inputs to this appendix were from the Economic Base and Projections and Water Resources Appendixes. Outputs to other than the General Program and Alternatives Appendix, stem to the Water Resources Appendix. Water quality inputs were provided by the Water Quality, Pollution Control, and Health Factors Workgroup.

The demand for water and water-related services by the municipal and industrial sectors depends upon the population and the level and type of economic activity within the Region. Data on economic trends, projected output of goods and services, and population projections are provided in the Economic Base and Projections Appendix.

Projected growth and increased industrial development requires additional lands. Thus, encroachment upon other land-use areas occurs. In most instances, encroachment is made upon agricultural land areas, which reduces at-site agricultural production and agricultural water requirements with a corresponding increase in the water supply available for municipal and industrial water uses. Encroachment on land-use areas is discussed in the Land Resources and Use Appendix.

Description of the Region

The study area is the Upper Colorado Region which comprises the drainage basin of the Colorado River above Lee Ferry, Arizona, and the Great Divide Basin in southcentral Wyoming. The Region includes parts of Arizona, Colorado, New Mexico, Utah and Wyoming. It encompasses an area of 113,496 square miles, including 109,580 square miles in the Upper Colorado River drainage and 3,916 square miles in the Great Divide Basin.

The Region is bounded on the east and north by mountains forming the Continental Divide and on the west by the Wasatch Mountains. On the south it opens to the Lower Colorado Region at Lee Ferry in northern Arizona.

The study area has been divided into three hydrologic subregions comprising the natural drainage basins of the Colorado River and its two principal tributaries, the Green and San Juan Rivers.

The Region is sparsely populated. The population was about 336,000 in 1965. The average density was about three persons per square mile compared with a national average of 64. Forty-one percent of the population resided in the Upper Main stem subregion, 30 percent in the Green River subregion and 29 percent in the San Juan-Colorado subregion. The 1965 and projected population are presented in Table 1.

Table 1 - Present and Projected Population 1/
OBE-ERS Projections
Upper Colorado Region

Area	1965	1980	2000	2020
Green River	100,579	107,100	124,400	151,200
Colorado	19,300	23,600	30,100	35,300
Utah	42,500	43,900	50,800	63,000
Wyoming	38,779	39,600	43,500	52,900
Upper Main Stem	136,725	142,900	171,400	204,200
Colorado	129,425	134,300	159,400	187,900
Utah	7,300	8,600	12,000	16,300
San Juan-Colorado	128,725	176,200	241,900	324,800
Arizona	29,100	41,700	52,300	64,300
Colorado	37,725	47,500	63,300	90,700
New Mexico	46,600	65,000	95,000	125,000
Utah	15,300	22,000	31,300	44,800
Upper Colorado Region	366,029	426,000	537,700	680,200

1/ Includes population in the hydrologic area of Arizona

About 40 percent of the Region's residents live in urban areas with populations of more than 2,500 inhabitants while the remainder are in rural areas. Only two communities have populations of more than 20,000--Grand Junction, Colorado (Upper Main Stem Subregion) with an estimated 1965 population of 22,400 and Farmington, New Mexico (San Juan-Colorado Subregion) with approximately 21,000. The next largest towns are Durango, Colorado (San Juan-Colorado Subregion) with an estimated 1965 population of 11,200 and Rock Springs, Wyoming (Green River Subregion) with a population of about 10,400. All other communities have populations of less than 10,000.

Manufacturing in the Upper Colorado Region represents a small part of the total economic activity and primarily consists of commodities to supply local market demands. The Food and Kindred Products sector leads the manufacturing sectors in contributing to the Gross Regional Product. Much of the food processing activity is in the form of bakeries, dairies, meat packers, and soft-drink plants dispersed throughout the Region. Although the Lumber and Wood Products sector is a major employer, most of the operations involve logging and milling which do not require large amounts of water. Other manufacturing operations are varied and are generally located in the population centers.

History

People in the Upper Colorado River Basin have supported themselves principally by exporting the products of their farms and mines. The products have been shipped direct from the farm gate and the mine mouth, and offloaded at points outside the basin. Little handling or processing of the raw products has taken place in the basin. This has limited population, market, and industrial concentration within the basin; and consequently, the need for water for municipal and industrial purposes. Lack of water is generally not considered to have constrained urban or industrial development in the basin.

Planning for domestic, municipal, and industrial water supply was historically secondary in the Region to planning for irrigation. The locations of most of the settlements which have become today's towns and cities were influenced by farmers having the primary objective of locating as near as possible to an irrigation water supply. In many instances, the water needed to meet a settlement's domestic requirements was hauled or conveyed by other means from distant springs or creeks, since the quality of the irrigation water supply was not suitable for household use. In some rural and Indian reservation areas, domestic water is still hauled. In still a few other rural areas, individual home storage cisterns for household water are filled direct from irrigation canals. Government agencies responsible for planning and constructing water supply projects in the Upper Colorado Region have only recently included development of municipal and industrial water supplies as a project purpose. Of the last nine Bureau of Reclamation projects authorized for construction in the Region (all participating projects of the Colorado River Storage Project), six include plans to develop water for municipal and industrial uses, largely, to meet anticipated demands perhaps a decade or more away.

The development and distribution of water for domestic and municipal uses was one of the first services provided in settlements after they became established. Many of the settlements became incorporated to facilitate the financing of municipal water supply systems. The early systems were comparatively simple. Many have not changed over the years; while others, particularly those serving larger towns and cities, have been improved by addition of metering equipment, treatment plants, pressure stations, etc.

Soon after the Federal Government became the trustee for the Indians, development and improvement of surface and ground water supplies in Indian areas was undertaken. Numerous springs, wells, and ponds were developed for livestock water. Many of these have been modified to also supply domestic water. The municipal water supply systems on reservation lands have been developed by federal and state agencies, private businesses, and by the Indian tribes. In many instances, systems developed by these

various entities are interconnected to supply more than a single community. Almost every town and city in the Region has developed its own municipal water supply system. These systems supply only a very small portion of the water used by industry. The industrial water requirements are largely self supplied.

PART II

PRESENT STATUS

Water Supply Requirements - Quantity

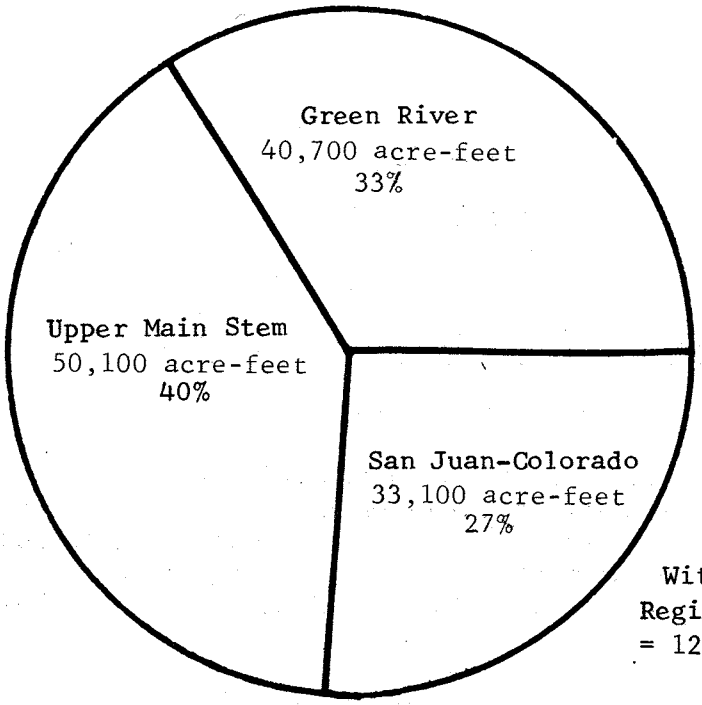
Regional Summary

Water withdrawal requirements for municipal and industrial (M&I) water uses in the Upper Colorado Region amounted to 123,900 acre-feet in 1965. Water depletion requirements for these uses was 62,300 acre-feet, amounting to 50 percent of the withdrawal requirement. Regional withdrawal and depletion requirements for M&I water uses are summarized in Table 2 and Figure 1.

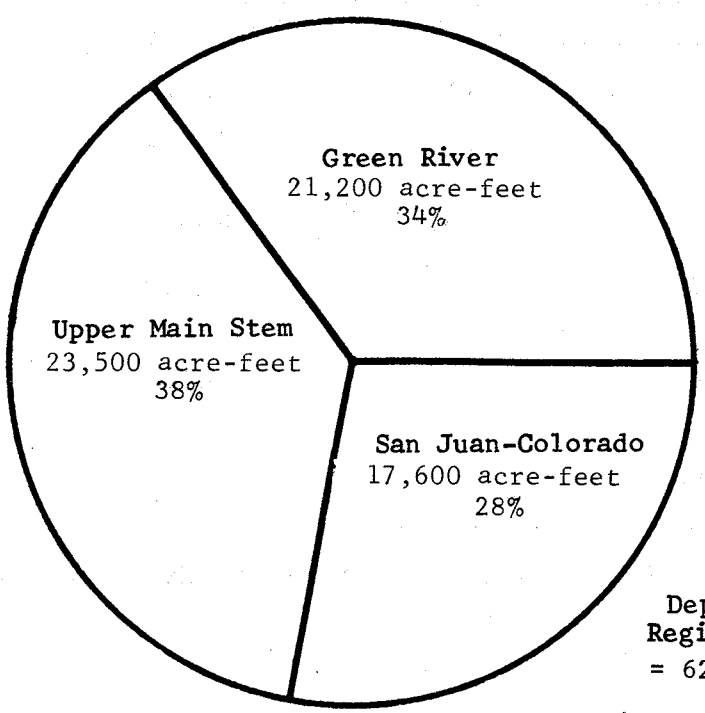
Table 2 - Regional Summary of 1965 Municipal and Industrial Withdrawal Water Requirements and Depletions

Water Use	Withdrawal (acre-feet)	% of Regional Total	Depletion (acre-feet)	% of Regional Total
Domestic	52,400	48	18,800	31
Manufacturing	11,500	10	1,900	3
Livestock	34,900	30	34,900	58
Governmental	10,700	4	1,000	1
Commercial & Other	14,400	8	5,700	7
Regional Total	123,900	100	62,300	100

A summary of the 1965 depletions by states within the Region is presented in Table 3.



WITHDRAWAL REQUIREMENTS



DEPLETIONS

FIGURE 1: 1965 Municipal and Industrial Withdrawal Water Requirements and Depletions

Table 3 - Regional Summary of 1965 Municipal and Industrial Water Depletions by States (acre-feet per year)

State	M&I (excludes livestock) Depletions	Livestock Depletions	Total M&I Depletions
Arizona	1,500	1,100	2,600
Colorado	15,900	20,700	36,600
New Mexico	2,400	2,400	4,800
Utah	5,000	6,200	11,200
Wyoming	2,600	4,500	7,100
Upper Colorado Region	27,400	34,900	62,300

Domestic Water Use

A population of 336,000 within the Region, including the hydrologic area of Arizona, had an average domestic withdrawal requirement of 132 gallons per capita per day (gpcd) and an average domestic depletion requirement of 54 gpcd in 1965. Domestic depletions were about 42 percent of domestic withdrawal requirements. The Upper Main Stem Subregion had the largest subregional domestic requirements.

There are numerous factors affecting domestic water requirements. Such factors as available water supply, metering, water pricing policy, water-use regulations, personal per capita income, lot size, population density, family size, sewering, number of plumbing facilities, and climate are significant. 1/ The policies of municipalities and water distribution agencies relating to metering, water pricing, water-use regulations, and land-use regulations can act as controls on municpal-domestic water use. 2/ Metering of municipal-domestic water is common practice throughout the Region. It is significant that the rural-domestic water requirements of the Regional Indian population, located almost exclusively in the San Juan-Colorado Subregion, are largely influenced by the lack of adequate plumbing facilities.

1/ References: 4, 23, 24, 25, 30, 33, 41.
2/ References: 1, 4, 24, 30, 33.

Domestic water uses can generally be categorized as exterior or interior. Exterior uses include lawn and plant watering, swimming pools, and car washing. Interior uses include laundering, dishwashing, garbage disposal operations, cooking and food preparation, and air conditioning (when water cooled) as well as personal uses such as toilet flushing, bathing and drinking. Domestic uses of water have been increasing as technology makes an increasing number of water-using appliances available and economically attractive.

Most interior domestic uses of water do not have high depletions. Water used for lawns, plants, and automobile washing is virtually all depleted which accounts for the large domestic per capita depletion.

Domestic water requirements exhibit definite seasonal variations. Withdrawal requirements vary from a maximum during the summer months of about 160 percent of the average monthly withdrawal requirement to a minimum during the winter months of about 60 percent of the average monthly withdrawal requirement. Peak demands occur primarily during the months of June, July, and August.

Manufacturing Water Use

Manufacturing activity within the Region is not intense and has been largely confined to sectors related to agriculture, mining, forestry, and tourism. Withdrawal requirements for the manufacturing water-use category were 11,500 acre-feet in 1965; depletions were 1,900 acre-feet, or 16 percent of the withdrawals. The Upper Main Stem Subregion had the largest subregional manufacturing water requirements.

Manufacturing water requirements vary significantly between different industries. There are also significant variances among manufacturing plants within a particular industry. Among the many factors which affect manufacturing water requirements are withdrawal water cost; operating rate of production; technological change; quality of raw product inputs; waste effluent controls; size, age and location of the plant; and water management practices (recirculation). Indications are that manufacturing water requirements are particularly responsive to various economic factors. As the cost of water to manufacturing industries increases either through increased water supply costs or increased waste disposal costs, water management practices, such as recirculation, will be used to decrease withdrawal water requirements (4) (6).

Manufacturing industries require water for a variety of uses including cooling, steam generation, process, sanitary and other water uses. Water for cooling and steam generation is required in most manufacturing industries. Cooling water is used to absorb and carry away waste heat. Cooling water which is distributed in once-through cooling systems is

passed through heat exchange equipment once and then discharged back to the stream system or used for other needs. Cooling water which is distributed in recirculating systems is passed through heat exchange equipment, where heat is absorbed, and then passed through a cooling tower or spray pond, where the heat is lost before recirculation. Water is depleted in recirculating systems by evaporation and leakage, and must be replaced by make-up water. Water withdrawal requirements for recirculating cooling systems are significantly less than for once-through systems. 1/

Water quantity requirements for manufacturing processes vary widely. 2/ The food and kindred products industry included fruit and vegetable canners and beet sugar manufacturers which generally require process water for washing, cleaning, blanching, cooking, sterilizing, and transporting foodstuffs. Meat packing firms require water for a variety of processes, including carcass dressing and rendering, hair removal, washing and cleaning. Soft drink bottling firms use water as a raw material in the final product. Dairies use large quantities of water for washing and cleaning and cooling milk and milk products after pasteurization.

The lumber and wood products industry requires water for spraying logs to prevent cracking, debarking of logs by water jets, and in the preparation of wood preserving solutions. The printing and publishing industry has essentially no water requirements other than for personal sanitary purposes. The fabricated metals industry in the Region is composed primarily of steel fabricators and boiler shops which require water for cooling and sanitary purposes. Firms in the stone, clay and glass industry, which make concrete products and ready-mix concrete, require large quantities of process water for washing sand and gravel and for incorporation in the product.

The manufacturing demand for water does exhibit seasonal variations; however, seasonal patterns are not as predictable as for domestic water use. Some manufacturing industries require significant increases during the summer months for seasonal process water. Other manufacturing industries such as some firms in the food and kindred products industry require major increases when raw food products are available for processing. Generally, however, manufacturing industrial water demands vary from a maximum of 120 percent of the average monthly withdrawal requirement during the summer months to a minimum of 80 percent during the winter months.

Livestock Water Use

Livestock water requirements are significant throughout the Region, with the largest total requirement in the Green River Subregion.

1/ References: 5, 13, 32, 34.
2/ References: 3, 13, 22, 26, 27, 28, 32, 34, 37, 38, 42, 43, 44.

Livestock water requirements depend upon climatic factors, such as temperature and precipitation; number, species, age and condition of the animal; nature of the diet; and upon water management practices (22) (32).

Livestock water requirements include water consumed by the animals plus water evaporated from stock watering ponds. For 1965, 11,000 acre-feet was consumed by animals and 23,900 acre-feet evaporated from 22,000 stock ponds in the Region. The total depletion of 34,900 acre-feet is more than all other municipal and industrial requirements combined. This comparison dramatizes the rural character of the study area. Further, the livestock depletion was about 28 percent of the 1965 Regional M&I withdrawal requirements.

Governmental Water Use

Governmental water requirements were the smallest of the five water-use categories, with only 10,700 acre-feet withdrawn in 1965. Depletions were 1,000 acre-feet, or 9 percent of the withdrawal requirements.

Governmental requirements for water result from a wide range of federal, state, and local governmental activities. A variety of factors affect these requirements; size of cities and climate are probably the most significant factors, and cost of water the least significant (4). Some of the governmental uses of water include supplies for: public buildings such as post offices, schools, hospitals, and office building; military installations; watering public lawns, parks, and golf courses; fire control; street cleaning; public swimming pools; and various research activities. Governmental water requirements are seasonal in nature and are largest during the summer months.

Commercial and Other Water Use

Withdrawal requirements for the commercial and other water uses were 14,400 acre-feet in 1965; the depletions were 5,700 acre-feet, or 40 percent of the withdrawals. The Upper Main Stem Subregion had the largest subregional commercial and other water requirements.

Commercial requirements for water refer to the requirements of the trades and services industries. These requirements depend primarily upon three factors: size of resident population, its per capita income, and the extent to which commercial services are provided for a transient population (4). This latter factor is particularly relevant in the Upper Colorado Region which supports a significant tourist industry.

Commercial uses of water are varied and closely approximate domestic uses of water. The use of water in commercial establishments such as

restuarants, service stations, laundries, hotels and motels is important in the provision of goods and services. However, in other commercial establishments such as dry goods stores, grocery stores, department stores, and automobile dealerships the use of water is small and incidental to the provision of goods and services. Commercial water uses exhibit seasonal variations, with a maximum during the summer months of 120 to 180 percent of the average monthly withdrawal requirements. Minimum requirements during the winter months range from 50 to 80 percent of the average monthly withdrawal requirements.

Water requirements for the contract construction industry have been included in the commercial and other uses category. Water uses in the contract construction industry include dust control, batching of concrete, and various washing processes.

Green River Subregion

M&I water uses in the Green River Subregion had a withdrawal requirement of 40,700 acre-feet in 1965. The water depletion for these uses was 21,200 acre-feet which amounted to approximately 52 percent of the withdrawal requirement. The subregional withdrawal requirements and depletions for M&I water uses are summarized in Table 4.

Table 4 - Summary of 1965 Municipal and Industrial Withdrawal Water Requirements and Depletions Green River Subregion

Water Use	Withdrawal (acre-feet)	Depletion (acre-feet)
Domestic	18,600	6,000
Manufacturing	2,100	300
Livestock	13,300	13,300
Governmental	3,300	300
Commercial & Other	3,400	1,300
Subregional Total	40,700	21,200

A population of almost 100,600 in the Green River Subregion had an average domestic withdrawal requirement of 165 gpcd. The average domestic depletion was 53 gpcd. Domestic depletions were 32 percent of domestic withdrawal requirements.

Manufacturing depletions were 14 percent of manufacturing withdrawal requirements. The manufacturing water requirements in the subregion were required primarily by dairies, meat packing plants, and soft drink bottlers in the food and kindred products industry; by saw mills and planing mills in the lumber and wood products industry; and by ready-mix concrete firms in the stone, clay and glass industry.

Livestock, governmental, and commercial water requirements were significant in the subregion. Commercial and governmental water withdrawal requirements accounted for 8 percent of total withdrawals in both categories. Livestock requirements accounted for 33 percent of total withdrawals and 63 percent of total depletions. Evaporation from stock watering ponds accounted for 8,400 acre-feet or 63 percent of total livestock depletion in the Green River Subregion.

Upper Main Stem Subregion

M&I water uses in the Upper Main Stem Subregion had a withdrawal requirement of 50,100 acre-feet in 1965. The depletion for these uses was 23,500 acre-feet, which amounted to approximately 47 percent of the withdrawal requirement. The subregional withdrawal requirements and depletion for water uses are summarized in Table 5.

A population of just over 136,700 in the Upper Main Stem Subregion had an average domestic withdrawal requirement of 141 gpcd. The average depletion requirement was 52 gpcd. Domestic depletion requirements were 37 percent of domestic withdrawal requirements.

Table 5 - Summary of 1965 Municipal and Industrial Withdrawal Water Requirements and Depletions Upper Main Stem Subregion

Water Use	Withdrawal (acre-feet)	Depletion (acre-feet)
Domestic	21,600	7,900
Manufacturing	5,600	1,000
Livestock	11,200	11,200
Governmental	4,500	400
Commercial & Other	7,200	3,000
Subregional Total	50,100	23,500

Manufacturing depletions were 18 percent of manufacturing withdrawal requirements. The manufacturing water requirements in the subregion were required primarily by fruit and vegetable canners, dairies, beet sugar manufacturers, and meat packing plants in the food and kindred products industry; by saw mills and planing mills in the lumber and wood products industry; by structural steel fabricators and boiler shops in the fabricated metals industry; and by ready-mix concrete manufacturers in the stone, clay and glass industry.

Livestock, governmental, and commercial water requirements were significant in the subregion. Commercial and governmental water withdrawal requirements accounted for 14 and 9 percent of total withdrawals, respectively. Livestock requirements accounted for 22 percent of total withdrawals and 48 percent of total depletions. Evaporation from stock watering ponds accounted for 7,300 acre-feet or 65 percent of total livestock depletions in the Upper Main Stem Subregion.

San Juan-Colorado Subregion

M&I water uses in the San Juan-Colorado Subregion had a withdrawal requirement of 33,100 acre-feet in 1965. The depletion for these uses was 17,600 acre-feet, which amounted to 53 percent of the withdrawal requirements. The subregional withdrawal requirements and depletions for M&I water uses are summarized in Table 6.

Table 6 - Summary of 1965 Municipal and Industrial Withdrawal Water Requirements and Depletions San Juan-Colorado Subregion

Water Use	Withdrawal (acre-feet)	Depletion (acre-feet)
Domestic	12,200	4,900
Manufacturing	3,800	600
Livestock	10,400	10,400
Governmental	3,900	300
Commercial & Other	3,800	1,400
Subregional Total	33,100	17,600

A population of 128,700 in the San Juan-Colorado Subregion (includes population in the hydrologic area of Arizona) had an average domestic withdrawal requirement of 85 gpcd. The average domestic depletion was 34 gpcd or 40 percent of domestic withdrawal requirements. These relatively low per-capita requirements can be attributed to a large Indian population within the subregion, amounting to nearly 50 percent of the total population for the hydrologic subregion. The per-capita water use for the Indian population is low, amounting to an average domestic withdrawal requirement of 28 gpcd and an average domestic depletion of 21 gpcd. These low requirements are largely due to a lack of adequate water distribution facilities.

Within the economic boundaries of the San Juan-Colorado Subregion, which excludes primarily the Arizona drainage into the San Juan River, a population of just over 99,600 had a average domestic withdrawal requirement of 96 gpcd and an average depletion of 30 gpcd.

Domestic depletions for the Arizona portion of the San Juan-Colorado hydrologic subregion were 1,500 acre-feet in 1965; and livestock depletions were 1,100 acre-feet. Both requirements are included in the appropriate water-use category figures given in Table 6. A high use-rate by the city of Page, Arizona and a low use-rate by a large number of Indians make up the 1,500 acre-feet per year of domestic depletion in Arizona.

Manufacturing water requirements in the subregion were required primarily by refineries in the all other manufacturing sector; by dairies and meat packing plants in the food and kindred products industry; by saw mills and planing mills in the lumber and wood products industry; and by

ready-mix concrete manufacturers in the stone, clay and glass industry.

Livestock, governmental, and commercial water requirements made up a significant part of total requirements. Commercial and governmental water withdrawal requirements accounted for 11 and 9 percent of total withdrawals, respectively. Livestock requirements accounted for 31 percent of total withdrawals and 59 percent of total depletions. Evaporation from stock watering ponds accounted for 8,200 acre-feet or 79 percent of total livestock depletions in the San Juan-Colorado Subregion.

Water Supply Requirements - Quality

Physical, chemical, and biological qualities of water for municipal and industrial water uses must be controlled to prevent undesirable esthetic, physiological and economic effects. Quality requirements for all of these uses are generally satisfied by water of quality meeting the recommended limits of the Public Health Service Drinking Water Standards of 1962 (39). Water of higher quality is required for many manufacturing water uses. Water of lower quality may be satisfactory for many manufacturing water uses, livestock water use, and lawn irrigation.

Domestic Water Use

Domestic water uses require a safe, clear, potable, and esthetically pleasing water supply which meets the recommended limits of the Public Health Service Drinking Water Standards of 1962. These standards for physical, chemical and biological characteristics reflect our national attitudes toward domestic water quality criteria.

Physical qualities include the turbidity, color, taste, odor, and temperature of water which must be limited to be acceptable to domestic water use. Turbidity is caused by the presence of suspended and colloidal matter which affects the clearnesss of water and the penetrability of light. Turbidity should be limited to less than 5 turbidity units.

Color is caused by substances and materials of natural mineral or vegetable origin and by inorganic or organic soluble wastes (32). Color makes drinking water less acceptable and may cause dullness in clothes, and may stain food, fixtures and utensils. Color should be limited to less than 15 color units.

Undesirable tastes and odors can be caused by decaying orgainic matter, waste products and the presence of living organisms. Objectionable tastes and odors should be virtually absent from domestic water supplies, and odors should be limited to a threshold odor number of 3.

Temperature increases may be caused by natural climatic phenomena or by discharged waste waters. Water becomes less palatable and less useful

for cooling purposes as temperature increases. The most desirable range of temperature for domestic water use is between 10° and 15° C. (32)

The recommended limits of chemical quality by the Public Health Service Drinking Water Standards are shown in Table 7.

Table 7 - Public Health Service Drinking Water Standards

Element or Group	Recommended Limit of 1962 PHS Drinking Water Standards 1/
Alkyl benzene sulfonate	0.5
Arsenic	0.01-0.05 2/
Barium	1.0 2/
Cadmium	0.01 2/
Carbon chloroform extracts	0.2
Chloride	250
Chromium hexavalent	0.05 2/
Copper	1.0
Cyanide	0.01-0.2 2/
Fluoride	0.8-1.7 3/
Iron	0.3
Lead	0.05 2/
Manganese	0.05
Nitrate	45
Phenols	0.001
Selenium	0.01 2/
Silver	0.05 2/
Sulfate	250
Total Dissolved Solids	500
Zinc	5
Radium	3 pc/1 4/
Strontium	10 pc/1 4/
Gross Beta	1,000 pc/1 4/

1/ In milligrams per liter except as noted.
2/ Amounts in excess of this figure constitute grounds for rejection of supply.
3/ The limit for any locality depends upon the annual average of maximum daily air temperatures.
4/ pc/1 = picocuries per liter.

Dissolved solids in water consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates and possibly nitrates of calcium, magnesium, sodium and potassium, with traces of iron, manganese and other substances (32). Waters which have excessive concentrations of dissolved solids may

not be palatable and may have a laxative effect on new users. Sodium sulfate and magnesium sulfate are well known laxatives. The presence of excessive concentrations of nitrates can have serious physiological effects causing infant methemoglobinemia.

Hardness describes a quality characteristic of water mainly attributable to the presence of calcium and magnesium ions. Hardness has a detrimental economic effect, resulting in excessive soap consumption, fabric wear and scale formation. It is generally accepted that hardness concentrations greater than 120 mg/l (as $CaCO_3$) should be softened in order to save money and produce a better result in laundering operations.

Some chemical constituents in water, such as iron, copper, zinc and possibly manganese, are essential for human nutrition. However, concentrations of these chemicals in water sufficient to meet nutritional requirements can be esthetically or economically undesirable by causing tastes, stains, and deposits. Since most diets provide ample amounts of these chemicals to satisfy nutritional requirements, the recommended limits of these chemicals are set to prevent the undesirable esthetic and economic effects.

Excessive concentrations of virtually all chemical constitutents in water have toxic physiological effects on humans if consumed in a short period of time. The detrimental effects on domestic water uses of pesticidal chemicals such as DDT, dieldrin, and endrin, which are consumed continuously over long periods of time, are uncertain; but indications are that they may have toxic effects and may cause taste and odor problems. Chemical constituents such as lead, arsenic, mercury and cadmium are toxic cumulative poisons which are not readily eliminated from the body. The toxic effects of these chemicals result from continuous consumption over a long period of time. Fluoride is toxic to humans in excessive concentrations, but in small concentrations it has the beneficial effect of reducing dental decay, especially in some children.

Radiation exposure can have harmful effects on humans. Radioactivity intake from all sources such as water, food and air must be limited. Water within the radiation limits shown in Table 7 is acceptable without further consideration of other sources of radiation.

Biological and microbiological characteristics of domestic water must be limited to prevent harmful esthetic and physiological effects. Saprophytic bacteria found in natural waters perform a variety of beneficial functions, including the dissolution of decaying organic matter and the concentration of elements essential to life. However, the presence of these bacteria in domestic water can cause undesirable tastes, odors, and colors. Domestic water should be free of pathogenic bacteria which can cause such diseases as dysentery, typhoid fever, parathyphoid fevers, cholera, and gastroentenitis. Domestic water should also be free of

enteroviruses such as coxsackie, polio, and infectious hepatitus viruses. Man is the primary source of pathogenic bacteria and enteroviruses.

Parasitic worms such as hookworms, flukes tapeworms and free-living worms such as chironomids and tubifex should be absent from domestic water.

Manufacturing Water Use

Generally, water of quality acceptable for domestic water use is acceptable for manufacturing water use. Water quality requirements vary significantly between different manufacturing industries. Even within a given manufacturing plant, water may have several different uses with different quality requirements for each. Cooling, steam generation, process, sanitary and other manufacturing water uses all have characteristic water quality requirements.

Cooling water is required in virtually every manufacturing industry. The initial temperature of the intake water should be low, particularly if a once-through cooling system is used. Low initial temperature is desirable if a closed or recirculating cooling system is used, although the water will eventually be cooled by some mechanism such as a cooling tower.

Wooden cooling towers are subject to physical, chemical, and biological deterioration. High temperature water can cause physical deterioration. Chemical deterioration is caused primarily by high chlorine residuals and high alkalinity concentrations. Biological growth and slime in cooling system water can cause biological deterioration of wooden cooling towers and corrosion and loss of heat transfer within the cooling system.

Corrosion and scale formation are significant detrimental effects of water quality on cooling and steam generation systems. Corrosion is caused by the chemical or electrochemical attack on a metal by its environment. High oxygen and carbon dioxide concentrations and low pH are the primary quality characteristics contributing to the corrosion of ferrous metals (5). Low pH, ammonia, cyanides, hydrogen sulfide and sulfur compounds are the principal contributors to the corrosion of non-ferrous metals. Because of evaporation and resulting concentration of chemical constituents, corrosion is a more acute problem in closed and recirculating cooling systems than in once-through open cooling systems.

Scale formation results from the crystallization or precipitation of salts from solution. As temperature increases, the solubilities of scale forming salts decreases, making scale formation a major problem in cooling and steam generation systems. Many other factors such as operating pressure, boiler design, makeup rates and steam uses affect boiler scale formation (22). The primary detrimental effects of scale

formation are the retardation of heat transfer and the overheating of boilers resulting in failures. Calcium carbonate, magnesium silicate, and calcium sulfate are the principal chemical constituents of scale formation (5).

Water quality requirements for manufacturing process water uses vary widely. The food and kindred products industry requires process water which is free of pathogenic bateria and enteroviruses and free of saprophytic organisms that may cause spoilage. Various chemical constituents must be limited to prevent undesirable tastes, odors, colors, deposits, toughening or deterioration of quality or vitamine content (32). Some chemical constituents in water produce desirable and beneficial reactions.

The lumber and wood products industry generally requires process water which is free of suspended solids greater than 3 mm in diameter which may damage equipment. The pH should be between 5 and 9 to prevent equipment corrosion. Water for preparation of solutions for treatment of the lumber should be reasonably free of turbidity and those ions which might react to form precipitates (22).

The chemicals industry may require water as a reactant (a substance that contributes its atoms to the final product) or as a solvent (3). Chemical constituents of the water which might cause adverse chemical reactions must be limited.

Generally, firms in the stone, clay and glass industry, particularly ready-mix concrete firms and firms producing concrete products, require water which is clean and free of oils, acids, alkalis, salts, and organic materials (2). Decaying vegetable matter may interfere with the setting of cement (32).

Livestock Water Use

Livestock water quality requirements are satisfied by water which is satisfactory for domestic water use, although it appears livestock can tolerate water of lesser quality. High dissolved solids concentrations are the most common livestock water quality problem. High concentrations of dissolved solids in the form of salts can cause physiological disturbances in animals such as gastrointestinal symptoms, wasting disease, and death. Animals whose productivity depends upon such functions as lactation, reproduction and rapid growth may have these functions impeded by high salinity concentrations. There are indications that low concentrations of some compounds such as nitrates, fluorides, and the salts of selenium and molybdenum can be specifically toxic to livestock. Limits of dissolved solids concentrations for various livestock are shown in Table 8. (22)

Table 8 - Threshold Concentrations of Salinity for Livestock

Animals	Dissolved Solids Concentrations (mg/l)
Poultry	2,860
Pigs	4,290
Horses	6,435
Dairy Cattle	7,150
Beef Cattle	10,000
Sheep	12,000

Generally, livestock are able to consume bacterially polluted water over long periods with no apparent detrimental effects, although water is suspected of transmitting animal diseases. Organic pollution improves the probability of the production of blue-green algaes which are toxic to livestock. Livestock can be infested with waterborne parasitic worms such as tapeworms and flukes which may be transmitted to humans (32).

Governmental, Commercial and Other Water Use

Generally, water of quality meeting the recommended limits of the Public Health Service Drinking Water Standards of 1962 is adequate for governmental, commercial and other water uses. Water hardness is particularly objectionable to commercial laundries, as it increases soap and detergent consumption, water softening costs, and equipment damage.

Distribution Systems and Sources

Regional Summary

The 1965 Regional M&I intake requirements supplied by various distribution systems are summarized in Table 9. Seventy-five percent of these requirements were supplied by surface water sources and the remainder by groundwater sources.

Table 9 - Regional Summary of 1965 M&I Withdrawal Requirements by System and Source

System	Source: Groundwater (acre-feet)	Source: Surface Water (acre-feet)	Total System Withdrawal Requirement (acre-feet)
Municipal	21,350	46,550	67,900
Rural-Domestic	4,100	400	4,500
Self-Supplied Manufacturing, Commercial and Governmental	4,100	12,500	16,600
Livestock	1,100	33,800	34,900
Regional Total	30,650	93,250	123,900

Municipal systems serve domestic, manufacturing, commercial, governmental and some livestock water uses. An estimated population of 260,800, or 78 percent of the Regional population including the hydrologic area of Arizona was served by 192 municipal systems in 1965. 1/ The average municipal withdrawal requirement excluding reservoir evaporation was 239 gpcd. There were 181 municipal systems with an independent source of supply of which 96 (53%) utilized a groundwater source, 74 (41%) utilized a surface water source, and 11 (6%) utilized a combination ground-surface water source. 2/ There were at least 11 municipal systems which were dependent upon other municipal systems for their supply. Sixty-eight percent of the Regional municipal withdrawal requirements was supplied by surface water sources. The remainder was supplied by groundwater sources. The number of independent municipal systems serving various population ranges is shown in Table 10.

1/ The total number of municipal systems in the Region was compiled from numerous sources and is not considered to be all inclusive. References: 10, 14, 19, 29, 35, 36, 40.

2/ Many municipalities use an underground infiltration gallery in the alluvium of a surface stream as a source of supply. Although most of these infiltration galleries were considered as groundwater sources for convenience, the interconnection of the groundwater and surface water in these cases makes such a distinction superfluous. Also, many municipalities with a combination ground-surface water source use one source only except in case of emergency.

Table 10 - Regional Municipal Distribution Systems and Percent of Population Served, 1965

Population Served	Number of Municipal Systems	Percent of Regional Municipal Population Served
More than 5,000	9	46
2,000 - 4,999	21	25
1,000 - 1,999	25	13
500 - 999	31	8
Less than 500	95	98
	181	100

The U. S. Public Health Service 1963 Inventory of Municipal Water Facilities listed 136 municipal systems in the Region (36) (40). The inventory showed that 84 municipal systems needed improvement to provide adequate water Service. 1/ It was indicated that 27 municipal systems needed source improvement and 60 needed water treatment improvement. Although the exact nature and extent of the needed improvements cannot be determined from the inventory, it is evident that inadequate municipal water service is prevalent in the Region. Chlorination is the major improvement required, while inadequate groundwater collection facilities and/or inadequate isolation from waste sources also need attention.

Treatment provided by Regional municipal water systems listed by the 1963 U. S. Public Health Service Inventory of Municipal Water Facilities is shown in Table 11.

Table 11 - Regional Municipal Water Treatment

Type of Water Treatment	Number of Municipal Systems
More than disinfection 2/	41
Disinfection only	46
None	49
	136

2/ Includes one or more of the following treatment processes: aeration, sedimentation, coagulation, and filtration.

1/ The base year for this study is 1965 while the PHS inventory year was 1963. It is very possible that some of the needed improvements have already been made.

Disinfection is used to kill pathogenic organisms that cause waterborne disease. Disinfection alone may be adequate treatment for groundwater depending on the quality of the supply; however, it generally is not adequate treatment for surface water supplies.

The extent of water treatment necessary in a municipal system is dependent upon the water quality of the source of supply. High concentrations of dissolved solids are present in many of the groundwater and surface water sources of the Region. Some municipalities are utilizing water in which the dissolved solids concentration exceeds 500 mg/l the recommended limit of the Public Health Service Drinking Water Standards of 1962. In the absence of water of better quality, persons often adjust to water containing substantially higher concentrations of dissolved minerals. Adherence to the drinking standards would restrict domestic use of surface and ground supplies in many parts of the three subregions.

Hardness in water (as $CaCO_3$) associated with dissolved solids is present in significant concentrations at lower elevations and generally exceeds 120 mg/l. Various water softening processes can be used, either at the municipal treatment plant or on an individual water user basis. Water softening at municipal water treatment plants is not prevalent in the Region.

Other chemical paraments such as chlorides, sulfates, nitrates and fluorides do not present widespread Regional problems. There are isolated areas where high concentrations of these chemicals are of concern. 1/

Various heavy metals such as iron, manganese, arsenic and cyanide are present in excessive concentrations in source waters being used by some municipalities. Removal of these elements will require additional treatment processes at additional cost.

The presence of pathogenic bateria and viruses in municipal source waters does not appear to be a significant Regional problem. Occasional isolated problems do occur. For this reason disinfection should be considered a minimum public health safeguard against the chance of bacterial or viral contamination of groundwater supplies; and coagulation, sedimentation, filtration, and disinfection should be the minimum public health safeguard against the chance of bacterial or viral contamination of surface water supplies.

For a more thorough and detailed evaluation of drinking water quality, the reader is referred to a section entitled, "Drinking Water Supply," Part IV of the Water Quality, Pollution Control and Health Factors Appendix.

1/ Refer to Water Quality, Pollution Control and Health Factors Appendix.

An estimated population of 75,200, or 22 percent of the Regional population including the hydrologic area of Arizona, was served by rural-domestic systems. Groundwater from individual wells was utilized to provide 90 percent of the rural-domestic supply. A large percentage of the Indian population in the Region were without adequate water supply facilities.

Rural-domestic water supplies receive little or no treatment. Problems can arise in areas where there are concentrations of population using individual water supply systems and individual septic tank waste disposal systems. There are numerous rural communities in the Region with populations greater than 50 with no central municipal system where such problems could arise.

There was insufficient data available to evaluate the adequacy of sources and the effects of water quality on self-supplied manufacturing, governmental and commercial establishments. Water quality problems caused by dissolved solids, heavy metals, temperature and sediment could involve significant treatment costs to prevent corrosion, scale formation, and process water damage.

Livestock requirements are supplied primarily by surface water sources because groundwater sources are usually expensive to develop as well as being of generally poorer quality.

Green River Subregion

The 1965 Green River Subregion M&I withdrawal requirements supplied by various distribution systems are summarized in Table 12. Seventy-two percent of these requirements were supplied by surface water sources and the remainder by groundwater sources.

Table 12 - Summary of 1965 Municipal and Industrial Withdrawal Water Requirements by System and Source
Green River Subregion

System	Source		Total System Withdrawal Requirement (acre-feet)
	Groundwater (acre-feet)	Surface Water (acre-feet)	
Municipal	9,100	14,100	23,200
Rural-Domestic	1,000	100	1,100
Self-Supplied Manufacturing, Commercial and Governmental	800	2,300	3,100
Livestock	400	12,900	13,300
Subregional Total	11,300	29,400	40,700

An estimated population of 73,500, or 73 percent of the subregional population was served by 69 municipal systems. The average municipal withdrawal requirement excluding reservoir evaporation was 280 gpcd. There were 63 municipal systems with an independent source of supply of which 31 (49%) utilized a groundwater source, 31 (49%) utilized a surface water source, and 1 (2%) utilized a combination ground-surface water source. There were at least 6 municipal systems which were dependent upon other municipal systems for their supply. Fifty-eight percent of the subregional municipal intake requirement was supplied by surface water sources. The remainder was supplied by groundwater. The number of municipal systems serving various population ranges is shown in Table 13.

Table 13 - Municipal Distribution System and Percent of Population Served, 1965
Green River Subregion

Population Served	Number of Municipal Systems	Percent of Subregional Municipal Population Served
More than 5,000	2	33
2,000-4,999	7	29
1,000-1,999	10	19
500-999	9	9
Less than 500	35	10

The largest municipalities in the subregion and 1960 populations are Price, Utah (6,802); Vernal, Utah (3,655); Craig, Colorado (3,984); Rock Springs, Wyoming (10,371); and Green River, Wyoming (3,497). The Rock Springs and Green River municipal systems are supplied by a single treatment plant.

The 1963 PHS inventory listed 46 municipal systems in the subregion. The inventory showed that 28 municipal systems needed improvement to provide adequate water service. It was indicated that 10 municipal systems needed source improvement and 29 needed water treatment improvements. Craig, Colorado was listed as needing both surface water source and treatment improvements.

The extent of water treatment provided by subregional municipal systems is shown in Table 14.

Table 14 - Municipal Water Treatment
Green River Subregion

Type of Water Treatment	Number of Municipal Systems
More than disinfection	14
Disinfection only	19
None	13
	46

An estimated population of 18,000, or 18 percent of the subregion population was served by rural-domestic systems. There are numerous rural communities in the subregion with population greater than 50 which do not have central municipal systems.

Upper Main Stem Subregion

The 1965 Upper Main Stem Subregion M&I withdrawal requirements supplied by various distribution systems are summarized in Table 15. Seventy-five percent of these requirements were supplied by surface water sources and the remainder by groundwater sources.

Table 15 - Summary of 1965 Municipal and Industrial Withdrawal Water Requirements by System and Source
Upper Main Stem Subregion

System	Source		Total System Withdrawal Requirement (acre-feet)
	Groundwater (acre-feet)	Surface Water (acre-feet)	
Municipal	8,400	19,800	28,200
Rural-Domestic	1,900	200	2,100
Self-Supplied Manufacturing, Commercial and Governmental	2,100	6,500	8,600
Livestock	200	11,000	11,200
Subregional Total	12,600	37,500	50,100

An estimated population of 101,400, or 74 percent of the subregional population was served by 69 municipal systems. The average municipal withdrawal requirement excluding reservoir evaporation was 243 gpcd. There were 64 municipal systems with an independent source of supply of which 25 (39%) utilized a groundwater source, 31 (48%) utilized a surface water source, and 8 (13%) utilized a combination ground-surface source. There were at least 5 municipal systems which were dependent upon other municipal systems for their supply. Sixty-nine percent of the subregional municipal withdrawal requirement was supplied by surface water sources. The remainder was supplied by groundwater sources. The number of municipal systems serving various population ranges is shown on Table 16.

Table 16 - Municipal Distribution Systems and Percent of Population Served, 1965
Upper Main Stem Subregion

Population Served	Number of Municipal Systems	Percent of Subregional Municipal Population Served
More than 5,000	4	52
2,000 - 4,999	8	23
1,000 - 1,999	6	8
500 - 999	15	10
Less than 500	31	7
	64	100

The largest municipalities in the subregion and 1960 populations are Grand Junction, Colorado (18,694); Montrose, Colorado (5,044); Delta, Colorado (3,832); Gunnison, Colorado (3,477); and Moab, Utah (4,682).

The 1963 PHS inventory listed 58 municipal systems in the subregion. The inventory showed that 36 municipal systems needed improvement to provide adequate water service. It was indicated that 4 municipal systems needed source improvement and 32 needed water treatment improvement. Moab, Utah and Gunnison, Colorado were listed as needing both groundwater source and treatment improvement. The extent of water treatment provided by subregional municipal systems is shown in Table 17.

Table 17 - Municipal Water Treatment
Upper Main Stem Subregion

Type of Water Treatment	Number of Municipal Systems
More than disinfection	18
Disinfection only	20
None	20
	58

Dissolved solids and heavy metals could cause water treatment problems for some municipal supply systems in the subregion. Process water for food processing manufacturers in the subregion could also be undersirable because of these water quality parameters.

An estimated population of 35,300, or 26 percent of the subregional population was served by rural-domestic systems. There are many rural communities in the subregion with populations greater than 50 which do not have central municipal systems. Some rural households are supplied with water from individual cisterns which are supplied by hauling or direct from irrigation ditches.

San Juan-Colorado Subregion

The 1965 San Juan-Colorado Subregion M&I withdrawal requirements supplied by various distribution systems are summarized in Table 18. Eighty percent of these requirements were supplied by surface water sources and the remainder by groundwater sources.

Table 18 - Summary of 1965 Municipal and Industrial Withdrawal Water Requirements by System and Source
San Juan-Colorado Subregion

System	Source		Total System Withdrawal Requirement (acre-feet)
	Groundwater (acre-feet)	Surface Water (acre-feet)	
Municipal	3,700	12,800	16,500
Rural-Domestic	1,200	100	1,300
Self-Supplied Manufacturing, Commercial and Governmental	1,200	3,700	4,900
Livestock	500	9,900	10,400
Subregional Total	6,600	26,500	33,100

An estimated population of 85,900, or 67 percent of the subregional population including the hydrologic area of Arizona, was served by 54 municipal systems. The average municipal withdrawal requirement excluding reservoir evaporation was 195 gpcd. There were 40 (74%) municipal systems which utilized groundwater source, 12 (22%) which utilized a surface water source, and 2 (4%) which utilized a combination ground-surface water source. Eighty percent of the total subregional municipal withdrawal requirement was supplied by surface water sources. The remainder was supplied by ground sources. The number of municipal systems serving various population ranges is shown in Table 19.

Table 19 - Municipal Distribution Systems and Percent of Population Served, 1965
San Juan-Colorado Subregion

Population Served	Number of Municipal Systems	Percent of Subregional Municipal Population Served
More than 5,000	3	50
2,000 - 4,999	6	24
1,000 - 1,999	9	13
500 - 999	7	6
Less than 500	29	7
	54	100

The largest municipalities in the subregion and 1960 populations are Farmington, New Mexico (23,786); Aztec, New Mexico (4,137); Durango, Colorado (10,530); and Cortez, Colorado (6,764).

The 1963 PHS inventory listed 32 municipal systems in the subregion. The inventory showed that 24 municipal systems needed improvement to provide adequate water service. It was indicated that 13 municipal systems needed source improvement and 8 needed water treatment improvement. Farmington, New Mexico was listed as needing improvement of its surface water source, however, modifications and improvements have eliminated the problems.

The extent of water treatment provided by subregional municipal systems is shown in Table 20.

Table 20 - Municipal Water Treatment
San Juan-Colorado Subregion

Type of Water Treatment	Number of Municipal Systems
More than disinfection	9
Disinfection only	7
None	16
	23

The Animas River occasionally has very high concentrations of heavy metals which exceed the recommended limits (21). The municipalities of Durango, Colorado; Aztec, New Mexico; and Farmington, New Mexico utilize the Animas River as a source of municipal supply.

An estimated population of 42,800, or 33 percent of the subregional population including the hydrologic area of Arizona was served by rural-domestic systems. There are many rural communities in the subregion with populations greater than 50 which do not have central municipal systems.

There was an estimated Indian and non-Indian population of 62,200 living on or near the Navajo Indian Reservation in the subregion. A significant portion of this Indian population has an inadequate supply. In some cases it is necessary to haul water from nearby sources to satisfy minimal requirements. Although improvements are being made, further improvements are needed to provide adequate service.

PART III

FUTURE DEMANDS

OBE-ERS Projections

Water Supply Requirements

Regional Summary

A Regional summary of projected domestic, manufacturing, livestock, governmental, and commercial and other M&I water requirements for each target year is presented in Table 21. A summary of projected municipal and industrial withdrawal and depletion water requirements by states excluding livestock water requirements is presented in Table 22 for the Region. A summary of livestock water use and stock pond evaporation estimates for all target years is presented in Table 23 for the Region.

As shown in Table 21, withdrawal requirements are projected to increase from 123,900 acre-feet per year in 1965 to 347,900 acre-feet per year in 2020, representing almost a two-fold increase over the study period. Withdrawals for commercial uses will be largest in 2020, with needs of 94,400 acre-feet per year. This requirement for the commercial water-use category is projected to be 50 percent greater than that projected for the manufacturing water-use category in 2020. Domestic uses are the next largest category, with 88,400 acre-feet per year projected in 2020. In descending order, the next largest withdrawal requirements are for the manufacturing livestock, and governmental categories.

A projected 86 percent increase in population (includes hydrologic area of Arizona), more than eight-fold increase in the value of manufacturing output, seven-fold increase in the economic activity in the commercial category, and a rising water-use rate by the Region's Indian and rural residents are the major reasons for the growth of municipal and industrial water demands.

Total water withdrawal for livestock will increase from about 35,000 acre-feet in 1965 to 59,000 acre-feet in 2020. The water consumed annually by livestock will increase from 11,000 acre-feet in 1965 to nearly 18,000 acre-feet by 2020. Increases in animal units over the study period from nearly 1 million to nearly 1.6 million account for the projected water uses. (See Table 23.)

Subregions

Tables 24, 25, and 26 present the projected withdrawal and depletion water requirements for the Green River, Upper Main Stem, and San Juan-Colorado Subregions, respectively. In 2020, depletions are projected to be 47,600, 61,000 and 60,500 acre-feet per year for the Green River, Upper

Table 21 - Regional Summary of Projected Municipal and Industrial Water Requirements (acre-feet per year)

Water Use	1965	1980	2000	2020
	Withdrawal			
Domestic	52,400	57,700	71,200	88,400
Manufacturing	11,500	20,300	36,200	62,400
Livestock	34,900	41,300	50,100	59,000
Governmental	10,700	16,400	27,900	43,700
Commercial	14,400	27,300	53,100	94,400
Total	123,900	163,000	238,500	347,900
	Depletion			
Domestic	18,800	26,200	33,700	43,100
Manufacturing	1,900	3,400	6,700	12,700
Livestock	34,900	41,300	50,100	59,000
Governmental	1,000	2,000	4,200	8,800
Commercial	5,700	11,400	23,200	45,500
Total	62,300	84,300	117,900	169,100

Table 22 - Projected Municipal and Industrial Water Requirements by States 1/
(acre-feet per year)

	1965		1980		2000		2020	
	Withdrawal	Depletion	Withdrawal	Depletion	Withdrawal	Depletion	Withdrawal	Depletion
Green River								
Colorado	5,200	1,500	7,600	2,600	11,900	4,100	16,700	6,200
Utah	11,800	3,700	14,200	4,800	20,100	6,900	29,800	11,000
Wyoming	10,400	2,700	12,800	4,300	17,200	5,900	25,000	9,200
Subtotal	27,400	7,900	34,600	11,700	49,200	16,900	71,500	26,400
Upper Main Stem								
Colorado	36,600	11,600	46,700	15,900	70,100	23,200	104,600	37,200
Utah	2,300	700	3,000	1,000	5,300	1,700	9,100	3,200
Subtotal	38,900	12,300	49,700	16,200	75,400	24,900	113,700	40,400
San Juan-Colorado								
Arizona	1,800	1,700	2,900	2,900	4,800	4,800	7,200	7,200
Colorado	7,700	2,100	12,200	4,300	19,700	7,000	33,600	12,600
New Mexico	9,800	2,500	16,700	5,900	29,500	10,600	46,300	17,300
Utah	3,400	900	5,600	2,000	9,700	3,500	16,600	6,200
Subtotal	22,700	7,200	37,400	15,100	63,700	25,900	103,700	43,300
Region								
Arizona	1,700	1,600	2,900	2,900	4,800	4,800	7,200	7,200
Colorado	49,600	15,000	66,500	22,100	101,700	34,300	154,900	56,000
New Mexico	9,300	3,400	16,700	5,900	29,500	10,600	46,300	17,300
Utah	17,700	5,500	22,800	7,800	35,100	12,100	55,500	20,400
Wyoming	10,700	2,900	12,800	4,300	17,200	5,900	25,000	9,200
Total	89,000	27,400	121,700	43,000	188,300	67,700	288,900	110,100

1/ Does not include livestock water requirements.

Table 23 - Projected Livestock Water Requirements and Stockpond Developments

Period	Animal Units 1/ (1,000)	Annual Requirements for Livestock Consumption (Ac. Ft.)	Stock Water Devel. (No.)	Ave. Ann. Net Evap. From Farm Ponds for Livestock Water (Ac. Ft.)	Total Annual Livestock Water Use 2/ (Ac. Ft.)
GREEN RIVER SUBREGION					
1965	436	4,900	9,160	8,400	13,300
1980	484	5,400	10,900	9,900	15,300
2000	549	6,100	13,300	12,100	18,200
2020	614	6,900	15,700	14,300	21,200
UPPER MAIN STEM SUBREGION					
1965	351	3,900	6,316	7,300	11,200
1980	414	4,600	7,900	9,100	13,700
2000	498	5,600	10,000	11,500	17,100
2020	582	6,500	12,200	14,100	20,600
SAN JUAN - COLORADO SUBREGION					
1965	198	2,200	6,559	8,200	10,400
1980	247	2,800	7,600	9,500	12,300
2000	312	3,500	9,000	11,300	14,800
2020	378	4,200	10,400	13,000	17,200
UPPER COLORADO REGION					
1965	985	11,000	22,035	23,900	34,900
1980	1,145	12,800	26,400	28,500	41,300
2000	1,359	15,200	32,300	34,900	50,100
2020	1,574	17,600	38,300	41,400	59,000

1/ Animal Unit is equivalent to beef cow with calf by side.

2/ Withdrawal and depletion requirements are the same for livestock water requirements.

Table 24 - Summary of Projected Municipal and Industrial Water Requirements
Green River Subregion
(acre-feet per year)

Water Use	1965	1980	2000	2020
	Withdrawal			
Domestic	18,600	18,500	19,900	22,400
Manufacturing	2,100	3,500	6,400	10,800
Livestock	13,300	15,300	18,200	21,200
Governmental	3,300	5,200	8,400	12,700
Commercial	3,400	7,400	14,500	25,600
Total	40,700	49,900	67,400	92,700
	Depletion			
Domestic	6,000	7,400	8,000	9,000
Manufacturing	300	500	1,000	1,900
Livestock	13,300	15,300	18,200	21,200
Governmental	300	600	1,300	2,500
Commercial	1,300	3,200	6,600	13,000
Total	21,200	27,000	35,100	47,600

Table 25 - Summary of Projected Municipal and Industrial Water Requirements
Upper Main Stem Subregion
(acre-feet per year)

Domestic	1965	1980	2000	2020
	Withdrawal			
Domestic	21,600	21,100	23,500	25,800
Manufacturing	5,600	10,000	17,400	29,100
Livestock	11,200	13,700	17,100	20,600
Governmental	4,500	5,800	9,200	14,000
Commercial	7,200	12,800	25,300	44,800
Total	50,100	63,400	92,500	134,300
	Depletion			
Domestic	7,900	8,400	9,400	10,300
Manufacturing	1,000	1,800	3,400	6,500
Livestock	11,200	13,700	17,100	20,600
Governmental	400	700	1,400	2,800
Commercial	3,000	5,300	10,700	20,800
Total	23,500	29,900	42,000	61,000

Table 26 - Summary of Projected Municipal and Industrial Water Requirements
San Juan-Colorado Subregion
(acre-feet per year)

Water Use	1965	1980	2000	2020
	Withdrawal			
Domestic	12,200	18,100	27,800	40,200
Manufacturing	3,800	6,800	12,400	22,500
Livestock	10,400	12,300	14,800	17,200
Governmental	2,900	5,400	10,300	16,900
Commercial	3,800	7,100	13,300	24,100
Total	33,100	49,700	78,600	120,900
	Depletion			
Domestic	4,900	10,400	16,300	23,800
Manufacturing	600	1,100	2,200	4,300
Livestock	10,400	12,300	14,800	17,200
Governmental	300	700	1,500	3,400
Commercial	1,400	2,900	5,900	11,800
Total	17,600	27,400	40,700	60,500

Main Stem and San Juan-Colorado Subregions respectively. Upper Main Stem and San Juan-Colorado Subregions depletions in 2020 are projected to be about equal, even though the population (includes hydrologic area of Arizona) of the San Juan-Colorado Subregion is projected to be 324,800 as opposed to 204,200 for the Upper Main Stem Subregion. This is due primarily to the more intense pattern of commercial and manufacturing activity projected for the Upper Main Stem Subregion.

Estimates of M&I water depletions in the San Juan-Colorado Subregion by the year 2020 show on an increase of 244 percent over 1965 conditions. This compares with 125 and 160 percent increases for the Green River and Upper Main Stem Subregions, respectively.

The growth of municipal and industrial water requirements in the Upper Main Stem and San Juan-Colorado Subregions results from the expanding economies associated with the Grand Junction, Colorado and Farmington, New Mexico population centers, respectively. Due largely to the fact that the subregion economies are heavily service oriented, the domestic and commercial water use categories show the greatest water depletion requirements for all subregions in all target years.

Service Areas

The Comprehensive Framework Study (Type I) defines a service area as one whose problems are interrelated and where planning for water supply and waste disposal should be carried out on an integrated basis. These areas have also been defined as Standard Metropolitan Statistical Areas (SMSA's) by the U. S. Bureau of Census.

There were no SMSA's in the Region in 1965. Mesa County (Grand Junction) Colorado and San Juan County (Farmington) New Mexico, located in the Upper Main Stem and San Juan-Colorado Subregions, respectively, are projected to become SMSA's, as presently defined, during the study period. Their population projections and municipal and industrial withdrawal requirements excluding livestock requirements are given in Table 27. A major portion of the withdrawals developed for the counties would be needed in the Grand Junction and Farmington metropolitan areas.

Table 27 - Projected Municipal and Industrial Water Supply Requirements for Service Areas

Mesa County, Colorado			San Juan County, New Mexico	
Year	Population 1/	Withdrawals (A.F)	Population	Withdrawals (A.F.)
1965	54,400	13,700	46,600	6,900
1980	57,200	20,000	65,000	14,000
2000	71,000	31,000	95,000	25,000
2020	87,500	48,000	125,000	40,000

1/ Provided by Economics Workgroup, Upper Colorado Region

Quality Considerations

The sources of most municipal water supplies in the Region are in the headwaters of streams where the water quality is generally excellent. Future water quality problems, therefore, are expected to be minimal.

There are localized areas, however, where water quality may inhibit a beneficial use. For example, some areas in the Upper Main Stem have groundwater which contains a higher salt content than tolerable for human or livestock consumption. Also, seasonal thundershowers cause localized turbidity problems for some domestic supplies.

Means of Meeting the Needs

Future municipal and industrial needs including livestock, will be met by developing additional surface and limited groundwater supplies and by some conversion of irrigation water. This conclusion is supported by the fact that 2020 depletions (169,000 A.F.) will be less than 3 percent of the total water requirements (6.5 million A.F.) projected for the Region, and that the Region has surface water physically available to meet its needs.

To provide adequate stockwater for proper range management, 16,000 stockwater developments are estimated to be needed by 2020, with evaporation loses increasing from about 24,000 acre-feet in 1965 to 41,400 acre-feet in 2020. (See Table 23).

Livestock water use by 2020 is estimated to be less than one percent of the total projected water use (6.5 million A.F.) in the Upper Colorado Region.

In general, the quality of surface water supplies is adequate for livestock use. With the small increase in water demand projected for livestock, no problems of any magnitude are foreseen within the Region. Local problems will continue to occur where groundwater supplies are not suitable, where present surface supplies are not adequate and storage methods are not practical. These problems are expected to occur only with range cattle, as livestock feeding operations are not likely to develop where the water supply is limited.

Grand Junction's present source of supply, Kahnah Creek, has an annual discharge that is adequate to meet the 2020 municipal and industrial demands (18). However, the full use of the creek as a water supply may be impossible due to the projected agricultural and recreational uses. Consequently, other sources of supply may have to be developed. Two authorized projects that have been planned for the area will supply additional municipal and industrial water.

With proposed developments, the annual discharge of the Animas River will be adequate to supply the municipal and industrial requirements of Farmington, New Mexico through 2020. Quality of water problems in the area will require careful attention.

Use of Regional surface-water sources will be by far the most common means of meeting municipal and industrial water needs in the next several decades. A number of federal multi-purpose surface-water supply projects have recently been constructed, are under construction, or are planned for all major areas of expanding M&I needs in the Region. For example, the Bureau of Reclamation's Central Utah Project will supply municipal and industrial water in the Duchesne River Basin. The Animas-LaPlata Project will supply water in the Aztec-Farmington-Shiprock, New Mexico, and Durango, Colorado areas. Other projects from which new supplies of M & I water will be available include the Glen Canyon, Flaming Gorge, Curecanti, and Navajo storage units; the proposed Dolores, Dallas Creek, San Miguel, West Divide and Yellow Jacket Projects in Wester Colorado, and the Green River Project in southwestern Wyoming.

Because of the rural character of the Region, however, there are wide areas where small community systems will be developed by non-federal funds. This is especially true in the Utah portion of the San Juan-Colorado Subregion. Programs of the Bureau of Indian Affairs, Department of Housing and Urban Development, and Economic Development Administration will by large be used to meet the Indian needs projected for Arizona and portions of the San Juan-Colorado Subregion. Other areas like the Wyoming portion of the Green River Subregion and the Utah portion of the Green River Subregion south of the Duchesne River Valley have many small communities scattered over wide areas that will meet their needs through private development.

After considering the spatial relation of future needs to the delivery areas of authorized projects, it was estimated that 30, 20, and 30 percent of the future M&I needs projected in each time frame for the Green River, Upper Main Stem, and San Juan-Colorado Subregions, respectively, would be met by other than federal development. Single-purpose development and treatment costs of the programs are shown in Table 28. The non-federal investment costs are $2.6, $6.5 and $9.0 million for the 1966-1980, 1981-2000 and 2001-2020 time frames, respectively.

Table 28 - Municipal and Industrial Program Costs for Single-Purpose Development ($1,000)

	Non-Federal Investment Costs		
	1966-1980	1981-2000	2001-2020
Green River Subregion	360	890	1,420
Upper Main Stem Subregion	340	1,380	1,630
San Juan-Colorado Subregion	1,900	4,270	5,970
Region	2,600	6,540	9,020

Capital costs of water treatment plants to treat all future requirements are included. Cost of distribution systems from the treatment plant to the consumer are not included. Cost of federal multi-purpose projects that have a M&I water supply allocation, that is, those that will meet 70 to 80 percent of each subregional need, are also not included, but are summarized in the cost totals given in the General Program and Alternatives Appendix.

The annual OM&R costs needed for the up-keep of programs summarized in Table 28 are given in Table 29.

Table 29 - Municipal and Industrial Operation, Maintenance and Replacement Costs 1/ ($1,000)

	1980	2000	2020
Green River Subregion	57	131	201
Upper Main Stem Subregion	95	232	345
San Juan-Colorado Subregion	153	264	384
Region	305	627	930

1/ Costs are annual incremental costs; all costs are non-Federal.

State Alternatives

Three alternatives in addition to the regional interpretation of OBE-ERS have been suggested and incorporated in the General Program and Alternatives Appendix. The total regional depletion requirement for the first level is 6.5 million acre-feet (m.a.f.) in 2020. This alternative is a reapportionment of water as developed from the translation of the regionally interpreted OBE-ERS projections.

The second alternative is set at a regional depletion level of 8.16 million acre-feet in 2020, and the third alternative is for the water supply available at the site of use. The justifications for these three alternatives are given in the General Program and Alternatives Appendix. Table 30, 31 and 32, however, summarize the municipal and industrial (M&I) depletions. Figure 2 shows the comparisons of the three alternatives with the level developed in this appendix.

Table 30 - Projected Municipal and Industrial Water Depletions (excludes stock-pond evaporation and livestock use) for the 6.5 m.a.f. State Alternative (acre-feet)

Area	1980	2000	2020
Green River Subregion	12,200	26,100	42,600
Upper Main Stem Subregion	16,200	31,900	47,400
San Juan-Colorado Subregion	18,200	31,400	57,600
Region	46,600	89,400	147,600
Arizona	(2,900)	(4,800)	(7,200)
Colorado	(22,100)	(48,300)	(70,000)
New Mexico	(7,200)	(13,600)	(29,100)
Utah	(10,100)	(16,800)	(32,100)
Wyoming	(4,300)	(5,900)	(9,200)

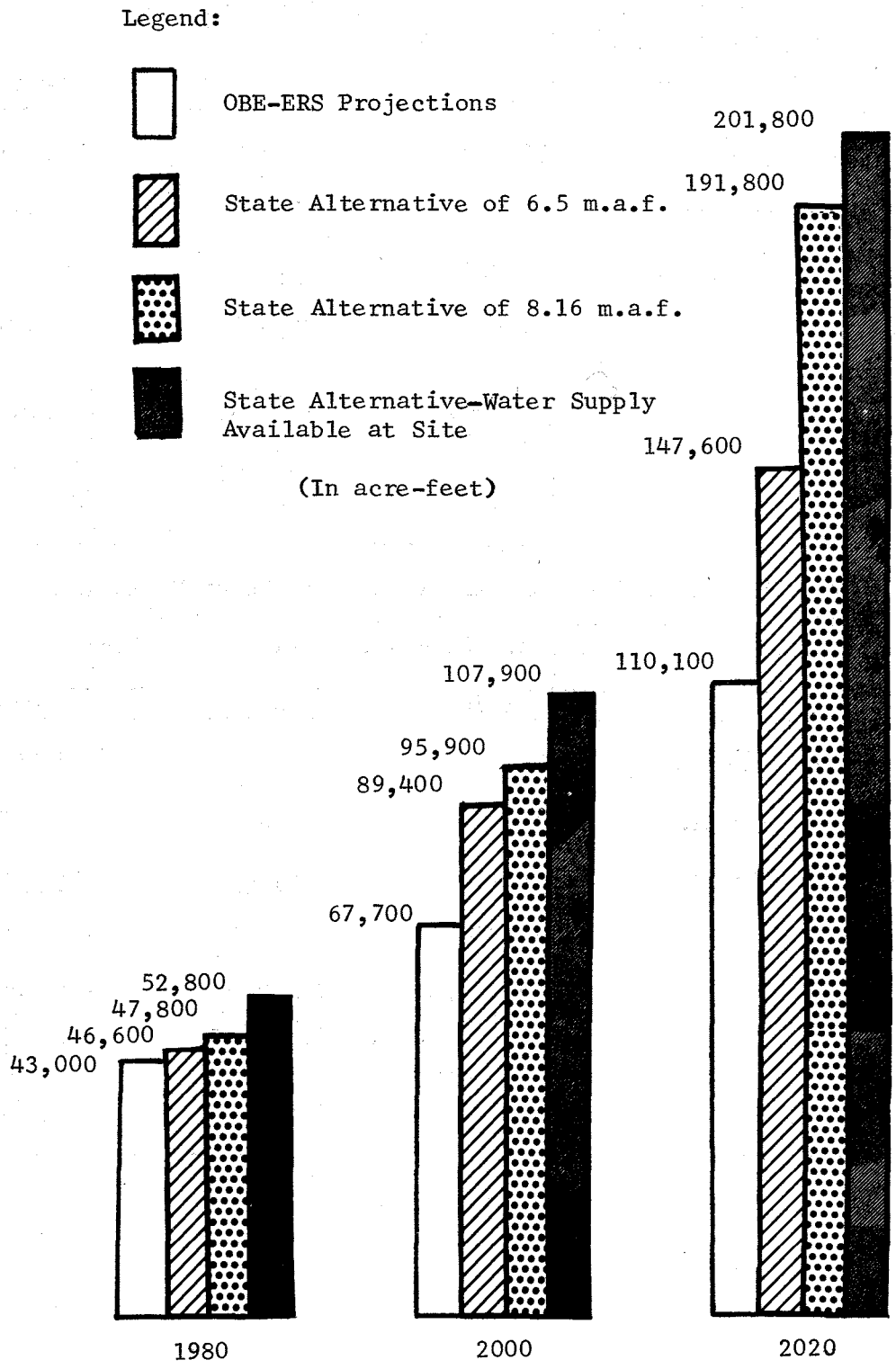


Figure 2: Comparisons of Regional Municipal and Industrial Water Supply Depletions for Four Projection Levels

Table 31 - Projected Municipal and Industrial Water Depletions
(excludes stock-pond evaporation and livestock use)
for the 8.16 M.A.F. State Alternative (acre-feet)

Area	1980	2000	2020
Green River Subregion	13,400	29,500	78,300
Upper Main Stem Subregion	16,200	31,900	54,400
San Juan-Colorado Subregion	18,200	34,500	59,100
Region	47,800	95,900	191,800
Arizona	(2,900)	(4,800)	(7,200)
Colorado	(22,100)	(50,000)	(84,100)
New Mexico	(7,200)	(13,600)	(29,100)
Utah	(10,100)	(20,200)	(42,500)
Wyoming	(5,500)	(7,300)	(28,900)

Table 32 - Projected Municipal and Industrial Water Depletions
(excludes stock-pond evaportion and livestock use)
for Water available at Site State Alternative (acre-feet)

Area	1980	2000	2020
Green River Subregion	18,400	41,500	88,300
Upper Main Stem Subregion	16,200	31,900	54,400
San Juan-Colorado Subregion	18,200	34,500	59,100
Region	52,800	107,900	201,800
Arizona	(2,900)	(4,800)	(7,200)
Colorado	(22,100)	(50,000)	(84,100)
New Mexico	(7,200)	(13,600)	(29,100)
Utah	(10,100)	(20,200)	(42,500)
Wyoming	(10,500)	(19,300)	(38,900)

Research Needs

Basic research is needed to refine the development of water-use coefficients used in this report.

Research is needed to determine the relationship of scarcity or price on quantity of water used.

There is a need for studies concerning the future relationships between water use and technological changes, water substitution possibilities and the relationship of water to other inputs in the production process.

Further research is needed in the fields of wastewater reclamation and desalination.

There is a need to develop more efficient stock watering systems.

PART IV

METHODOLOGY AND ASSUMPTIONS

Municipal and industrial water demands in the Upper Colorado Region were determined by a systematic analysis of the water requirements for each industrial use. The systems which collect and distribute the water and the sources of supply were also analyzed. Present and future municipal and industrial water requirements were determined by correlating water use with the economic and demographic characteristics of the subregions. A conceptual diagram for this systematic analysis is depicted in Figure 3.

Water requirements for each industrial sector shown in the economic models were developed using the following measures of use:

W = Withdrawal
R = Return water
D = Depletion

Using the above measures of water use an equation can be drawn to express the equilibrium condition in the water-use cycle, i.e., withdrawal (W) is equal to depletion (D) plus return (R).

Water-use data by disaggregated industrial sectors at the regional level are almost nonexistent. Considerable effort, however, was devoted to the development of water-use coefficients relating water intake and depletions to value of output on a regional basis in recent studies of the Colorado River Basin (45). These water-use coefficients formed the basis for the municipal and industrial water requirements analysis. Members of the Municipal and Industrial Water Supply Workgroup suggested and incorporated numerous revisions and refinements based on additional research and limited field work in updating the water-use coefficients to 1965 and developing projected coefficients for 1980, 2000 and 2020.

Economic output data and the developed water-use coefficients, were used to estimate the withdrawal and depletion water needs in the manufacturing, governmental, and commercial and other water-use categories for 1965, 1980, 2000, and 2020. The total present and future annual quantity of water required by each ecomonic sector was determined by multiplying the annual total gross output (TGO) for each sector by the appropriate water-use coefficient. For example, the Food and Kindred Products sector in the Upper Main Stem Subregion had a 1965 total gross output of $20.4 million, a withdrawal coefficient of 14.7 gallons per dollar, and a depletion coefficient of 3.1 gallons per dollar. This yields 299.9 million gallions and 63.2 million gallons as the 1965 withdrawal and depletion requirements, respectively.

Water requirements for all other manufacturing, commercial and governmental sectors were similarly developed for each economic subregion

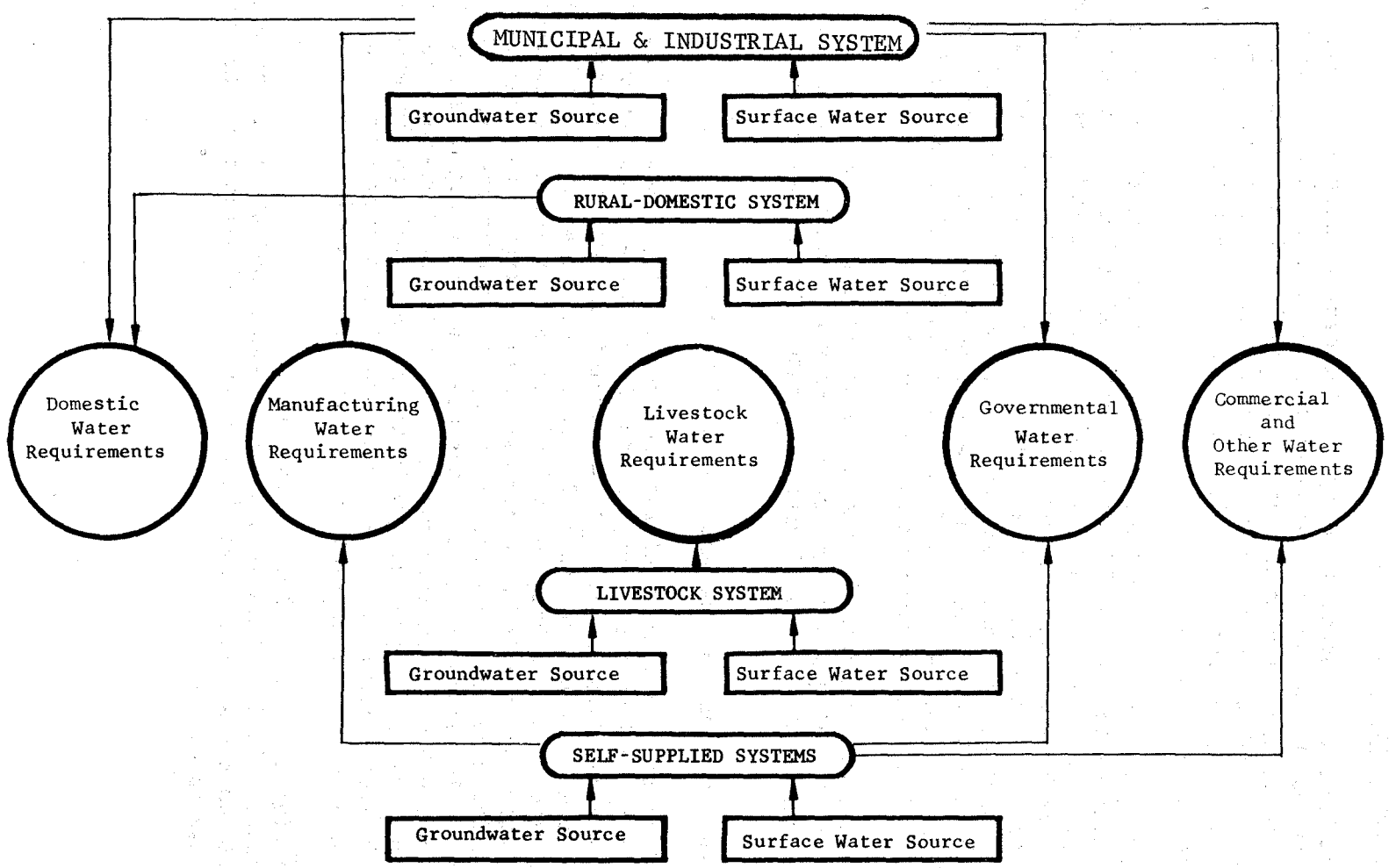


FIGURE 3: Conceptual Flow Diagram for Municipal and Industrial Water Requirements.

economy based on total gross output data contained in the Economic Base and Projections Appendix.

Recirculation, encouraged in part by increasing water costs and future water quality needs, was considered as having the largest future impact on the withdrawal coefficients. The results of a regression analysis of the relationship between Regional and national water-use coefficients indicated that the major influence of Regional factors is on the withdrawal coefficients.

Water requirements for the household sector were developed using withdrawal and depletion coefficients in units of gallons per capita per year (gpcy). The population of a subregion within the hydrologic boundary was multiplied by the household sector coefficients for that subregion to determine the requirements. For example, the 1965 population of the Upper Main Stem hydrologic subregion was 136, 725, the household withdrawal coefficient was 51,465 (gpcy), and the household depletion coefficient was 18,780 gpcy. This equals 7,036.5 MG and 2.567.7 MG as the 1965 withdrawal and depletion requirements, respectively.

Water-use coefficients for the household sector represent a weighted average of municipal-domestic and rural-domestic, including Indian water-use rates. To derive the household water-use rates the following steps were taken:

1. Develop Municipal-Domestic Water-Use Rate.

A weighted average municipal water-use rate, which includes all uses served by municipal systems, was developed for each subregion for 1965 from several data sources. 1/ The municipal-domestic withdrawal water-use rate was estimated to be 70 percent of the municipal withdrawal water-use rate in each subregion in 1965. 2/ For example, the municipal-domestic water-use rate in the Upper Main Stem Subregion for 1965 was 70 percent of 243 gpcd, or 170 gpcd. Further, it was estimated that this percentage would remain the same in the Green River Subregion and would decrease in the Upper Main Stem and San Juan-Colorado Subregions in the future target years. A projected weighted average municipal water-use rate was developed for each subregion for the future target years using reasoned judgment and consideration of county urbanization.

1/ References: 10, 11, 12, 19, 29, 36, 40.
2/ References: 23, 41. Data in these references indicate that the municipal-domestic water-use rate ranges between 60 and 75 percent of the municipal water-use rate.

2. Develop Rural-Domestic Water-Use Rate.

The 1965 rural-domestic withdrawal water-use rate in the Green River, Upper Main Stem and San Juan-Colorado Subregions was estimated to be 60, 60 and 50 gpcd, respectively (11) (31). Further, this rate was estimated to remain the same in the Green River Subregion and to increase to 75 gpcd in the Upper Main Stem Subregion and to 65 gpcd in the San Juan-Colorado Subregion by the year 2020.

The water-use rate by Indians living in rural areas is much less than the average rural-domestic rates shown above. Because of the relatively large number of rural Indians living in the San Juan-Colorado Subregion water requirements for the rural-domestic population in the San Juan-Colorado Subregion were adjusted to reflect water use by the Indian population. The withdrawal water-use rate by the Indian population was estimated to be 28 gpcd in 1965 and to increase to 65 gpcd by 2020. Indian populations in the other subregions were not large enough for independent consideration.

3. Determine the Weighted-Average Household Water-Use Rate.

To determine a weighted-average household withdrawal water-use coefficient for each subregion, it was first necessary to determine the percentage breakdown of the population served by municipal, rural, and Indian systems. A lengthy procedure was used which utilized 1960 and estimated 1965 county population data and the estimated population served by municipal systems in 1963 from U. S. Public Health Service inventories (36). The basic assumption in the procedure was that changes in population served by rural systems from 1960 to 1965 would occur at the same rate as changes in the farm labor force (45).

As a result of this procedure, for example, it was estimated that in the Upper Main Stem Subregion in 1965, a population of 101,225 were served by municipal systems and a population of 35,500 were served by rural-domestic systems. The population served by each system multiplied by the withdrawal rate (gpcd) for each system gives total water use in million gallons per day (mgd). The proportion of the population served by municipal and rural systems in the Green River and San Juan-Colorado Subregions was estimated to remain the same in future target years. The proportion of the population served by municipal systems in the Upper Main Stem Subregion was estimated to increase from 74 percent in 1965 to 81 percent in 2020.

The 1965 household sector weighted-average withdrawal coefficients for the Green River and Upper Main Stem Subregions in each year were developed as illustrated by the following example for the Upper Main Stem Subregion.

Type of System	1965 Population Served	Domestic Withdrawal Use Rate (gpcd	Total Use (mgd)
Municipal	101,225	170	17.208
Rural-Domestic	35,500	60	2.130
	136,725		19.338

1965 household withdrawal coefficient = $\frac{19.338 \text{ mgd}}{136,725}$ = 141 gpcd or 51,465 gpcy.

Household sector withdrawal coefficients for the San Juan-Colorado Subregion were determined by a similar procedure as the weighted average of the municipal-domestic, rural-domestic, and Indian water-use rate.

Assumptions given in the above procedure resulted in the subregional household sector coefficients shown in Table 33. Coefficients in the Green River and Upper Main Stem Subregions decrease with time because future wastes are minimized.

Table 33 - Projected Withdrawal Rates for the Household Sector (gpcd)

Subregion	1965	1980	2000	2020
Green River	165	154	143	132
Upper Main Stem	141	132	122	113
San Juan-Colorado	85	92	103	110

The 1965 depletion water-use coefficients for the household sector were estimated to be about 35 percent of the withdrawals. In the future target years, the depletion coefficients for the household sector were estimated to b 40, 40 and 50 of the withdrawal coefficients for the Green River, Upper Main Stem and San Juan-Colorado Subregions, respectively.

Water requirements of the livestock sector include water evaporated from stock ponds and water consumed by the animals. Livestock withdrawal requirements were assumed to equal livestock depletion requirements. The average annual net loss from farm ponds due to evaporation was obtained by multiplying the estimated net surface area of livestock water ponds by an average net evaporation rate for each subregion and state. The net evapo-

ration rate is the net water loss rate obtained by subtracting the precipitation rate from the sum of the surface and evapotranspiration rates. The gross surface area multiplied by an annual fullness factor is defined as the net surface area.

Water consumed by the animals was estimated by converting all livestock (cattle, sheep, horses, dairy cows, pigs, and poultry) to animal units (AU) and multiplying that sum by the water-use coefficient of 10 gallons per day, or 0.0112 acre-feet per year. 1/ For example, in the Upper Main Stem Subregion there were 351,000 AU in 1965. Therefore: 351,000 AU multiplied by 0.0112 acre-feet per year equals 3,900 acre-feet. Animal units were developed from the OBE-ERS projections as regionally interpreted by the Economic Base and Projections Workgroup.

Evaporation from single purpose municipal and industrial reservoirs was determined by the same method as were the stock watering pond losses. Reservoir evaporation is treated as a collection system use and is not called a requirement per se in this appendix. Evaporation from multipurpose reservoirs that serve municipal and industrial purposes is not included in this appendix. However, it is included in the total water resource requirements of the Region and listed in the Water Resources Appendix.

The quantity of withdrawal water supplied by municipal systems in each subregion in 1965 was determined by the following equation:

$$M = \Sigma N\ (Y)\ (P) + RE$$

Where: M = Subregion municipal withdrawal in MG per year.

Y = Weighted-average county municipal water-use rate in gpcy.

P = County population served by municipal systems

RE = Reservoir evaporation

N = Number of counties in the subregion.

The quantity of withdrawal water required by rural-domestic systems for each subregion in each target year was determined by multiplying the estimated average subregional rural-domestic water-use rate times the population served by rural-domestic systems. Quantities of water supplied by livestock systems are equal to the withdrawal requirements of the livestock sector.

1/ Source, U. S. Department of Agriculture Task Force.

The quantity of water supplied by self-supplied manufacturing, governmental and commercial systems was determined by the following equation:

$$S = T + RE - M - Z - L$$

Where: S = Self-supplied manufacturing, governmental and commercial withdrawal quantity.

T = Total subregion withdrawal requirement without reservoir evaporation.

RE = Reservoir evaporation.

M = Municipal withdrawal quantity.

Z = Rural-domestic withdrawal quantity.

L = Livestock withdrawal quantity.

For example, in the Upper Main Stem Subregion in 1965:

T = 45,600 acre-feet (a.f.)

RE = 1,100 a.f.

M = 24,800 a.f.

Z = 2,100 a.f.

L = 11,200 a.f.

Therefore: S = 8,600 a.f.

The various systems collected their supplies from groundwater and surface water sources. The proportionate quantity of water obtained from each source by each system was developed only for the base-year 1965. The percentages shown in Table 34 were used.

Table 34 - Percent of Surface and Groundwater Use
1965

System/Source	Subregion: Green River	Upper Main Stem	San Juan-Colorado
Municipal			
Groundwater	42	32	21
Surface Water	58	68	79
Rural-Domestic			
Groundwater	90	90	90
Surface Water	10	10	10
Livestock			
Groundwater	3	2	5
Surface Water	97	98	95
Self-Supplied Manufacturing, Governmental and Commercial			
Groundwater	25	25	25
Surface Water	75	75	75

Problems and needs were determined by comparing M&I water requirements with alternative means to satisfy these requirements. Numerous references were consulted to identify present and future problems and to identify alternative means to satify needs.

Water withdrawal and depletion coefficients by economic sector for each of the subregion economic models are not presented in this report. The water-use data have been aggregated to five major categories for evaluation and analysis. More appropriately, however, water depletion coefficients by detailed economic sector and a discussion of the economics of water uses are presented in the Economic Base and Projections Appendix.

GLOSSARY

WITHDRAWAL REQUIREMENT - The quantity of water which must be available at the point of use to supply the consumptive and nonconsumptive requirements of various water uses.

DEPLETION REQUIREMENT - The quantity of water consumptively used or discharged to the atmosphere and no longer available as a water source.

GROSS WATER USE - The total quantity of water which would have been needed if no water were recirculated or reused.

RECIRCULATION RATIO - Indicates the number of times a given quantity of water is recirculated and is defined as the gross water use divided by the total water withdrawal volume.

MUNICIPAL AND INDUSTRIAL (M&I) WATER REQUIREMENTS - Defined to include domestic, manufacturing, livestock, governmental, and commercial and other water-use categories.

MUNICIPAL AND INDUSTRIAL WATER-USE RATE - The quantity of water used per person in a specified amount of time for domestic, manufacturing, governmental, and commercial purposes which is supplied by a municipal system; the rate is expressed in terms of gallons per capita per day.

MUNICIPAL-DOMESTIC WATER-USE RATE - The quantity of water used per person in a specified amount of time for domestic purposes in households served by municipal systems; the rate is expressed in terms of gallons per capita per day.

RURAL-DOMESTIC WATER-USE RATE - The quantity of water used per person in a specified amount of time for domestic purposes in households served by rural-domestic systems; the rate is expressed in terms of gallons per capita per day.

MUNICIPAL AND INDUSTRIAL SYSTEM: The physical facilities of a central distribution system which collect, treat, and distribute water from the source to domestic, manufacturing, governmental, and commercial water users in a municipality or community.

RURAL-DOMESTIC SYSTEM - Physical facilities other than a municipal system which collect and distribute water directly from the source to one or more households for domestic use.

SELF-SUPPLIED SYSTEM - The physical facilities other than municipal systems which collect, treat, and distribute water directly from the source to individual manufacturing, governmental, and commercial water uses.

LIVESTOCK SYSTEM - The physical facilities for stock watering purposes which collect and distribute water from the source to the point of use.

TDS - Total dissolved solids. A measure of the mineral content or salinity in water.

ppm - Parts per million which is a unit for expressing the concentration of chemical constitutents by weight, usually as grams of constituents per million grams of a solution. By assuming that a liter of water weighs 1 kilogram, parts per million in equivalent to milligrams per liter for concentrations roughly less than 10,000 ppm.

ECONOMIC SECTOR - An aggregation of Standard Industrial Classification codes representing a segment of the regional economy for the convenient presentation and analysis of economic data. The economic sectors are listed under WATER-USE CATEGORY. (For more information refer to the Economic Base and Projections Appendix.)

WATER-USE CATEGORY - The various economic sectors were conveniently aggregated into five water-use categories, namely:

Water-Use Category	Economic Sector	
Domestic	Households	
Manufacturing	Food & Kindred Products	
	Lumber & Wood Products	
	Printing & Publishing	
	Stone, Clay & Glass	
	Chemicals, Petroleum & Coal	
	Fabricated Metals	
	All Other Manufacturing	
Livestock	Livestock	
Governmental	Government	
Commercial & Other	Wholesale Trade	Trade and Services Sectors
	Service Stations	
	All Other Retail	
	Eating & Drinking Places	
	Agricultural Services	
	Lodging	
	All Other Services	
	Transportation	
	All Other Utilities	
	Contract Construction	
	Rentals & Finance	

(For a description of the Economic Sectors refer to the Standard Industrial Classification Manual (53)).

WATER-USE COEFFICIENT - For the sectors listed in the manufacturing, governmental, and commercial and other water use categories, the coefficient is equal to the quantity of water required to produce one dollar's worth of total gross output annually. Each sector has two coefficients, a withdrawal coefficient and depletion coefficient, both of which are expressed in terms of gallons per dollar of TGO annually. For the households sector, the coefficients are expressed in terms of the quantity of water withdrawn and depleted for domestic purposes per person per year. For the livestock sector, the coefficients are expressed in terms of the quantity of water withdrawn and depleted per animal unit (AU) per year.

SIC - Standard Industrial Classification. The Standard Industrial Classification is used to classify establishments by types of economic activity. See ECONOMIC SECTOR.

TGO - Total gross output of each economic sector expressed in dollars annually. For each processing sector, the total gross output is equal to the total value of goods and services sold to all other industries or sectors.

OBE-ERS PROJECTIONS - Projections prepared for the Water Resources Council by the office of Business Economics (OBE), U. S. Department of Commerce, and the Economic Research Service (ERS), U. S. Department of Agriculture.

SMSA - Standard metropolitan statistical area which represents a county or group of contiguous counties which contains at least one city of 50,000 inhabitants or more or "twin cities" with a combined population of at least 50,000.

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