WESTERN U.S. WATER PLAN

THE ROLE OF GROUND WATER IN RESOURCE PLANNING IN THE WESTERN UNITED STATES

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by S.W. West

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THE ROLE OF GROUND WATER IN RESOURCE PLANNING

IN THE WESTERN UNITED STATES

by

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ABSTRACT

Water resources generally are classified as surface water and ground water, but such a close relationship exists between them that they should not be treated individually as unique sources of water. A change in the regimen of either will generally affect the other.

The renewable water supply of a region is the sum of the surface-water runoff, the ground-water outflow, and the natural evapotranspiration. The runoff, or water yield, of a region and part of the natural evapotranspiration represent most of the water that can be controlled or modified to a degree by man. Vast supplies of ground water are present in most subregions, but this supply cannot be used without causing a decrease in surface runoff or in evapotranspiration, or both. Conversely, surface water generally cannot be used without affecting ground water. The use of ground water does not add to the perennial water supply, but it can be an effective method of improving surface-water management and control of noneconomic evapotranspiration.

Where ground water is "mined," it can provide a water supply at rates that greatly exceed the rate of replenishment for a limited time.

The principal aquifers in most subregions are unconsolidated sediments, commonly in or adjacent to stream valleys, and volcanic rocks, or both. In parts of some subregions, consolidated sedimentary rocks are productive aquifers.

In planning ground-water management, the complete hydrologic system needs to be considered, including water supply available from all sources, as well as present demands and consumption. Relating the supply to demands, and determining the effects of withdrawal and consumption on the hydrologic system are aspects to be analyzed. Where the demand for water is small but the supply is large, defining

the potential for new development is an important part of ground-water management.

Water-resources problems most frequently described by Westwide participants include: (1) seasonal variations in streamflow, including both floods and seasonal shortages of water; (2) a need to determine instream flow requirements for fish and wildlife, outdoor recreation, and salinity control; (3) inadequate supplies or water of poor chemical quality for small cities and towns; (4) increasing demand for water for energy development; (5) increasing salinity of water in major river basins; (6) a need to determine Indian water requirements and the impact of meeting the requirements on distribution of supplies; (7) a need for conservation and reuse of water supplies; (8) a need for more effective flood plain management; (9) localized needs for additional flat-water recreation opportunities; (10) a need for preservation of additional wild and scenic rivers and wilderness areas; and (11) a need for more effective land- and water-resource planning and management.

Integrating ground water into all planning and management of water resources would assist in resolving most of the problems listed above. The storage capacity of the natural underground reservoirs is many times the storage capacity of all the surface reservoirs that have been constructed or that likely will be constructed. Ground-water reservoirs can be used for input and output of water the same as surface reservoirs, by artificial recharge and withdrawal by pumping. The extremely large storage capacity of the ground-water reservoirs has a greater capability for regulating annual, or long-term variations in streamflow than surface reservoirs.

In areas where ground-water reservoirs are large but recharge is small, water demands can be met for many years by "mining" the ground water.

Integration of ground- and surface-water management can be an effective tool in controlling the chemical quality of water. In some areas, withdrawal and desalting or evaporation of the more saline ground water could significantly improve the overall quality of water in a basin.

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INTRODUCTION

This report attempts to place ground water in its proper perspective in planning water-resources management. Water resources are cataloged, for convenience, as surface water, ground water, and atmospheric water. According to common usage, surface water may be defined as any water on the land surface, regardless of whether it was derived directly from precipitation (atmospheric water) or from discharge of ground water. Ground water, in contrast, is defined as water below the land surface in the zone of saturation, regardless of whether it was derived from direct infiltration of precipitation or from infiltration of water flowing across or standing on the land surface. Traditionally, surface water has received more attention than ground water, because the surface water is visible, is easily measured, and commonly can be diverted for use by gravity flow. Although ground water is out of sight, modern technology has provided tools for its measurement and utilization. Technology has also shown such a close relationship between surface water and ground water that they cannot be treated individually as unique sources of water. A change in the regimen of either will generally affect the other.

Ground water has not been entirely ignored in water-resources development, but, in general, it has not been considered in systematic planning for total water management. Although ground water comprised 21 percent of the water used in the United States in 1970 (26 percent in the Westwide States), planning for ground-water development has been limited to the municipal, water district, or private level, except for a few instances. Furthermore, the impact of ground-water development on surface supplies has been largely neglected. In general, State and Federal agencies have not adequately considered ground water in comprehensive water-resource planning.

This report summarizes the general setting, the surface-water supply, the availability and use of ground water, the possibilities or alternatives for ground-water management, and hydrologic information needed in each of the Water Resources Council (WRC) regions, by subregions, in the 11 States lying wholly or partly west of the Continental Divide (fig. 1). This is being done as a contribution to the Western U.S. Water Plan (Westwide Study), which was authorized by Congress in P.L. 90-537, September 30, 1968, as a part of the Colorado River Basin project act.

The descriptions of alternatives in ground-water management are based on physical factors, without full consideration of costs and legal constraints. In a report of this type it is possible to present only the general magnitude of the ground-water supply and general concepts of management. In most areas, feasibility studies will be necessary before a suggested management practice can be adequately evaluated.

General Concepts of Ground-Water Occurrence

The renewable water supply of a region is the sum of the surface-water runoff, the ground-water outflow (which commonly is small), and the natural evapotranspiration. The runoff, or water yield, of a region and part of the natural evapotranspiration represents the water that can be controlled or modified to a degree by man.

Vast supplies of ground water are present in most regions, but these supplies cannot be used without lowering ground-water levels and causing a decrease in surface runoff or in natural evapotranspiration, or both. Conversely, the use of surface water, especially for irrigation, generally causes rising ground-water levels and an increase in ground water in storage and commonly an increase in evapotranspiration. Consequently, the use of ground water does not add to the perennial water supply. However, it can be an effective method of improving water management and by lowering ground-water levels, a control of noneconomic evapotranspiration. The storage capacity of the ground-water reservoirs in the Western States dwarfs the storage capacity of all the surface reservoirs that have been constructed. Also, "mining" of ground water can add significantly to the economy of many areas for a finite period of time, which depends on the rate of mining and the initial quantity of ground water in storage, as is true of any mineral resource. Some States permit the mining of ground water; others try to regulate ground-water withdrawal within a theoretical "safe yield."

Ground-water reservoirs can be classified on the basis of rock characteristics, physiography, and geographic distribution. For convenience of describing the reservoir rocks, in this report they have

Figure 1. - Map of the Western United States water plan study area.

been divided into four basic types: (1) Unconsolidated sediments, consisting of unconsolidated to poorly consolidated sand and gravel, commonly interbedded or intermixed with clay and silt; (2) volcanic rocks, consisting primarily of basalt and tuff but including all extrusive igneous rocks and small intrusive bodies; (3) consolidated sedimentary rocks, consisting primarily of sandstone and shale but including other rocks, such as limestone, dolomite, and gypsum; and (4) crystalline rocks, consisting of large bodies of intrusive igneous rocks and metamorphic rocks.

The unconsolidated sediments include stream alluvium; terrace deposits; fan deposits; broad slope deposits, such as the Ogallala Formation on the High Plains; lake deposits; and younger coastal deposits, including dune sand. These deposits comprise the principal aquifers or ground-water reservoirs in the southern half of the study area and in the coastal areas of Oregon and Washington. Unconsolidated sediments generally have specific yields ranging from 10 to 20 percent but have a wide range of permeabilities, due to wide ranges in the size and distribution of interstices between the grains. Saturated beds of sand and gravel commonly yield a few hundred to a few thousand gallons per minute of water to wells.

Volcanic rocks, primarily basalt, comprise the principal aquifers in the northwestern quarter of the study area. Thick deposits of tuff (primarily beds of welded tuff) contain significant aquifers in the mountain ranges and beneath the unconsolidated sediments in some of the valleys in the Great Basin region. The basalts and welded tuffs generally have low specific yields, ranging from less than 1 to about 3 percent depending on the width and distribution of fractures and openings in scoria and rubble of contact zones. They may have very high permeabilities where extensively fractured. Yields of a few hundred gallons per minute of water from wells completed in these rocks are widespread and yields of a few thousand gallons per minute are common from wells in the Snake Plain aquifer in Idaho and in the Klamath basin in Oregon and northern California. Highest porosity and highest yields are obtained from beds of basaltic cinders.

Consolidated sedimentary rocks, especially limestone, dolomite, gypsum, and sandstone, contain excellent aquifers in parts of the Great Basin, the Western Missouri River, and the Rio Grande regions. The specific yield and permeability of limestone and dolomite generally are comparable to those of basalt, depending on the width and density of fractures and solution openings. The specific yield of sandstone generally is greater than that of basalt and less than that of unconsolidated sediments. The permeability generally is less than that of basalt and unconsolidated sediments, depending on the size and distribution of interstices, extent of fracturing, and amount of cementing material. Yields of individual wells completed in limestone commonly range from a few hundred to a few thousand gallons per minute. The yields of wells completed in sandstone generally range from a few tens to a few hundred gallons per minute. The yield of wells completed in shale generally is less than 10 gpm (gallons per minute).

Crystalline rocks are widespread in the Rocky Mountains and the Sierra Nevada. The specific yield and the permeability of these rocks generally are low, so they rarely contain productive aquifers. They generally yield less than 10 gpm to wells, but they do provide adequate water for domestic supplies at many mountain campgrounds and home sites.

Water enters the reservoir rocks by infiltration from precipitation, from surface streams that are above the water table, from canals and irrigated fields, and by interformational flow. The amount of infiltration (recharge) depends primarily on the surface area covered with water, the quantity of water available on the land surface, the depth of the water on the land surface, the permeability of the rocks, and the length of time that water is on the surface. The water moves underground from recharge areas to points of discharge at lower elevations, most commonly along stream valleys. Ground water contributes more than half the annual flow of some streams. Other discharge areas are lakes, playas, and hillside springs. Where the water table is within a few feet of land surface, ground water is also discharged by evapotranspiration. In some subregions the amount of water discharged by noneconomic evapotranspiration is as large or larger than the amount consumed by man's activities.

As ground water moves down the hydraulic gradient in an aquifer, it may become confined by overlying and underlying rocks having much lower permeabilities than the aquifer. The pressure in such a confined aquifer may be great enough in some areas to cause the water (commonly termed artesian water) to flow from wells at the land surface, even though the wells may tap aquifers at depths of several thousand feet. Slow movement of water from a confined aquifer to other aquifers having lower heads is a common phenomenon.

As water infiltrates and moves down gradient in the aquifer, it inevitably comes in contact with soluble minerals, some of which are taken into solution. The greater the abundance and solubility of the minerals, the more saline the ground water becomes. The most abundant sources of soluble minerals are unconsolidated sediments having a high clay content and consolidated sedimentary rocks containing beds of shale, gypsum, and salt (halite). Disseminated gypsum and salt are common in many of the consolidated sedimentary rocks. The chemical quality of ground water may be changed significantly by ion exchange, as well as by solution of soluble minerals, as the water moves from recharge to discharge areas.

Ground water may become polluted due to man's activities. The most common sources of pollution are certain manufacturing processes, fertilized fields, pesticides, sewage effluent, feedlots, and solid-waste disposal sites. Ground water is less susceptible to pollution than surface water, but once ground water is polluted, the pollution may persist for a long time.

Underground space, the pores and fractures in rocks, can be utilized even though the space is initially dry. In many parts of the West, thick accumulations of rocks lie above the water table, and the average porosity of this unsaturated material commonly is equivalent to, or higher than, that of the saturated material. By constructing spreading ponds or other recharge facilities, excess surface flow resulting from rainstorms or rapid snowmelt could be used in areas favorable for artificial recharge of ground water. Thus, the volume of ground water in storage could be increased significantly in some localities.

As excess surface water is diverted to recharge facilities, part of the flow of streams is regulated without surface storage facilities. Most of the water recharged into the ground in stream valleys during periods of excess surface flow will eventually find its way back to the stream as additional ground-water discharge.

Dispersed introduction of excess surface water of good chemical quality into aquifers containing water of inferior quality can improve the general quality of the ground water. This approach would have the greatest potential for water-quality improvement in areas such as the Pecos Valley, New Mexico, and certain closed basins of the Southwest.

As the war against pollution mounts, the interest in underground storage of wastes is growing. Underground space above the zone of saturation, as well as impermeable materials such as thick beds of salt, can be used in favorable areas (where vaults can be mined and kept dry) for storage of solid wastes. If deemed necessary, wastes stored in this manner can be recovered at any time. Liquid wastes can be stored in saturated materials, where adequate safeguards, such as enclosing nearly impermeable beds, are present. These conditions exist in many localities, where the consolidated sedimentary rocks are thick and highly variable in permeability. Underground disposal of wastes requires thorough testing and analysis of the receiving environment before its safety can be assured.

Release of heated water from thermal electric plants and some types of industrial plants has caused severe problems of thermal pollution of nearby streams in many areas of the country. The principal ground-water reservoirs in parts of the study area could be used as receptacles for thermal waters from these types of plants. If the thermal water was injected into the principal aquifers at considerable distances from discharge points, either natural discharge points or wells, the heat would be dissipated before it could reach the surface again.

Development of geothermal energy is another special utilization of underground space. In favorable geothermal areas, natural steam can be withdrawn through wells and used to drive turbines for generation of electricity. Experiments to evaluate the injection of cool water into dry geothermal areas for conversion of the water to steam and its recovery for driving turbines for electrical power generation are underway, but the outcome is open to speculation. In some parts of the Westwide States, geothermal waters are used directly for heating of homes, offices, and greenhouses.

Experiments indicate that in favorable areas, both heating and cooling of buildings can be accomplished by direct use of ground water from different depths. (This procedure is now being used in Portland, Oregon.) Shallow ground water, which commonly is cool, can be obtained in summer for cooling buildings and can be reinjected at greater depths for conservation of the water. Warm water from greater depths can be obtained for heating buildings in winter and can be reinjected at shallow depths to maintain the balance between withdrawal and injection. Any thick, permeable sequence of aquifers could be favorable for this application.

Information Needed for Planning Ground-Water Management

Much work has been done toward evaluating the ground-water resources in parts of the study area, but much more remains to be done before systematic planning for ground-water management can be accomplished. Planners for ground-water management must recognize the close relationship between ground water and surface water.

For systematic planning, the planner must have detailed information on: (1) the flow characteristics of streams; (2) the position of the streambed in relation to the water table; (3) infiltration rates from undisturbed ground, streams, canals, ditches, and irrigated fields; (4) potential infiltration rates from recharge ponds or spreading areas; (5) the contribution of ground-water discharge to streams; (6) the chemical quality of ground water and surface water; and (7) the changes in ground-water storage due to past management of the water resources. Typically, use of surface water causes an increase in ground-water storage, due to infiltration losses; the use of ground water causes a decrease in storage, as a function of ground water withdrawn and not returned.

Determining the quantity of recoverable ground water in storage at different depths is important as it represents the reserves available for extraction and the volume of the underground reservoir that can be managed readily for storage of water. Rough estimates of ground-water storage in the major aquifers of some regions have been made to show the water resources in general perspective. However, more accurate information is needed in most areas to be considered for systematic ground-water management.

The physical properties of aquifers control the quantity of water that can be stored or yielded, the rate at which water can be added to or withdrawn from the underground reservoirs, and the change in water levels that will result from withdrawal of a given volume of water. The mineral composition of aquifer materials largely controls the chemical quality of the ground water. The physical properties of the aquifers can be determined by imposing a hydraulic stress on the system (pumping) and measuring the response of the system (water-level changes). Useful information has already been obtained by pumping from individual wells or from well fields and measuring water-level changes in some areas. Additional information could be obtained from existing wells. In other areas the depth and spacing of wells are inadequate for acceptable tests, and special test wells are needed.

The depth to water and the pumping lifts that will be required must be known in order to estimate pumping costs.

Unconsolidated sediments commonly contain extensive beds or lenses of clay and silt. When water is withdrawn from sand and gravel within these sediments, slow drainage of water from the clay may permit its compaction. If the clay beds comprise a significant part of the sediments, the compaction due to withdrawal of water may result in subsidence of the land surface. Therefore, an analysis of the clay content of the aquifers is important in conjunction with the other studies of aquifer properties.

Chemical analyses of ground water are needed to define the variations in quality, both laterally and vertically, within the aquifers. Variations in chemical quality of water within an aquifer can lead to intermixing of fresh and saline water as freshwater is withdrawn, due to movement of saline water into space previously occupied by freshwater. Withdrawal of saline water reverses the situation.

Mapping of wetlands and phreatophyte areas in detail will assist in determining the quantity of water consumed by evapotranspiration. The significance of these areas as wildlife habitats has not been determined and the impact of changing the habitat has not been evaluated. Eradication of phreatophytes by mechanical means and selective elimination by controlling ground-water levels needs to be appraised in relation to a need for maintaining adequate wildlife habitats and providing for maximum beneficial use of the water resources.

The responses of water resource systems to hydraulic stresses can best be analyzed by employing an analog or a digital model, or a combination of the two, to simulate the ground-water reservoir and its hydraulic stresses. Once the models are completed and verified with historic records, the effects of alternative plans for water management and optimum locations, spacing, and depths of wells can be analyzed.

The studies described above constitute what is termed a "quantitative" water-resources study in this report.

Information on the benefits and costs, both economic and environmental, are needed for evaluation of alternative plans for water management. The planners and the public should be aware of the benefits and costs of water use and the value of benefits foregone if the water is not used. The cost analysis of a proposed project would include: (1) The cost of the investigative program; (2) the cost of the construction program; and (3) the cost of the operational program, including the cost of monitoring the response of the water resource system. Any proposed project regardless of benefits and costs, must be acceptable within legal, social, and ecological constraints.

Once a water resource project becomes operational, monitoring the response of the system to the new stresses very likely will show that modifications of the models are necessary to improve their predictive capability. Depending on the actual response of the water-resource system, minor modifications in operations, as well as modifications of the models, may be necessary.

Metric Units

Quantities in this report are given in English units. Metric equivalents can be obtained by using the following conversion factors.

English		Multiplied by	Metric	
Unit	Abbreviation		Unit	Abbreviation
Acre	acre	0.4047	Hectare	ha
Acre-foot	acre-ft	.0012335	Cubic hectometer	hm^3
Foot	ft	.3048	Meter	m
Gallons per minute	gpm	5.45	Cubic meters per day	m^3pd
Inch	in	2.54	Centimeter	cm
Mile	mi	1.6093	Kilometer	km
Square mile	mi^2	2.59	Square kilometer	km^2

Chemical concentrations are given only in metric units - milligrams per liter (mg/l). For concentrations less than 7,000 mg/l, the numerical value is about the same as for concentrations in the English unit, parts per million.

GROUND-WATER SUPPLIES AND MANAGEMENT ALTERNATIVES

In planning ground-water management, the complete hydrologic system needs to be considered, as explained previously. The major components of hydrologic systems in the Westwide study area have been summarized by subregions in a series of tables. These tables show "water income," which includes surface-water inflow (both natural inflow and imports) from adjacent subregions and surface-water yield (the amount of surface water derived from within the subregion); and "water outgo," which includes surface-water outflow (both natural outflow and exports), consumptive losses due to man's activities, evapotranspiration from wetlands and phreatophyte areas, and evaporation from surface reservoirs. Surface and subsurface storage capacities are presented to further describe the hydrologic system of each subregion. Recoverable ground water in storage, rather than total, was used for all subregions, except as indicated in footnotes of tables.

Most of the data for this report were taken from Comprehensive Framework Study reports for each region, except for the Western Arkansas and Northern Rio Grande regions; Comprehensive Framework reports for these regions have not been prepared. Much of the data in those reports were estimates only. The data are used in this report as previously published or they have been rounded to show less significance. The methods and types of data presented in the Framework reports were not consistent from one region to another, so in many cases interpretations and extrapolations of data were necessary to present a consistent set of tables for this report. The "income" and "outgo" for each subregion should balance, but in some cases they do not balance because of errors in hydrologic data, ground-water overdraft or mining, or lack of data on evapotranspiration losses. The consumption of water by man's activities includes that from both surface- and ground-water sources. Most budgets of income and outgo are balanced within 5 to 10 percent.

Other sources of data include U.S. Geological Survey annual reports "Water Resources Data for (State), 197_"; U.S. Geological Survey regional ground-water reports; U.S. Geological Survey Circular 676, "Estimated use of water in the United States in 1970"; unpublished Westwide State reports; and published and unpublished reports and records of State and Federal agencies.

A series of maps are presented to show the general availability of ground water. Only the areas where a yield of 100 gpm or more of water is generally available were emphasized, except in the Upper Colorado region where a lower limit of 50 gpm was used. For the areas where data on the yields of wells were not available, only the distribution of principal aquifers is shown.

As part of the Westwide effort, each participating agency prepared issue papers to describe critical water-related problems. The descriptions were intended to: (1) state the problem, (2) dimension the problem, (3) draw conclusions from it, and (4) make recommendations on what needs to be done to solve the problem. These issue papers were used in evaluating the possibilities of integrating ground water in the solution of critical water-related problems.

To facilitate the descriptions of ground-water resources and possible management alternatives, the same division of water-resources regions into subregions was used in this report as in the Comprehensive Framework reports, whenever feasible. The description of each region by subregions follows.

Columbia-North Pacific Region

Clark Fork-Kootenai-Spokane Subregion

The Clark Fork-Kootenai-Spokane subregion includes that part of Montana lying west of the Continental Divide, part of northern Idaho, and part of northeastern Washington (fig. 2). Elevations in the subregion range from about 1300 feet along the lower part of the Spokane River to as much as 10,000 feet along the Continental Divide. Most of the subregion is mountainous, with narrow intermontane valleys. Croplands are limited to the valley floors and small prairies.

Precipitation varies widely with season, elevation, and location. Annual totals range from 15 inches along the lower Spokane River to nearly 100 inches on the west slopes of the mountains in northwestern Montana. Some of the small valleys in the precipitation shadows of mountains receive as little as 10 inches average annual precipitation. Most of the moisture falls as snow in the mountains during winter.

The average yield of surface water in the subregion is 26.2 million acre-feet per year. An additional 8.86 million acre-feet per year flows into the subregion from Canada. Most of the streamflow is derived from snowmelt, and maximum discharge is in April, May, and June.

Surface reservoirs for regulation of flow have a combined storage capacity of 11.5 million acre-feet (table 1). Evaporation from the reservoirs averages 1.08 million acre-feet per year.

The chemical quality of surface water generally is excellent, with a dissolved-solids concentration of less than 250 mg/l (milligrams per liter). However, the quality of water in some streams is degraded by inflow of mine drainage water.

About 7 percent of the average surface runoff is withdrawn for consumptive uses, but only about 3 percent (707,000 acre-feet per year) is consumed. Irrigation is the largest use; public supplies are second. The largest diversions are in the Flathead River and Spokane River Valleys. Large quantities of water are used for hydropower generation, which is a nonconsumptive use.

The principal aquifers in the subregion consist of unconsolidated sediments in the major stream valleys. These aquifers generally yield from 100 gpm to more than 2,000 gpm of water to individual wells, depending on their thickness and the coarseness of material (fig. 2). The largest, most productive aquifer is in the Spokane

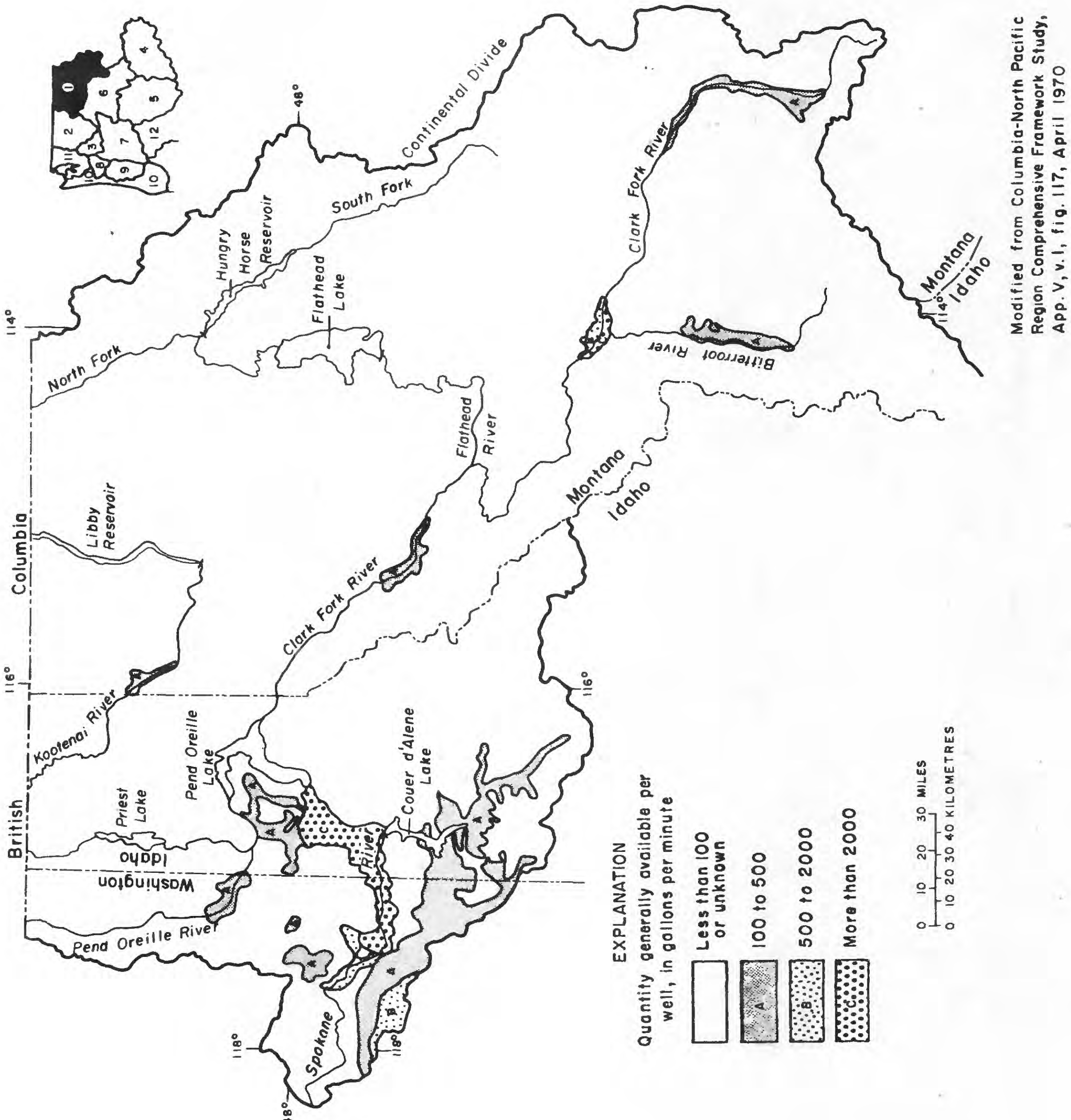


Figure 2. - General availability of ground water in the Clark Fork-Kootenai-Spokane subregion.

Table 1.--Generalized water budget for the Columbia-North Pacific region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption			Surface water (ac-ft)	Ground water (ac-ft)
				Man's activities (ac-ft per yr) 2/	Wet land and phreatophytes (ac-ft per yr)	Reservoir evaporation (ac-ft per yr)		
Clark Fork, Kootenai, Spokane	8,860	26,200	36,800	816	-	1,080	11,500	69,000 3/
Upper Columbia	79,600	3,800	84,000	1,480	-	780	14,100	35,000 4/
Yakima	0	3,390	2,360	1,030	-	50	1,070	13,000 3/
Upper Snake	0	11,000	6,220	5,470	-	645	5,420	67,000 4/
Central Snake	6,220	8,410	11,900	2,620	-	382	5,800	100,000 4/
Lower Snake	11,900	23,400	34,800	366	-	212	5,500	31,000 4/
Mid Columbia	120,000	11,700	128,000	786	-	447	1,820	47,000 4/
Lower Columbia	157,000	18,100	175,000	288	-	58	3,290	8,000 3/
Willamette	0	27,900	27,400	470	-	74	2,600	27,000 3/
Coastal	0	63,500	63,300	232	-	10	166	27,000 3/
Puget Sound	0	38,400	38,100	235	-	90	3,200	40,000 3/
Oregon closed basin	0	1,190	0	323	864	-	22	56,000 3,4/
Totals (rounded)		237,000		14,100	864	3,830	54,700	520,000

1/ Data from comprehensive Framework Report and Westwide State Reports.
2/ Consumption of both surface water and ground water.
3/ Upper 50 feet of saturated material.
4/ Upper 100 feet of saturated material.

River valley in both Idaho and Washington. South of the Spokane River valley, basalt comprises a major aquifer which yields 100 gpm to more than 500 gpm of water to wells.

The depth to water in most of the aquifers is less than 100 feet below land surface, but in some areas the depth is more than 400 feet.

Generally, ground water in the unconsolidated sediments contains less than 200 mg/l of dissolved solids, and water in the basalt contains less than 250 mg/l of dissolved solids.

The quantity of ground water stored in the upper 50 feet of saturated material in the subregion is estimated to be 69 million acre-feet, which is about six times the storage capacity of all the surface reservoirs in the subregion (table 1). About 51 million acre-feet of this water is stored in the unconsolidated sediments in the major stream valleys. A large part is stored in areas where the yields of wells are more than 2,000 gpm.

The amount of ground water withdrawn in 1970 for various uses in the subregion is shown in table 2. Because of the large supply of surface water for irrigation, more ground water is withdrawn for public supplies than for irrigation. Although 299,000 acre-feet of ground water was withdrawn for use in 1970, only 109,000 acre-feet was consumed (table 2). The remainder (190,000 acre-feet) returned to the ground-water reservoirs or to streams.

Major water-resources problems in the Clark Fork-Kootenai-Spokane subregion that were identified by the Westwide study group include: (1) need for development of additional hydropower generation, especially in the Flathead River basin; (2) need for information on instream flow requirements for fish and wildlife, and outdoor recreation; (3) water shortages due to seasonal variations in streamflow; and (4) full development of the total water resources. Table 1 shows a physical surplus of water in the subregion (36.8 million acre-feet per year outflow). However, variations in streamflow are a factor in all the problems listed above.

The seasonal distribution of streamflow could be regulated to some extent with additional storage and controlled release of water, and this storage can be in either surface or underground reservoirs. Table 1 shows an underground storage capacity of 69 million acre-feet in the upper 50 to 100 feet of saturated material. The principal aquifers are valley alluvium in most of the subregion, and the aquifers are in direct contact with the streams. In times of excess surface flow, water could be diverted to recharge facilities along

Table 2.--Estimated use of ground water in 1970 in the Columbia-North Pacific region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generated	Total	
Clark Fork, Kootenai, Spokane	137	10	101	51	0	299	109
Upper Columbia	34	8	161	27	0	230	84
Yakima	40	8	81	10	0	139	51
Upper Snake	56	16	1,960	322	0	2,360	866
Central Snake	34	16	526	22	0	598	219
Lower Snake	27	8	49	35	0	119	44
Mid Columbia	16	13	132	67	0	228	84
Lower Columbia	39	85	36	105	0	265	97
Willamette	35	50	126	6	0	217	80
Coastal	4	30	61	23	0	118	43
Puget Sound	96	24	37	14	0	171	63
Oregon closed basin	1	1	60	6	0	68	25
Total	519	269	3,335	688	0	4,811	1,765

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.
Source: U.S. Geological Survey Circular 676 (1972).

the outer margins of the aquifers, and eventually it would return to the streams. The rate and time of increased ground-water discharge to the streams would depend on aquifer properties; the gradient of the water table which varies with the rate and amount of ground-water recharge and discharge; and the distance of recharge facilities from the streams.

In some valleys the available volume of void space in the aquifers for additional storage is limited, because the water table is shallow. In these areas, the storage potential could be increased by withdrawing ground water through wells during periods of low flow. The water withdrawn could be used directly for consumptive uses, such as irrigation or public supplies, or returned to the stream below the area of pumping to satisfy instream flow requirements. This approach to water management would require careful analysis to assure physical and economic feasibility and desired results.

Areas where regulation of streamflow by utilization of underground reservoirs for storage has the greatest potential are between Pend Oreille and Couer d'Alene Lakes and along the upper Spokane River valley, where excellent aquifers in unconsolidated sediments are available, and south of the Spokane River, where volcanic rocks comprise the aquifers (fig. 2). Both of these ground-water reservoirs have large storage capacities, and wells in both areas will yield 100 gpm to more than 2,000 gpm.

Ground-water use at the present time is small, except in a few local areas (table 2).

Quantitative hydrologic studies in the areas containing the principal aquifers (fig. 2) would be needed before planning for underground storage of water through artificial recharge.

Upper Columbia Subregion

The upper Columbia subregion lies entirely in Washington, east of the crest of the Cascade Range (fig. 3). Elevations range from 340 feet above sea level where the Columbia River leaves the subregion to 9000 feet along part of the Cascade Range. Much of the subregion is on the Columbia Plateau, which is characterized by an irregular but nonmountainous topography.

Annual precipitation in the subregion ranges from 7 inches on parts of the Columbia Plateau to more than 160 inches along the higher parts of the crest of the Cascade Range. Over most of the Columbia Plateau, annual precipitation ranges from 7 to 12 inches. Most of the moisture in the subregion falls as snow on the Cascade Range.

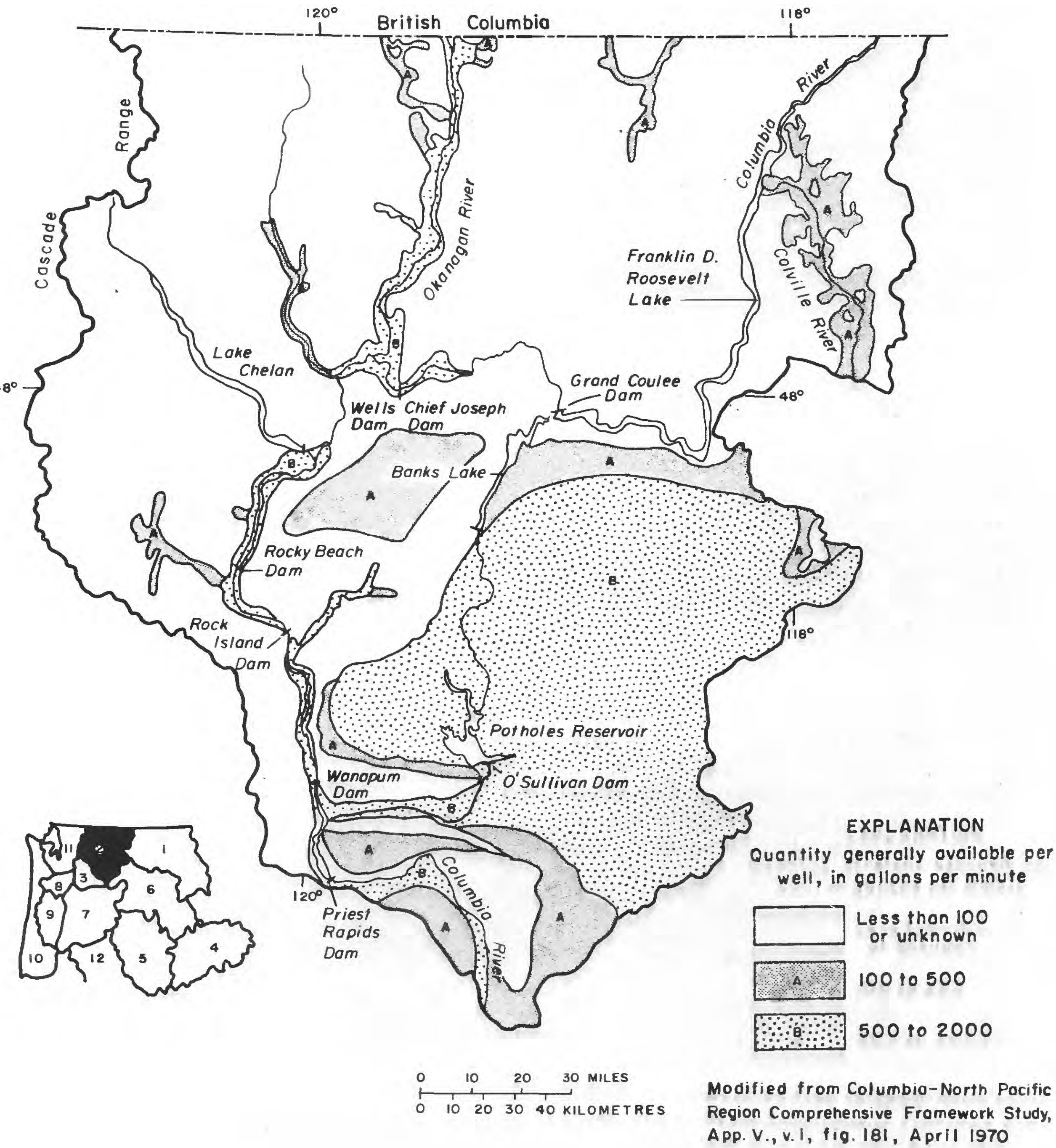


Figure 3. - General availability of ground water in the Upper Columbia subregion.

The Columbia River is the principal stream in the subregion. Inflow from Canada and the Clarks Fork-Kootenai-Spokane subregion is 79.6 million acre-feet per year. In contrast, the surface-water yield within the subregion is only 3.8 million acre-feet per year (table 1). Most of the streamflow is derived from snowmelt, and the maximum discharge of most streams is in spring or early summer.

Surface reservoirs for regulation of flow have a combined storage capacity of 14.1 million acre-feet. Evaporation losses from these reservoirs averages about 780,000 acre-feet per year (table 1).

The chemical quality of surface water generally is excellent. The average dissolved-solids concentration of water in the Columbia River as it enters the United States is 90 mg/l. The quality of the water is not changed significantly before it reaches the confluence with the Snake River. The quality of water in tributaries from the east is not as good as that in the Columbia, as the dissolved-solids concentration may at times exceed 500 mg/l, but the volume of water from the tributaries is insignificant in comparison to that of the Columbia River.

The largest use of surface water is irrigation. An average of 2.20 million acre-feet per year of water is diverted from the Franklin D. Roosevelt Lake for irrigation of 520,000 acres in the Columbia Basin project, the largest single project in the subregion, and 1.40 million acre-feet per year is actually consumed. A large amount of water is diverted for hydropower generation, which is a nonconsumptive use. In contrast, little of the water diverted for irrigation is returned immediately to the river because of evapotranspiration and much ground-water recharge miles from the river. As ground-water storage increases, the rate of irrigation return to the river through the ground-water reservoir also will increase.

The principal aquifers in the Upper Columbia subregion consist of basalt of the Columbia Plateau and unconsolidated sediments in the larger stream valleys. These aquifers generally yield from 100 to 2,000 gpm of water to individual wells (fig. 3). The largest ground-water reservoir is in the basalt, which underlies about 40 percent of the subregion. The yield of wells in about half of the Columbia Plateau part of the subregion (south and east of the Columbia River) range from 500 to 2,000 gpm. Where the remainder of the plateau has been explored, yields have ranged from 100 to 500 gpm. The unconsolidated sediments in much of the Okanogan River valley and in long reaches of the Columbia River valley below Grand Coulee Dam also yield 500 to 2,000 gpm of water to wells.

The depth to water in the basalt ranges from less than 5 feet to as much as 500 feet below land surface. The depths to water in the unconsolidated sediments are comparable to those in the basalt.

The dissolved-solids concentration rarely exceeds 400 mg/l in water from the unconsolidated sediments and 500 mg/l in water from basalt.

The quantity of water stored in the upper 50 to 100 feet of saturated material is estimated to be 35 million acre-feet, which is about 2.5 times the storage capacity of all the surface reservoirs in the subregion (table 1). About 23 million acre-feet of water is stored in unconsolidated sediments, which have an average specific yield of about 20 percent. Even though the basalt is more widespread than the unconsolidated sediments, only 5 million acre-feet of water is stored in its upper 50 feet of saturation, because the specific yield of basalt is about 1 percent or less. However, the saturated thickness of the basalt in most areas is much more than 50 feet and may be thousands of feet in many areas.

Most of the ground water withdrawn in the subregion is used for irrigation, as shown in table 2. In 1970, 230,000 acre-feet of ground water was withdrawn for all uses, but only 84,000 acre-feet was consumed.

Major water-resources problems in the upper Columbia subregion that were identified by the Westwide study group include: (1) Overappropriation of surface water from some streams; (2) need for information on instream flow requirements for fish and wildlife and outdoor recreation; (3) identification of Indian water needs and clarification of their water rights; and (4) flood control in the Okanogan River basin. Overall, there is no shortage of water in the subregion. Table 1 shows that 84.0 million acre-feet of water per year flows out of the subregion. However, variations in streamflow are a factor in all the problems listed above.

The seasonal distribution of streamflow could be regulated to some extent by additional storage in either surface or subsurface reservoirs. Table 1 shows an underground storage capacity of 35 million acre-feet in the upper 100 feet of saturated material. Aquifers in unconsolidated sediments (stream alluvium) in the major valleys are directly connected to the streams (fig. 3). In times of excess surface flow, water could be diverted to recharge facilities along the outer margins of these aquifers, and if not removed by pumping from wells, eventually the water would return to the streams as ground-water discharge. The rate and time of increased discharge to the streams would depend on aquifer properties; the gradient of the water table, which varies with the rate and amount of ground-water recharge and discharge; and the distance of recharge facilities from the streams. With proper management, this procedure could be used to reduce the danger of floods and supplement the flow during periods of normal low flow.

In some valleys the available volume of void space is limited, because the water table is shallow. In these areas, the storage potential could be increased by withdrawing ground water from wells during periods of low flow. The water withdrawn could be used directly for consumptive uses, such as irrigation or public supplies, or it could be returned to the streams below the areas of ground-water withdrawal to satisfy instream flow requirements.

Areas where regulation of streamflow by utilization of underground reservoirs has the greatest potential are the major stream valleys, especially the Okanogan and Columbia Rivers. The principal aquifers in these valleys will yield 500 to 2,000 gpm of water to wells (fig. 3).

Volcanic rocks (basalt of the Columbia plateau) underlie much of the subregion east of the Columbia River, and in more than half the area east of the River, these rocks will yield 500 to 2,000 gpm of water to wells (fig. 3). The depth to ground water in this area generally is more than 100 feet below land surface, so the storage capacity in presently unsaturated rock is as great as that in the upper 100 feet of saturated material. Water artificially recharged into the eastern part of this aquifer would not cause an increase in ground-water discharge to the river as rapidly as would recharge to the valley alluvium. On the other hand, because of the generally long distance to the river, the additional ground-water discharge would eventually stabilize, even though recharge was seasonally variable.

Ground-water use in the subregion at the present time is relatively small (table 2).

Quantitative hydrologic studies in areas containing the principal aquifers (fig. 3) would be needed before planning for underground storage of water through artificial recharge.

Yakima Subregion

The Yakima subregion includes the area drained by the Yakima River and its tributaries and lies entirely within the State of Washington (fig. 4). The subregion slopes eastward from the crest of the Cascade Range to the Columbia River. Elevations range from 340 feet

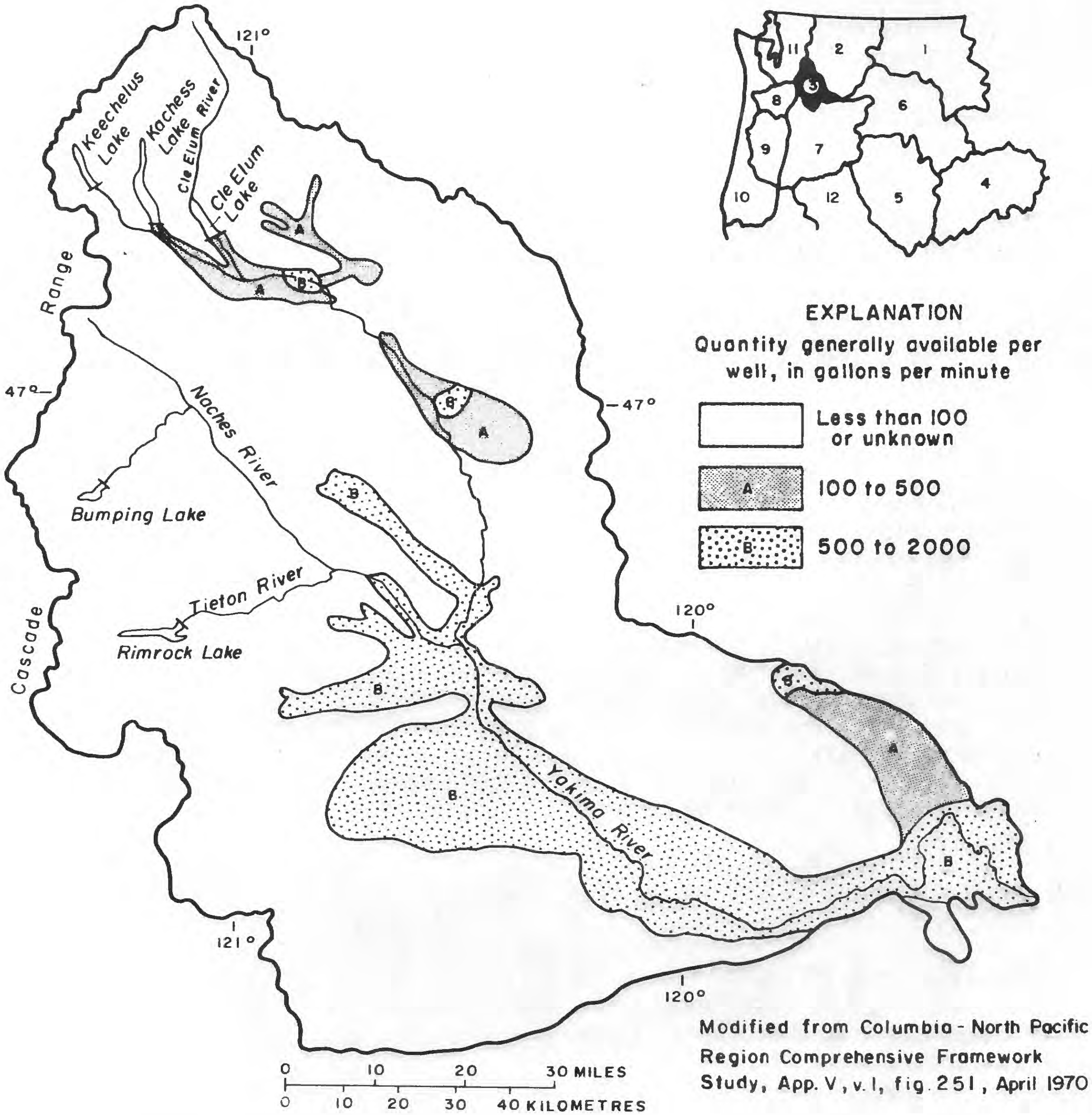


Figure 4. - General availability of ground water in the Yakima subregion.

above sea level where the Yakima River leaves the subregion to about 8000 feet in the Cascade Range. The topography is characterized by mountains and canyons in the western part and ridges and valleys in the eastern part.

Annual precipitation in the subregion ranges from less than 7 inches in the eastern part to more than 140 inches along the crest of the Cascade Range. Most of the moisture falls as snow on the Cascade Range during winter.

The Yakima River is the principal stream. Because the streams are fed mainly by snowmelt, the maximum discharge generally is in spring or early summer. Discharge decreases rapidly during July and generally reaches a minimum flow in August or September.

Surface reservoirs have a combined storage capacity of 1.1 million acre-feet. Evaporation losses from these reservoirs is about 50,000 acre-feet per year (table 1).

In the headwaters of the Yakima River and its tributaries, the water generally contains less than 40 mg/l of dissolved solids. Water samples collected near the mouth of the river, where much of the water is return flow from irrigation, contained concentrations of dissolved solids ranging from 67 to 242 mg/l and the average annual concentration was 169 mg/l. The percentage of salts in the lower Yakima River that are derived from irrigation return flows ranges from 50 to 60 percent.

Average annual diversions of surface water for irrigation of 500,000 acres in the subregion are about 2.4 million acre-feet. Diversions of surface water for other uses are small. About 979,000 acre-feet of the water diverted is consumed.

The principal ground-water reservoir in the Yakima subregion is unconsolidated sediments in the lower parts of the Naches and Yakima Rivers. Basalts of the Columbia Plateau, which are widespread in the subregion have not been extensively explored, but their water-bearing properties probably do not differ significantly from those typical of the basalt in other parts of the Columbia Plateau.

The yield of the unconsolidated sediments generally ranges from 100 to 2,000 gpm (fig. 4). The larger yields generally are in the valley of the Yakima River. The yield of wells tapping the basalt ranges from a few to as much as 3,000 gpm. Many irrigation wells are pumped at rates of 1,000 to 1,500 gpm.

The depth to water in the unconsolidated sediments commonly is less than 25 feet below land surface. The depth to water in the basalt may be considerably greater, depending on the topography.

The quantity of water stored in the upper 50 feet of saturated material in the subregion is estimated to be 13 million acre-feet, which is 12 times the storage capacity of all the surface reservoirs (table 1); about 8 million acre-feet of the total is stored in the unconsolidated sediments, in which the specific yield is 20 percent.

About 58 percent of the ground water withdrawn is used for irrigation, and about half as much is used for public supplies (table 2). In 1970, 139,000 acre-feet of ground water was withdrawn for all uses, of which 51,000 acre-feet was consumed. The remainder (88,000 acre-feet) was returned to the ground-water reservoir or to streams.

Major water-resources problems in the Yakima subregion that were identified by the Westwide study group include: (1) a need for more flood control; (2) instream flow requirements for fish and wildlife and outdoor recreation; (3) identification of Indian water requirements for the future and clarification of their water rights; (4) seasonal shortages of surface water; and (5) poor chemical and bacteriological quality of water in the Yakima River during periods of low streamflow and in some shallow aquifers. Overall, the water supply of the subregion is ample. Table 1 shows that 2.36 million acre-feet of water per year flows out of the subregion, from an annual supply of 3.39 million acre-feet. However, seasonal and annual variations in streamflow are factors in all the problems listed above.

The seasonal distribution of streamflow could be regulated to some extent by additional storage in either surface or subsurface reservoirs. Table 1 shows an underground storage capacity of 13 million acre-feet in the upper 50 feet of saturated material. Aquifers in unconsolidated sediments in the Yakima River valley are connected directly to the river (fig. 4). In times of excess surface flow, water could be diverted to recharge facilities along the outer margins of the aquifers, and if not pumped from wells, eventually the water would return to the river. The rate and time of increased ground-water discharge to the river would depend on aquifer properties; the gradient of the water table, which varies with the rate and amount of ground-water recharge and discharge; and the distance of recharge facilities from the river. With proper management, this procedure could be used to reduce the danger of floods, as well as to provide other beneficial effects. A large amount of artificial recharge is accomplished incidental to surface-water irrigation.

In much of the Yakima River valley, the volume of void spaces is limited because of a shallow water table (generally less than 20 feet below land surface in the unconsolidated aquifers). However, the storage capacity could be increased by withdrawing ground water through wells during periods of low streamflow. The water withdrawn could be used directly for consumptive uses, thus easing demands on low streamflow, or the water could be returned to the river downstream from areas of pumping to supplement streamflow. Wells could be spaced far enough from the river to have little effect on streamflow during the pumping period. Excessive ground-water recharge could cause severe problems of water logging in the valley lands. The water pumped back to the river would help satisfy the instream flow requirements. Lowering the water table by pumping would reduce the chances of bacterial pollution, as many types of bacteria could not survive the longer travel distance underground.

Areas having greatest potential for regulation of water supply by utilization of underground storage are in the lower half of the Yakima River valley. The unconsolidated aquifer in these areas is, at most places, capable of yielding 500 to 2,000 gpm of water per well. In general, the aquifers in the upper half of the drainage are narrow and less productive (fig. 4).

Ground-water use in the subregion is small at the present time (table 2). Withdrawal of ground water during periods of low streamflow could meet all the requirements for additional water without special facilities for artificial recharge, other than diversion of surface water for irrigation during periods of adequate streamflow. This is true for both seasonal and annual variations in streamflow, especially in areas where the water table is shallowest.

Quantitative hydrologic studies of the lower half of the Yakima River valley are needed, so alternative plans for total water-resource management can be made.

Upper Snake Subregion

The upper Snake subregion includes the Snake River drainage upstream from King Hill, Idaho (fig. 5). Most of the subregion is in Idaho, but small parts are in western Wyoming, northwestern Utah, and northeastern Nevada. The subregion contains rugged mountains in the headwaters area and the northern part of the drainage basin and lesser mountains on the south. The broad Snake River Plain, which is more than 50 miles wide in some areas, is the dominant feature in the central part of the subregion. The plain is level to irregular and is characterized by extensive, thick flows of basalt, overlain locally

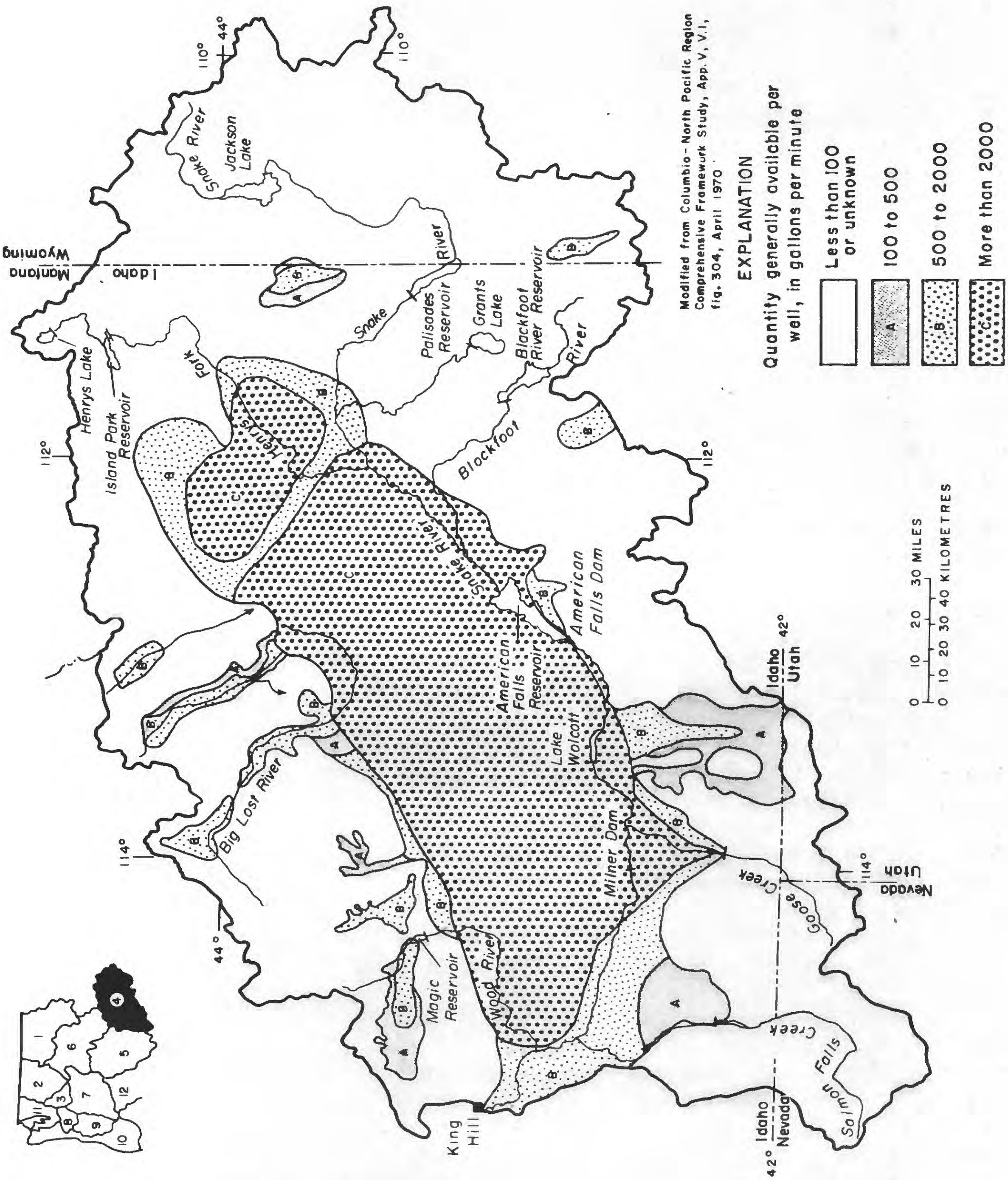


Figure 5. - General availability of ground water in the Upper Snake subregion.

by unconsolidated sediments along principal streams. The Snake River follows the east and south sides of the plain in a broad arc. Elevations range from about 2600 feet above sea level along the Snake River where it leaves the subregion to a little more than 13,000 feet on the higher peaks along the north and each sides of the subregion.

Average annual precipitation ranges from a little less than 8 inches in parts of the Snake River Plain to as much as 70 inches in the mountains. Most of the precipitation falls during winter as snow.

The average yield of surface water originating in the subregion is 11.0 million acre-feet per year (table 1). Runoff from the land ranges from less than 0.05 inch on the Snake River Plain to 30 inches in the mountains of the eastern part of the subregion.

Surface reservoirs for regulation of flow have a combined storage capacity of 5.4 million acre-feet (table 1). Evaporation losses from these reservoirs is 645,000 acre-feet per year.

Water in the streams in the upper part of the subregion generally contains from less than 100 to 300 mg/l of dissolved solids. Because of successive reuse of water downstream, some of the tributary water entering the Snake River may contain as much as 700 mg/l of dissolved solids. The concentration of dissolved solids in the Snake River increases downstream to a maximum of about 400 mg/l, but the concentration is diluted to 340 mg/l by inflow of spring water before the river leaves the subregion.

The principal use of surface water in the subregion is for irrigation, which accounts for 99 percent of all diversions. Almost a third of all the irrigated land in the entire Columbia-North Pacific region is in the upper Snake subregion.

The amount of surface water diverted for all uses in the subregion is 12.8 million acre-feet per year, but this quantity includes rediversion and reuse of return flows from irrigation. The amount actually consumed is about 4.60 million acre-feet per year. Diversions for other consumptive uses are largely for public supplies and self-supplied industries. Water is also diverted for nonconsumptive hydropower generation.

The principal aquifer in the subregion consists of unconsolidated sediments in the major stream valleys and basalt of the Snake River Plain, termed the Snake Plain aquifer. This aquifer is probably one of the most widespread and most productive aquifers in the nation. It occupies the entire Snake River Plain, and the yields of individual wells completed in this aquifer generally are more than 2,000 gpm (fig. 5). Unconsolidated sediments in the main stream valleys of the subregion generally yield 100 to 2,000 gpm of water/to individual wells.

The depth to water in the principal aquifers ranges from land surface along some of the streams to more than 1,000 feet in the north-central part of the Snake River Plain.

Water from the consolidated sediments and the basalt generally contains less than 500 mg/l dissolved solids, and the average probably is about 300 mg/l.

The quantity of ground water stored in the upper 100 feet of saturated material in the subregion is 67 million acre-feet, which is 12 times as much as the storage capacity of all the surface reservoirs (table 1). The Snake Plain aquifer is thousands of feet thick in a large part of the Snake River Plain, so the total volume of fresh water in storage is many times greater than the 67 million acre-feet in the upper 100 feet of saturation.

The quantity of ground water withdrawn in 1970 for various uses is shown in table 2. Most was withdrawn for irrigation (83 percent); the second largest use is for self-supplied industries (14 percent). Total ground water withdrawn in 1970 was 2.36 million acre-feet, but only 866,000 acre-feet was consumed (table 2). The remainder (1,494,000 acre-feet) was returned to streams or to the ground-water reservoirs.

Water-resources problems in the upper Snake subregion that were identified by the Westwide study group include: (1) a need for more flood control on upper tributaries of the Snake River; (2) determination of instream flow requirements for fish and wildlife and outdoor recreation; (3) seasonal shortages of surface water; (4) a need to modify reservoir management to improve water-based recreation, expecially at Jackson Lake; (5) a need to increase conjunctive use of ground water and surface water; (6) clarification of Indian water rights; (7) study and possible designation of wild and scenic rivers; (8) preservation or enhancement of esthetic values, such as large springs and water falls along the Snake River; and (9) replacement of American Falls Dam.

Overall, the water supply of the subregion is more than ample. Table 1 shows that 6.22 million acre-feet of water per year flows out of the subregion. However, seasonal and annual variations in streamflow are factors in most of the problems listed above.

The seasonal and annual distribution of streamflow could be regulated to some extent by additional storage in either surface or subsurface reservoirs. Table 1 shows an underground storage capacity of 67 million acre-feet in the upper 100 feet of saturated material in the subregion. This storage capacity is largely in the aquifer system of the Snake River Plain and tributary valleys.

In addition to the large storage capacity in the upper 100 feet of saturated material, the ground-water reservoir extends from hundreds to thousands of feet below this zone. Unsaturated rocks, having similar properties to the saturated rocks, are as much as 1,000 feet thick and average a few hundred feet thick throughout the Snake River Plain. Consequently, the total underground storage capacity of the subregion stretches the imagination.

The relationship of the Snake River and its tributaries to the principal aquifers is unusual in some respects. Whereas most large streams are continuous discharge lines for ground water, long reaches of the Snake River system are above the water table, and in these reaches the streams lose water by infiltration into the ground. The last point of surface-water division by gravity flow is a Milner Dam, and this point is also below all reaches where the water table is below the river.

The amount of surface water that flows past Milner Dam is theoretically the amount that is available for artificial recharge upstream, but excess surface water is available for artificial recharge only a short time each year. Norvitch, Thomas, and Madison (1969) reported a 50 percent chance of an average flow of 1.3 million acre-feet or more per year, which is the amount available for artificial recharge.

The areas most favorable for artificial recharge are where the major streams cross the principal aquifers (fig. 5). Depending on locations of recharge facilities, the water would return to the river, or be intercepted by pumpage, in a short distance, or it might traverse the entire length of the aquifer before returning to the surface. In either case, the hydraulic pressure transmission rate would greatly exceed the flow rate, causing an increase in groundwater discharge much earlier than actual arrival time of artificial recharge water.

Diversion of streamflow for artificial recharge during periods of excessive runoff could reduce the danger of floods. The basaltic rocks that comprise the principal aquifer extend to the land surface in much of the area without dimunition of permeability, so the potential rate of infiltration is very high. A large amount of ground-water recharge is accomplished incidental to surface-water irrigation.

Because of return flow of ground-water recharge to streams at a later date, artificial ground-water recharge could add to the base flow of streams, and help meet minimum flow requirements along some reaches of the streams. Withdrawal of ground water during seasons of low streamflow, could assure a full water supply throughout the year and during drought years. Pumping of ground water in some areas would eventually affect the discharge in the Thousand Springs area.

Even though surface reservoirs have provided a high measure of control of streamflow in the subregion, the large seasonal fluctuations in surface reservoir levels detracts from their recreation potential. The levels of surface reservoirs could be maintained at more consistent levels, if underground storage was utilized more extensively.

Greater utilization of underground storage would require broader application of conjunctive use of ground water and surface water. Much of the artificial recharge water would have to be withdrawn in a short time to meet the demands for irrigation water, the same as for storage in surface reservoirs.

Broader application of artificial recharge and withdrawal of the water as needed could increase the potential for new development on the Fort Hall Indian Reservation, and elsewhere. Artificial recharge water not intercepted for immediate consumptive uses would eventually enter the streams and help meet the needs for instream flow.

Wild and scenic rivers could be established in selected reaches, and artificial recharge could be accomplished below these reaches without adverse effects on the reaches selected for wild and scenic designations. Because of special conditions necessary for feasible surface storage, the same benefits could not be assured to exist.

Ground-water use in the subregion already is large (2.36 million acre-feet per year) (table 2), but the amount of withdrawal could be increased without serious adverse effects for many years. The large supply of ground water in storage, the remoteness of much of the aquifer system from population centers, and the favorable conditions for reducing the temperature of cooling water before it could reach discharge poionts, all indicate a favorable environment for installation of thermal power plants, including nuclear plants.

In some parts of the subregion, a potential for development of geothermal energy appears to exist, based on data from thermal wells and springs. Most of these areas are along the east and south margins of the Snake River Plain. Hydrothermally altered rocks and deposits of silica at shallow depths in some areas indicate a possibility of high temperatures at relatively shallow depths. The U.S. Geological Survey has designated one "known geothermal resources areas" (Godwin, and others, 1971) in the northeast part of the subregion.

Preliminary electric analog models of the Snake Plain aquifer have been constructed and analyzed for specific purposes, including the effects of artificial recharge (Norvitch, Thomas, and Madison, 1969). However, more refinement in the latest model is needed, before large scale artificial recharge is begun. More information is needed on distribution of aquifer properties, water levels in wells, and chemical reactions. In some areas, well drilling and testing may be required to obtain essential data. In other areas it may be necessary to acquire and analyze data that are available from previous drilling.

Areas containing thermal wells and springs should be explored to assess the potential for development of geothermal energy. These studies should include mapping and analysis of the general hydrologic system and temperature anomalies. Drilling and special testing probably will be required as a part of these studies.

Central Snake Subregion

The central Snake subregion is mostly in Idaho and Oregon, but it includes part of northern Nevada (fig. 6). It includes the Snake River drainage from a short distance below Oxbow Dam upstream to King Hill, Idaho. Elevations in the subregion range from about 2,000 feet along the Snake River to more than 11,000 feet on the highest peaks in the eastern part. The northern part of the subregion is mountainous; most of the remainder is an irregular, deeply dissected plateau.

Average annual precipitation in the subregion ranges from about 8 inches on the Snake River Plain of Idaho to about 80 inches on the highest mountain peaks in Oregon. Most of the moisture falls as snow in the mountainous areas.

The average yield of surface water originating in the subregion is about 8.41 million acre-feet per year. An additional 6.22 million acre-feet flows into the subregion from the upper Snake subregion (table 1). Most of the runoff is derived from snowmelt in the mountains and maximum runoff is in April and May.

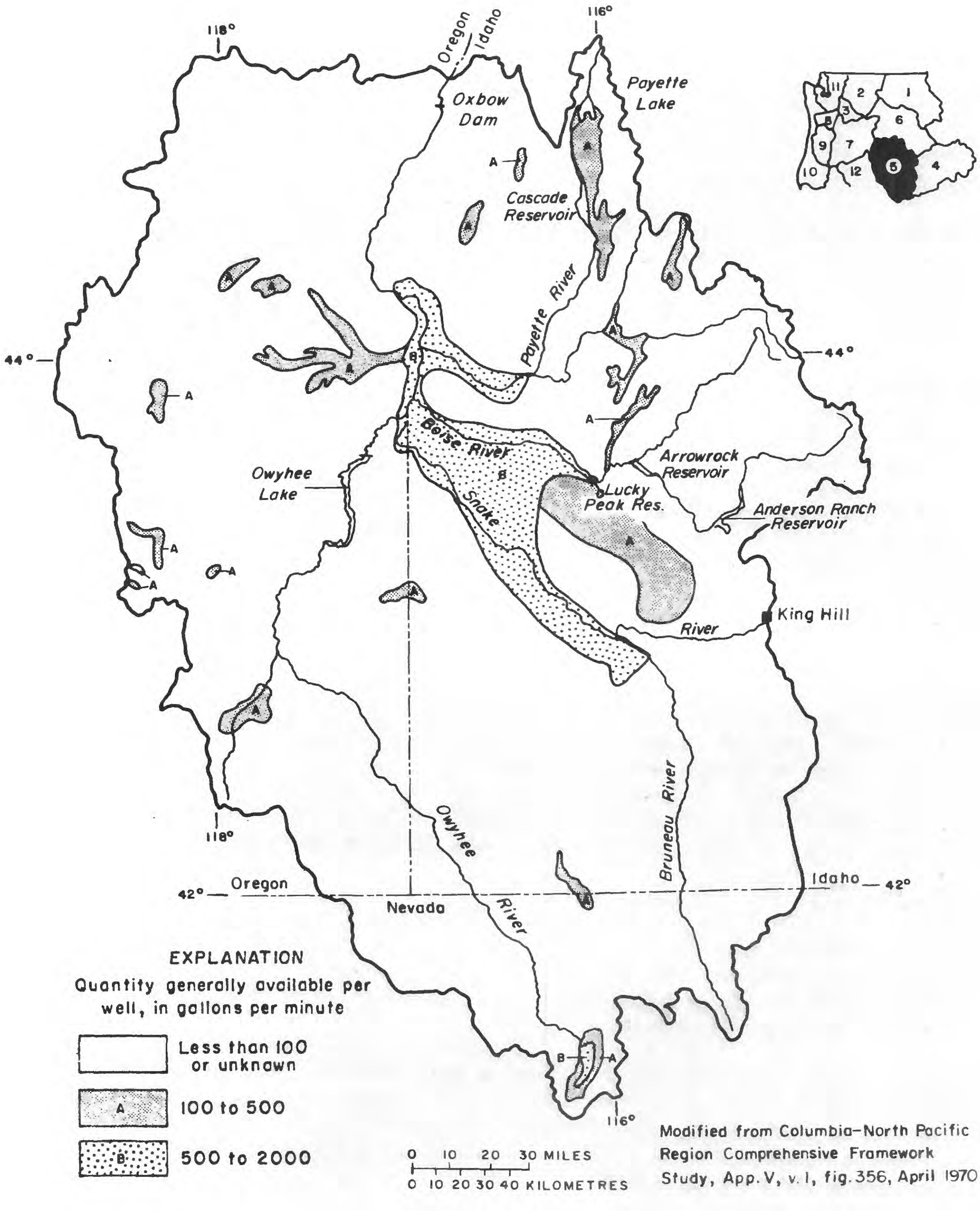


Figure 6. - General availability of ground water in the Central Snake subregion.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 5.8 million acre-feet (table 1). Evaporation losses from these reservoirs is 382,000 acre-feet per year.

The concentration of dissolved solids in streams in the headwaters areas generally is less than 200 mg/l. The concentration of dissolved solids is a little higher in tributaries in the semiarid areas of the southwest than in the tributaries of the more humid northeast part. The concentration of dissolved solids in the semiarid areas increases to as much as 1,300 mg/l primarily because of diversion and rediversion for irrigation.

The concentration of fluoride in the waters of the Brunneau River and some of its tributaries (2.7 to 9.5 mg/l) is higher than the limits recommended by the U.S. Public Health Service (1962) for drinking water.

About 97 percent of the surface water withdrawn for consumptive uses is for irrigation. The average annual withdrawal is 6.10 million acre-feet, and 2.40 million acre-feet per year is actually consumed. A moderate amount of surface water is diverted for nonconsumptive hydropower generation.

The principal aquifers in this subregion consist of unconsolidated sediments and volcanic rocks, including both basalt and tuff. The most productive aquifers are unconsolidated sediments in a relatively narrow band along the Snake, Boise, and Payette Rivers (fig. 6), where the yields of individual wells generally range from 500 to 2,000 gpm. The aquifers in several smaller valley areas yield 100 to 500 gpm to wells (fig. 6).

The depth to water in the principal aquifers ranges from land surface along some of the streams to several hundred feet beneath some of the plateaus. Flowing wells are common in some areas, especially south of the Snake River near its confluence with the Brunneau River.

The concentration of dissolved solids in water from the unconsolidated sediments and volcanic rocks generally is less than 500 mg/l. The concentration of fluoride in water from the volcanic tuff near the confluence of the Brunneau and Snake Rivers commonly is higher than the limits recommended by the Public Health Service for drinking water, and is as much as 24 mg/l. Water from many wells is warm to hot.

The quantity of ground water stored in the upper 100 feet of saturated material in the subregion is 100 million acre-feet, which is more than 16 times the storage capacity of the surface reservoirs (table 1). In most of the areas where the aquifers are most productive, the reservoir rocks are a few hundred to a few thousand feet thick and the total volume of fresh water in storage is much larger than 100 million acre-feet.

The amount of ground water withdrawn in 1970 for all uses was 598,000 acre-feet, of which 219,000 acre-feet was consumed (table 2). The remainder (379,000 acre-feet) returned to streams or the ground-water reservoirs. About 88 percent of the ground water withdrawn was used for irrigation. The second largest use was for public supplies (table 2).

Water-resources problems in the central Snake subregion that were identified by the Westwide study group include: (1) need for additional development of hydropower on the Snake River and its major tributaries; (2) recreation potential of the natural stream versus construction of more facilities for hydropower; (3) possible use of flood plains for recreation rather than for urban development; (4) enhancement of water-based recreation by different reservoir management; (5) instream flow requirements for fish and wildlife, outdoor recreation, and pollution abatement; and (6) seasonal and annual shortages of surface water, during periods of low streamflow.

Overall, the water supply of the subregion is more than adequate. Table 1 shows that 11.9 million acre-feet of water per year flows out of the subregion. However, seasonal and annual variations of streamflow relate to the last four of the problems listed above.

The seasonal and annual distribution of streamflow could be regulated to some extent by additional storage in surface or subsurface reservoirs. Table 1 shows an underground storage capacity of 100 million acre-feet in the upper 100 feet of saturated material. In most areas the saturated material in the principal aquifers is much more than 100 feet thick. Also, except in the lower part of stream valleys, the depth to the water table is more than 100 feet, so the total storage capacity in the principal aquifers and in the unsaturated, but similar, material above the water table is many times the 100 million acre-feet.

The Snake, Boise, and Payette Rivers in long reaches are closely connected to the principal aquifers (mainly unconsolidated sediments). These aquifers will yield 100 to 2,000 gpm of water to wells and in a large part the aquifers will yield 500 to 2,000 gpm to wells (fig. 6).

The principal aquifers could be used for storage of excess surface flow through artificial recharge. The water stored underground would eventually return to the streams, or it could be withdrawn as needed through wells. The areas most favorable for artificial recharge are those where the water table is more than 20 feet below land surface but not too distant from the streams, such as the areas lying between the lower half of the Boise River and the Snake River and the lower parts of the Boise and Payette Rivers (fig. 6).

The need for greenbelts in and near large cities cannot be denied, and conversion of flood plains to recreational greenbelts is one method of satisfying this need. However, to lessen the potential damage from floods, water could be diverted to artificial recharge facilities during peak flows. To a large extent, the present system for diversion and transmission of surface water for irrigation could be used to transmit water for artificial recharge, so spreading areas or recharge ponds would be the only additional facilities required.

Surface reservoirs could be managed for greater recreational benefits by maintaining more constant water levels in them and by utilizing the underground reservoirs for peak storage of water. Any artificial recharge water that returns to the streams tends to increase the base flow of the streams for meeting instream flow requirements for fish and wildlife and for pollution control, and underground storage of water decreases the amount of surface storage to meet water demands. In some cases it might be necessary to pump water from underground storage to provide adequate surface flow and to prevent water logging of low-lying agricultural lands. In fact, adequate drainage is a critical problem in large parts of the valleys, due to incidental ground-water recharge associated with surface-water irrigation.

Seasonal shortages of surface water could be alleviated in the agricultural areas by drawing on excess water in water-logged, low-lying areas. Utilization of the excess ground water could provide for new developments under present conditions and planned artificial recharge could increase the potential for new developments.

In some parts of the subregion, a potential for development of geothermal energy appears to exist, based on data from thermal wells and springs at several localities within the subregion. Many of the buildings in the older part of Boise, Idaho, have been heated for many years with natural hot water, which is also used for heating greenhouses. The U.S. Geological Survey has designated two small "known geothermal resources areas" (Godwin, and other, 1971) and some much larger "areas valuable prospectively" in the subregion.

Quantitative hydrologic studies in the areas containing the principal aquifers are needed for planning alternatives in ground-water management.

Areas containing geothermal wells and springs could be explored to assess the potential for development of geothermal energy. These studies would include mapping and analysis of the general hydrologic system and temperature anomalies. Drilling and special testing probably will be required as part of the studies.

Lower Snake Subregion

The lower Snake subregion lies in Idaho, Oregon, and Washington (fig. 7). It includes the Snake River drainage from near Oxbow Dam to Ice Harbor. Elevations in the subregion range from 340 feet at the confluence of the Snake and Columbia Rivers to more than 11,000 feet on the higher mountain peaks. The eastern part of the subregion is characterized by rugged mountains and deep, narrow canyons. The southwest part also is mountainous but with less relief. The northwest part contains rolling hills along the east side of the Columbia Plateau.

Average annual precipitation ranges from about 7.5 inches in the lowest part of the subregion to more than 60 inches on the higher mountains in the northeastern part. Most of the moisture falls as snow in the mountainous areas. Minimum precipitation is in July and August.

The average surface-water yield of the subregion is 23.4 million acre-feet per year. An additional 11.9 million acre-feet per year flows into the subregion from the central Snake subregion (table 1). Most of the streamflow is derived from snowmelt, and the maximum runoff is in May and June.

Surface reservoirs for regulation of streamflow in the subregion have a combined storage capacity of 5.5 million acre-feet (table 1). Evaporation losses from these reservoirs is 212,000 acre-feet per year.

The mean concentration of dissolved solids in waters of most tributaries generally is less than 100 mg/l and the maximum for all streams is about 300 mg/l. The Snake River contains 300 mg/l of dissolved solids where it enters the subregion, but the concentration is diluted to about 200 mg/l by the Salmon and Grande Ronde Rivers.

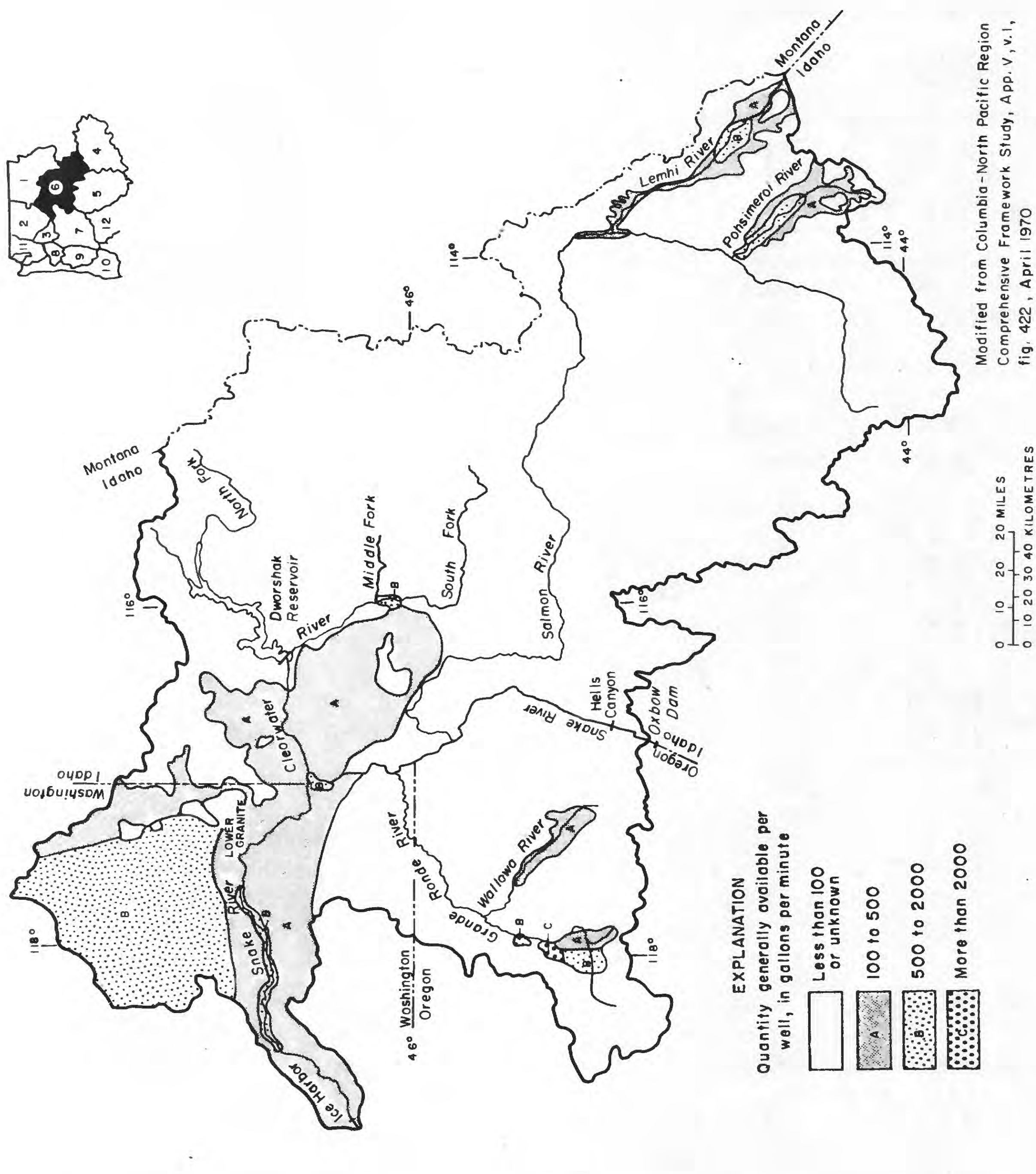


Figure 7. - General availability of ground water in the Lower Snake subregion.

Only 4.1 percent (964,000 acre-feet per year) of the surface flow is diverted for consumptive uses. Irrigation is the largest use of surface water, averaging 799,000 acre-feet diverted and 324,000 acre-feet consumed per year. The second largest use is for public supplies, which requires less than 3 percent of the water withdrawn. Most of the runoff passes through several hydropower plants.

The principal aquifer in the subregion is basalt of the Columbia Plateau. A secondary important aquifer is unconsolidated sediments of the Grande Ronde Valley. Individual wells completed in the basalt generally yield 100 to 2,000 gpm (fig. 7). In a large area in the northwestern part, individual wells yield 500 to 2,000 gpm of water to wells.

The depth to water has not been adequately described, but it probably ranges from land surface along some of the streams to several hundred feet beneath ridge tops.

The concentration of dissolved solids in ground water generally is less than 300 mg/l. However, a large number of thermal springs are present in the subregion, and the water from some of these springs is highly mineralized.

The quantity of ground water stored in the upper 100 feet of saturated material is 31 million acre-feet (table 1). In much of the northwestern part of the subregion, the aquifers are much more than 100 feet thick, and the total quantity of fresh water in storage is much more than 31 million acre-feet.

The amount of ground water withdrawn in 1970 for all uses was 119,000 acre-feet, and the amount consumed was 44,000 acre-feet. The largest use of ground water is for irrigation; withdrawal for self-supplied industries is second (table 2).

Water-resources problems in the lower Snake subregion that were identified by the Westwide study group include: (1) need for additional development of hydropower on the Snake River; (2) flood control on major tributaries of the Snake River; (3) seasonal shortages of surface water during periods of low flow; and (4) additional municipal water supplies.

Overall, the water supply is more than adequate. Table 1 shows that 34.8 million acre-feet of surface water per year flows out of the subregion. However, seasonal shortages are experienced in some of the tributary valleys.

Except in the northwestern part of the subregion, productive aquifers are limited to small, local areas in the major stream valleys (fig 7). Consequently, the opportunities for alternatives in ground-water management are limited.

Extensive aquifers (basalt) in the northwestern part of the subregion yield 100 to 2,000 gpm of water to wells (fig. 7). This area is characterized by sharp relief and rolling hills, which is not conducive to extensive development of ground water for irrigation nor conjunctive management of ground water and surface water. Demands for ground water are easily met, except where the aquifers are thin. Withdrawal of ground water for municipal supplies is causing water levels to decline locally, but the ground-water supply appears to be adequate for many years. However, it may become necessary to drill deeper wells and to disperse them over a larger area.

Mid-Columbia Subregion

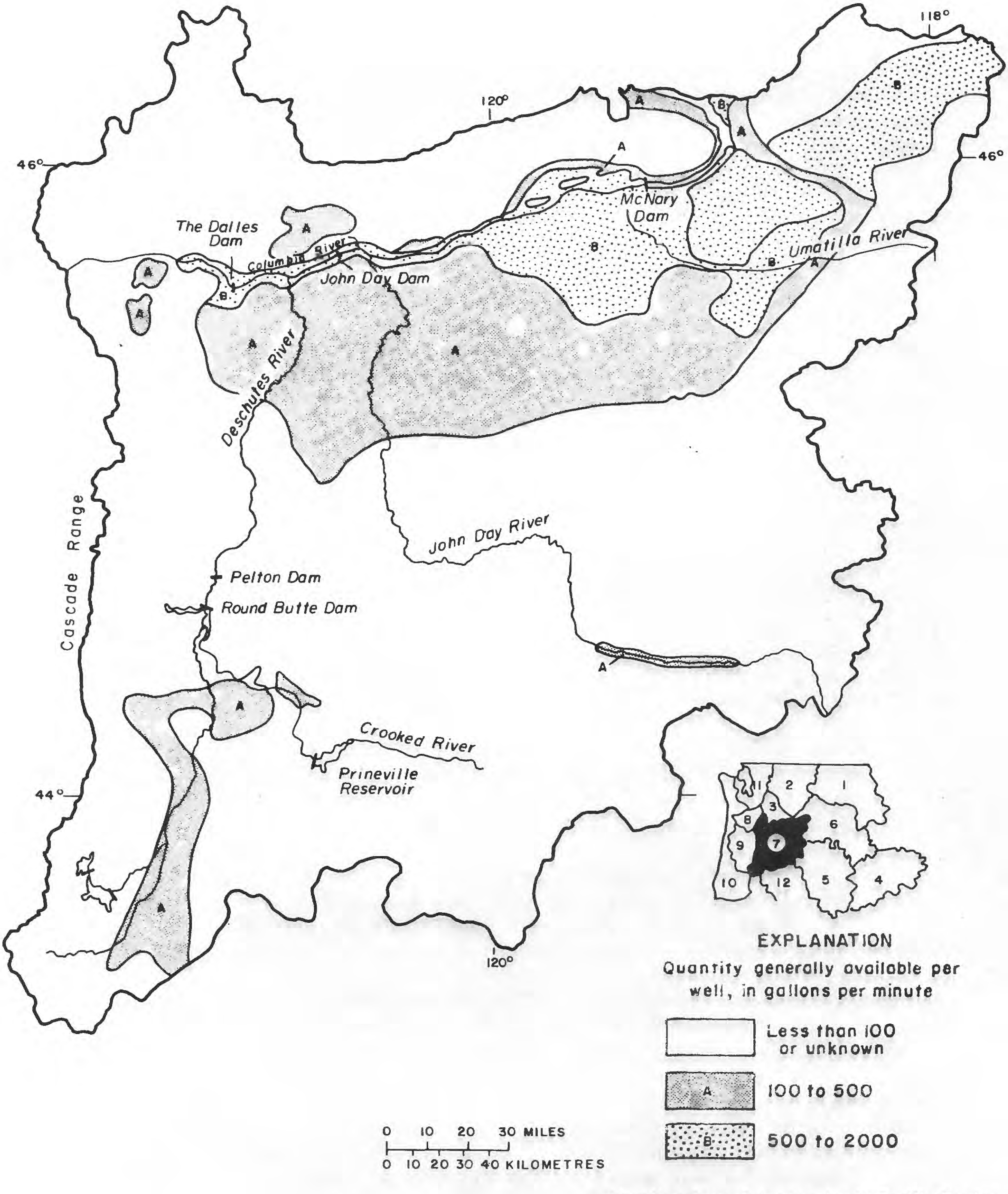
The mid-Columbia subregion lies mostly in Oregon but partly in Washington (fig. 8). It includes drainage of the Columbia River from the reservoir above McNary dam downstream to a short distance below the Dalles Dam. Elevations range from about 100 feet above sea level along the lower part of the Columbia River to near 12,000 feet in the Cascade Range. The subregion is characterized largely by the Columbia Plateau, but it also includes parts of the east slope of the Cascade Range.

The average annual precipitation ranges from less than 9 inches along the Columbia River to more than 100 inches along the highest parts of the Cascade Range. Most of the moisture falls in winter, as rain at lower elevations and as snow in the mountains.

The annual yield of streams is about 11.7 million acre-feet. An additional 120 million acre-feet per year flows into the subregion from adjacent subregions (table 1). Most of the streamflow is derived from snowmelt, both within this and adjacent subregions.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 1.82 million acre-feet (table 1). Evaporation losses from the reservoirs averages 447,000 acre-feet per year.

The concentration of dissolved solids in waters of the tributaries to the Columbia River generally is less than 200 mg/l. Locally, the concentration may be more than 300 mg/l because of return flow of water diverted for irrigation. The dissolved-solids concentration of water in the Columbia River where it leaves the subregion averages about 115 mg/l.



Modified from Columbia-North Pacific Region Comprehensive Framework Study, App. V, v.2, fig. 517, April 1970

Figure 8. - General availability of ground water in the mid-Columbia subregion.

About 18.1 percent (2.12 million acre-feet per year) of the originating surface-water discharge is withdrawn for consumptive uses, but only about 6.1 percent (702,000 acre-feet per year) is actually consumed. The largest user is irrigation (1.9 million acre-feet per year) and the second largest is self-supplied industries (188,000 acre-feet per year).

The principal aquifer is basalt of the Columbia Plateau. Locally, the thicker deposits of unconsolidated sediments also are productive aquifers. The yields of the more productive aquifers range from 100 to 2,000 gpm to individual wells (fig. 8). The most productive aquifers lie in a broad band along the south side of the Columbia River.

The depth to water has not been adequately defined, but it probably ranges from near land surface in some of the stream valleys to several hundred feet beneath some of the ridges.

The concentration of dissolved solids in the younger rocks generally is less then 350 mg/l; and in older rocks is generally less than 500 mg/l.

The quantity of water stored in the upper 100 feet of saturated material is 47 million acre-feet, which is about 26 times the storage capacity of all the surface reservoirs. Because the saturated thickness of basalt generally exceeds 100 feet, the total volume of fresh water in storage is much more than 47 million acre-feet.

The amount of ground water withdrawn in 1970 for all uses was 228,000 acre-feet, of which 84,000 acre-feet were consumed (table 2). The largest user was irrigation (132,000 acre-feet) and the second largest was self-supplied industries (67,000 acre-feet).

Major water-resources problems in the mid-Columbia subregion that were identified by the Westwide study group include: (1) a need for cooling water for thermal-electric plants; (2) a need to modify operations of reservoirs to improve recreation; (3) a need to improve overall water management in the Deschutes River Basin; (4) seasonal shortages of water in the Deschutes and Umatilla River basins; (5) loss of fishing in the Umatilla River; and (6) declining ground-water levels in parts of the Umatilla River Valley.

The Columbia River could provide all the cooling water needed for thermal-electric plants, but return of the heated water to the river could create problems of thermal pollution. However, experiments using warm water from powerplants for irrigation are being made with substantial success. Another alternative would be use of the heated water for artificial recharge at locations a considerable distance from discharge points. This would permit dissipation of the heat into the reservoir rocks and the atmosphere before the water could reach discharge points. Extensive aquifers capable of yielding 250 to 1,500 gpm of water to wells are present along the Columbia River in the northeast part of the subregion (fig. 8). Water artificially recharged into this aquifer would eventually return to the river.

Operation of multipurpose reservoirs probably could be modified to improve their recreation potential by greater use of ground-water reservoirs for storage of water. Table 1 shows that 47 million acre-feet of water is now stored in the upper 100 feet of saturated material. At least this volume is available for withdrawal and storage of water.

Overall water management could be improved by integrating the use of surface water and ground water. Some ground-water recharge is accomplished incidental to irrigation, and artificial recharge could be increased significantly in many areas by constructing infiltration facilities. During seasons of low streamflow, the ground water could be withdrawn for consumptive use or to augment streamflow below the areas of pumping.

In areas where ground-water levels are already declining because of pumping, artificial recharge during periods of excess streamflow could reduce the decline.

Quantitative hydrologic studies are needed in areas containing extensive aquifers (fig. 8) to provide a base for planning alternatives in water-resources management.

This subregion contains two small areas designated by the U.S. Geological survey as "known geothermal resources areas" and larger areas designated as "areas valuable prospectively" (Godwin, and others, 1971).

Exploring the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as a part of the studies.

Lower Columbia Subregion

The lower Columbia subregion lies mostly within Washington, but includes a small area in Oregon (fig. 9). Elevations in the subregion range from near sea level to about 12,000 feet in the Cascade Range. The subregion mostly lies north of the Columbia River West of the Cascade Range.

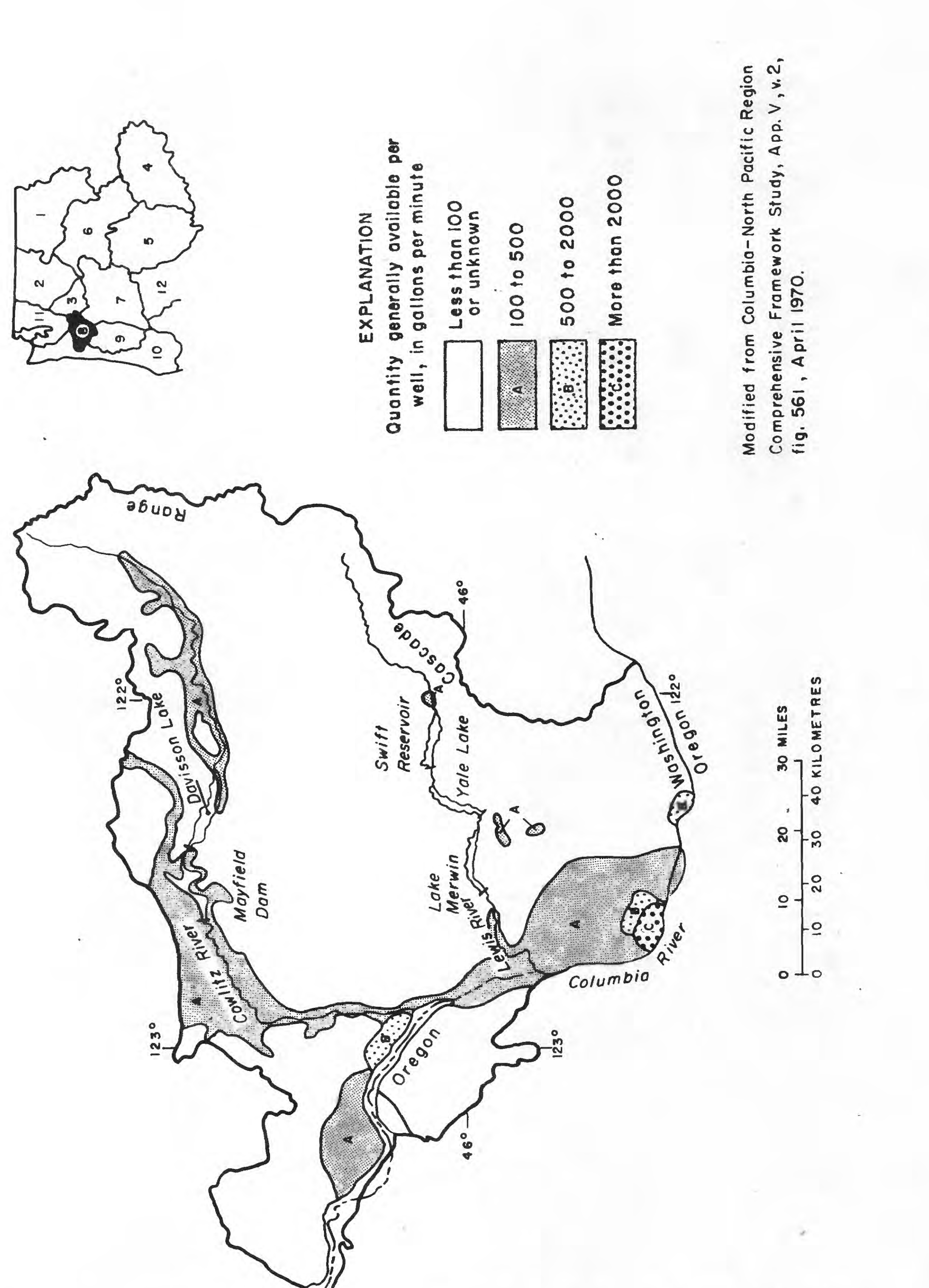


Figure 9. - General availability of ground water in the Lower Columbia subregion.

Average annual precipitation in the subregion ranges from 35 inches in the lower river valleys to more than 140 inches on the west slope of the Cascade Range. On the average measurable rainfall is recorded on 3 to 7 days each month in summer; 8 to 15 days each month in spring and fall; and 15 to 25 days each month in winter. Most of the moisture falls as rain at lower elevations and as snow in the higher mountains.

The average yield of surface water in the subregion is 18.1 million acre-feet per year. In addition, 157 million acre-feet per year flows into this subregion from adjacent subregions. Maximum streamflow usually occurs in winter from December to February. However, streams that flood from snowmelt usually peak in spring or early summer.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 3.3 million acre-feet (table 1). The uncontrolled flow of the Columbia River into the Pacific Ocean averages 175 million acre-feet per year. Evaporation losses from surface reservoirs is 58,000 acre-feet per year.

The mean concentration of dissolved solids in waters of most tributaries is less than 50 mg/l. The dissolved-solids concentration of Columbia River water changes little within the subregion, and ranges from 69 to 163 mg/l at the Dalles Dam.

About 2.4 percent (434,000 acre-feet per year) of the surface water originating within the subregion is diverted for consumptive uses, but only 1.0 percent (181,000 acre-feet per year) is actually consumed. The largest surface-water users are self-supplied industries (374,000 acre-feet per year) and the second largest is irrigation (31,000 acre-feet per year). Although more than 12 times as much water is withdrawn for self-supplied industries than for irrigation, more water is consumed by irrigation.

Aquifers in the lower Columbia subregion generally yield only small supplies of ground water to wells. The principal aquifers are unconsolidated sediments in the major stream valleys, where yields of 100 to 500 gpm are obtained (fig. 9).

The depth to water in the principal aquifers generally is less than 60 feet, but it exceeds 200 feet in some areas.

The concentration of dissolved solids in ground water generally is less than 300 mg/l.

The quantity of ground water stored in the upper 50 feet of saturated material is 8 million acre-feet (table 1).

The amount of ground water withdrawn in 1970 for all uses was 265,000 acre-feet, of which 97,000 acre-feet was consumed (table 2). The largest use was for self-supplied industries (105,000 acre-feet), and the second largest was rural use (85,000 acre-feet).

Water-resource problems in the lower Columbia subregion that were identified by the Westwide study team are broad in scope, relating to the entire region. These are (1) optimization of Columbia River management for maximum hydropower generation, and (2) realizing the full recreation potential of the region.

Because of a great surplus of surface water in the subregion (table 1), ground water has not been developed extensively (table 2) and a large demand for ground water does not exist. Therefore, alternatives for ground-water management will not be described for this subregion.

Williamette Subregion

The Willamette subregion is entirely within Oregon (fig. 10). It lies between the Cascade range on the east and the Coast Range on the west and is bounded by the Columbia River on the north. The subregion is drained by the Willamette River and its tributaries. Elevations range from near sea level at the confluence of the Willamette and Columbia Rivers to 6,000 feet along the crest of the Cascade and Coast Ranges.

Average annual precipitation ranges from 40 inches on the valley floor to as much as 200 inches along the crest of the Coast Range. Except for the middle and higher slopes of the Cascade Range, virtually all the moisture falls as rain. About 70 percent of the total falls in a 5-month period from November to March. Minimum precipitation is in July and August.

The average yield of surface water within the subregion is 27.9 million acre-feet per year (table 1). Most of the streamflow is derived from rainfall, and maximum discharge is in December and January. Low flow is in July, August, and September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 2.6 million acre-feet (table 1). Evaporation from the reservoirs is 74 acre-feet per year.

The dissolved-solids concentration in waters of most streams generally is less than 85 mg/l and commonly is less than 40 mg/l. The concentration of dissolved solids in water of the Willamette River near its mouth averages less than 65 mg/l.

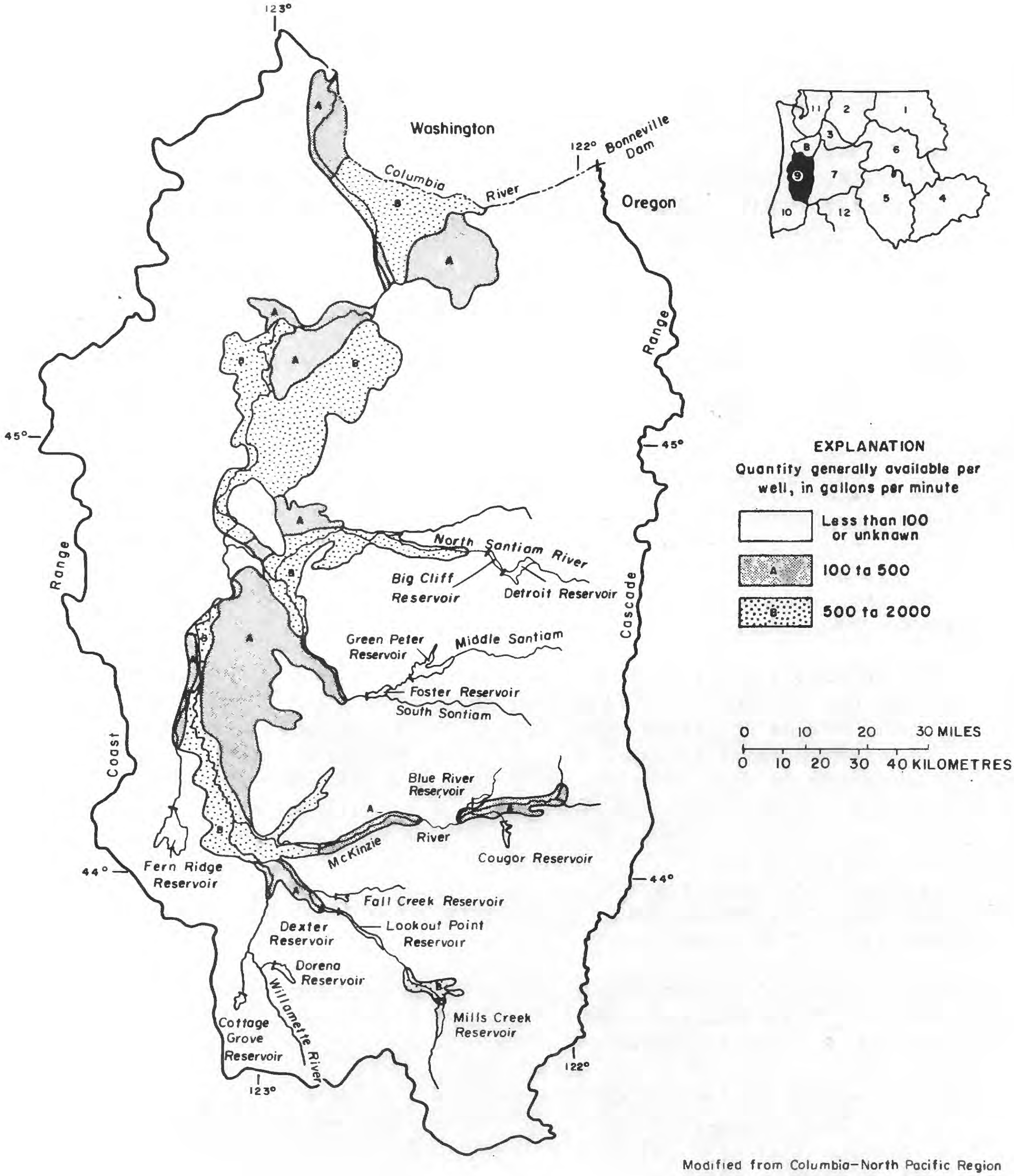


Figure 10. - General availability of ground water in the Willamette subregion.

About 4.4 percent (1.2 million acre-feet per year) of the annual discharge of the subregion is withdrawn for consumptive uses, but only 1.4 percent (390,000 acre-feet per year) is actually consumed. Hydropower is generated at many of the reservoirs, a nonconsumptive use.

The principal aquifers in the Willamette subregion are unconsolidated sediments in the valleys of the major streams. These aquifers generally yield more than 100 gpm of water to individual wells and in large areas they yield 500 to 2,000 gpm to wells (fig. 10).

The depth to water in the principal aquifers generally is less than 80 feet.

The concentration of dissolved solids in water from most aquifers is less than 500 mg/l. Saline water has been found in most of the consolidated (marine) sedimentary rocks at depths of 100 to several hundred feet.

The quantity of ground water in storage in the upper 50 feet of saturated material is 27 million acre-feet, which is about 10 times the storage capacity of all surface reservoirs (table 1). About 17.6 million acre-feet of ground water is stored in the principal aquifers.

The amount of ground water withdrawn in 1970 for all uses was 217,000 acre-feet, of which 80,000 acre-feet was consumed. The largest user was irrigation (126,000 acre-feet), and the second largest was for rural supplies (50,000 acre-feet) (table 2).

Water-resources problems that were identified by the Westwide study group include: (1) a need to modify operations of reservoirs to improve recreation, (2) overall improvement of water-management practices, and (3) poor seasonal distribution of surface water in some drainage basins.

Overall, the water supply is more than adequate. Table 1 shows that 27.4 million acre-feet of water per year flows out of the subregion.

Operation of multipurpose reservoirs probably could be modified to improve their recreation potential by greater use of underground storage. Table 1 shows that 27 million acre-feet of water is now stored in the upper 50 feet of saturated material in the subregion. At least this volume is available for manipulation in underground storage of water. Additional ground-water recharge could be induced, during periods of excess surface flow, through use of artificial recharge facilities. Eventually, a similar quantity of water would return to the streams, largely after the peak flow had passed. The water could be returned to the surface at any time by pumping.

Any approach to improving overall water management would need to treat surface water and ground water conjunctively. Only in rare situations can either source be used without affecting the other. In many areas, ground water could be pumped to meet water requirements during seasons of low streamflow, and the aquifer could be recharged in periods of normal or excess flow. Commonly, the use of surface water for irrigation when the supply is adequate causes enough incidental ground-water recharge to replace water pumped during periods of low streamflow. If not, artificial recharge facilities could be used to increase the rate of recharge. Highly productive aquifers underlie a large part of the valleys of the Willamette River and its major tributaries (fig. 10).

At present rate of ground-water consumption (table 2), the quantity of ground water in storage in the upper 50 feet of saturation (table 1) would be adequate for the next 335 years without any extra recharge.

This subregion contains two small areas designated by the U.S. Geological Survey as "known geothermal resources areas" and much larger areas designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies are needed in areas containing extensive aquifers (fig. 10). Special emphasis needs be given to conjunctive use of ground water and surface water in areas that experience seasonal or annual shortages of streamflow.

Exploring the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as a part of the studies.

Coastal Subregion

The coastal subregion comprises the coastal areas of both Washington and Oregon and lies between the crest of the Coast Range and the Pacific Ocean (fig. 11). Elevations range from sea level to about 12,000 feet in the higher mountains. The subregion is characterized by hills, valleys, bays, and estuaries.

Annual precipitation ranges from a little less than 20 inches in some of the low areas to nearly 240 inches on some of the mountains. Below an elevation of 1500 feet, nearly all the precipitation is rain, but above 1500 feet, much of the precipitation in winter is snow. Some of the mountainous areas receive 300 to 500 inches of snow during winter.

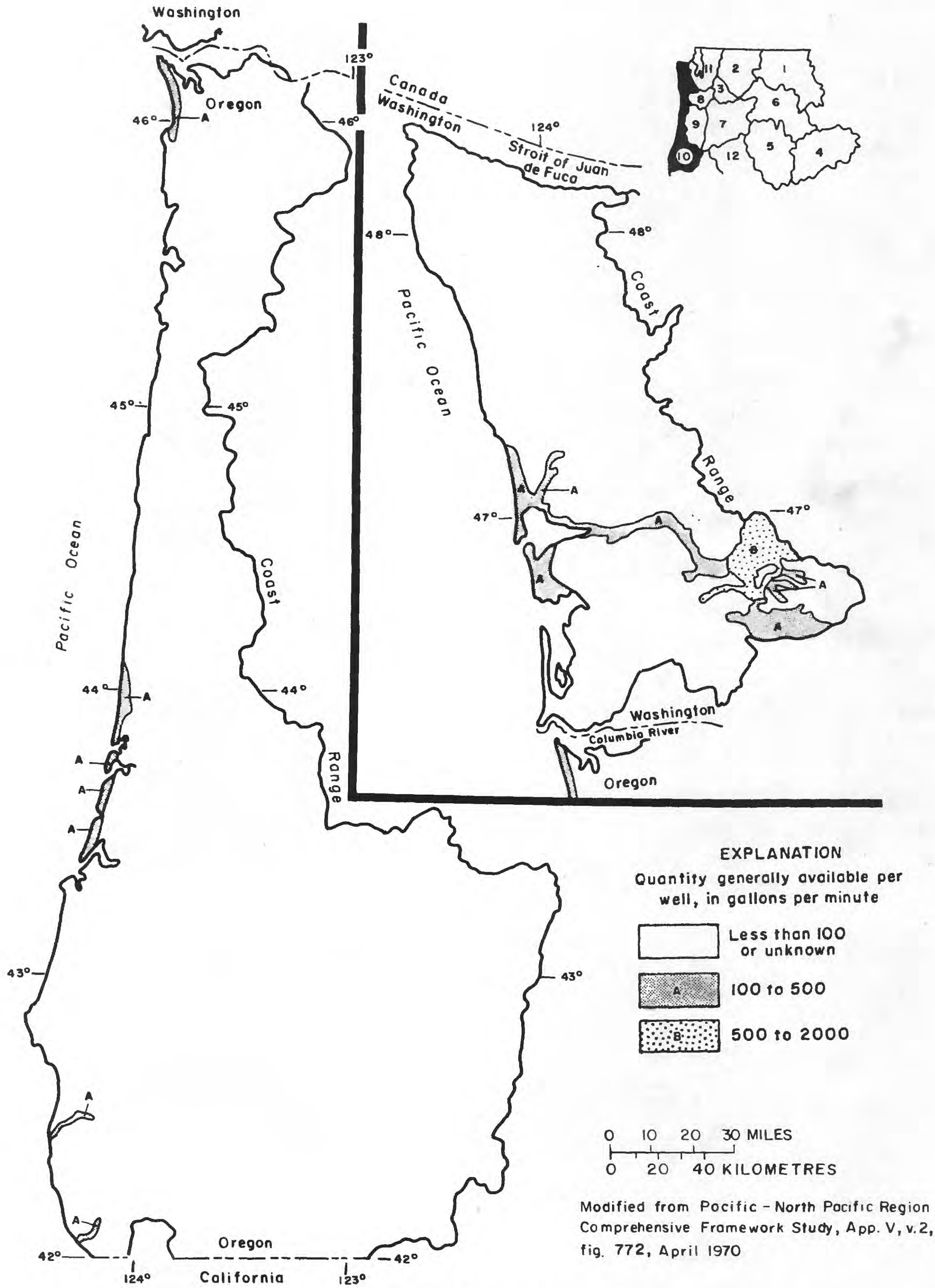


Figure 11. - General availability of ground water in the Coastal subregion.

The yield of surface water within the subregion averages 63.5 million acre-feet per year (table 1). Maximum runoff generally is during winter (December to February), and minimum runoff is in July, August, and September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 166,000 acre-feet (table 1).

The concentration of dissolved solids in surface waters generally is less than 60 mg/l. The maximum concentration is about 220 mg/l.

About 1.1 percent (698,000 acre-feet per year) of the surface-water yield is withdrawn for consumptive uses, but much less than 1 percent is actually consumed. The largest user of surface water is self-supplied industries (299,000 acre-feet per year); the second largest is irrigation (265,000 acre-feet per year).

Productive aquifers are very limited in areal extent in the coastal subregion. The aquifers are mostly unconsolidated alluvium, confined to narrow stream valleys, and narrow deposits of beach sands. Wells completed in these aquifers generally yield 100 to 2,000 gpm of water (fig. 11).

The depth to water in the principal aquifers generally is less than 20 feet.

The concentration of dissolved solids in water from the principal aquifers generally is less than 250 mg/l. The pH of the water commonly is less than 7.0 and problems of excessive iron and hydrogen sulfide occur locally.

The quantity of ground water stored in the upper 50 feet of saturated material is 27 million acre-feet, which is about 160 times more than the storage capacity of all the surface reservoirs (table 1).

The amount of ground water withdrawn in 1970 for consumptive uses was 118,000 acre-feet (table 2). The largest user was irrigation (61,000 acre-feet); the second largest was rural (30,000 acre-feet). Ground water actually consumed was only 43,000 acre-feet (table 2).

Water-resource problems in the coastal subregion that were identified by the Westwide study team include: (1) a need for protection and improvement of estuaries and bays for recreation and for protection of fish and wildlife; (2) a need to use flood plains for recreation and green belts; (3) removal of obstructions to fish migration from some streams; and (4) need for additional water for public supplies and irrigation, mostly due to seasonal variations in streamflow.

Overall, the water supply is more than adequate to meet all the demands. Table 1 shows that 63.3 million acre-feet of water per year flows into the ocean.

In some areas ground water could be developed to provide additional supplies during periods of low streamflow. However, productive aquifers containing freshwater are limited in the subregion (fig. 11). The aquifers that do contain freshwater probably could be utilized more for supplemental water during periods of low streamflow, with adequate recharge during the rainy season to replace the water withdrawn.

Quantitative hydrologic studies are needed in the areas containing freshwater aquifers (fig. 11).

Puget Sound Subregion

The Pudget Sound subregion is entirely within Washington, lying between the Cascade Range on the east and the Coast Range on the west (fig. 12). Elevations range from sea level to about 14,000 feet in the Cascade Range.

Annual precipitation ranges from a little less than 20 inches in the northwestern part of the Puget Sound area to 220 inches on parts of the Olympic Mountains. The moisture falls mostly as rain at lower elevations and as snow on the higher mountains. Precipitation is greatest in winter and least in July and August.

The yield of surface water in the subregion is 38.4 million acre-feet (table 1). Maximum flow of streams is in winter (December to February), when precipitation is at a maximum. However, streams that flood from snowmelt commonly peak in late spring. Minimum flow generally is during August and September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 3.2 million acre-feet (table 1).

The concentration of dissolved solids in stream waters generally averages less than 75 mg/l. Maximum concentrations of dissolved solids during low flow generally does not exceed 100 mg/l.

About 803,000 acre-feet per year of surface water is withdrawn for consumptive uses, but only 172,000 acre-feet per year is actually consumed. The largest use of surface water is for public supplies (610,000 acre-feet per year), but irrigation is the largest consumer of water (54,000 acre-feet per year consumption).

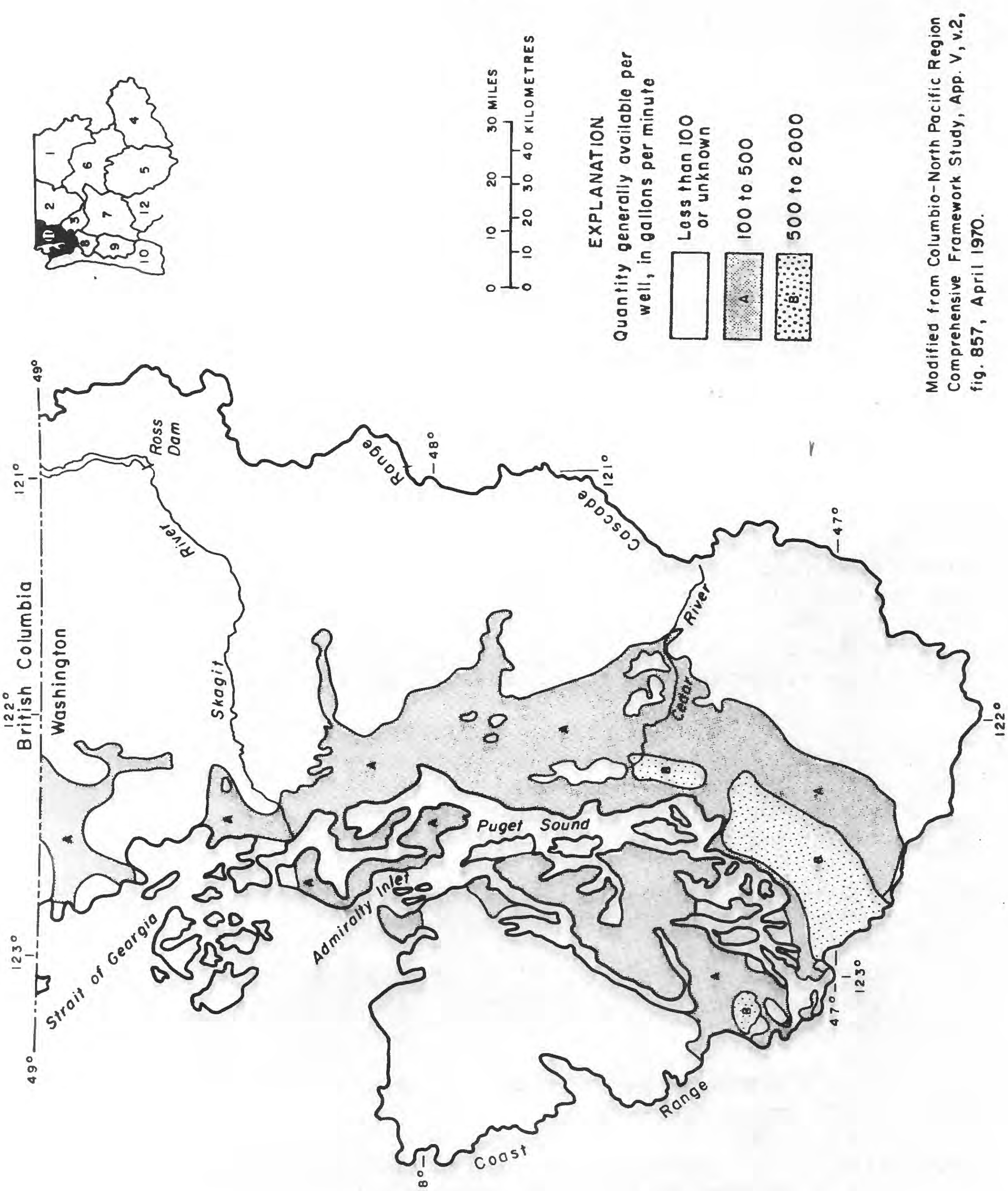


Figure 12. - General availability of ground water in the Puget Sound subregion.

The principal aquifers in the Puget Sound subregion are unconsolidated sediments in the broad lowland adjacent to Puget Sound. These aquifers generally yield 100 to 2,000 gpm of water to individual wells (fig. 12).

The depth to water in the principal aquifers generally is less than 100 feet.

The concentration of dissolved solids in the ground water generally is less than 150 mg/l. Excessive iron causes problems in some localities.

The quantity of ground water stored in the upper 50 feet of saturated material is 40 million acre-feet, which is 12 times more than the storage capacity of all the surface reservoirs (table 1). About 35 million acre-feet of the ground water is stored in the principal aquifers.

The amount of ground water withdrawn in 1970 for consumptive uses was 171,000 acre-feet, of which 63,000 acre-feet was actually consumed. The largest use was for public supplies (96,000 acre-feet); the second largest was irrigation (37,000 acre-feet) (table 2).

Water-resource problems in the Puget Sound subregion that were identified by the Westwide study group include: (1) a need for protection and improvement of coastlines, estuaries, and bays for recreation and for protection of fish and wildlife; (2) a need for more public access to water bodies; (3) a need to use flood plains that are subject to flooding for recreation and greenbelts; (4) flood control on several streams; (5) a need for information on water pollution in the vicinity of large metropolitan centers; and (6) additional harbor facilities for future growth of commerce.

Overall, the water supply is more than adequate for present and foreseeable demands. Each year about 38.1 million acre-feet of freshwater flows into the ocean from the subregion (table 1).

Alternatives in ground-water management do not apply to most of the problems listed above. However, extensive aquifers in the region could be used more for regulation of streamflow by utilizing underground storage of excess water in selected areas. Throughout the central lowland area, and extending up into some of the tributary valleys, aquifers are capable of yielding from 100 to 2,000 gpm of water to wells (fig. 12). About 40 million acre-feet of water is stored in the upper 50 feet of saturation in these aquifers (table 1). Additional storage space is available above the water table, which could be used for storage of excess surface flow by inducing additional recharge. Eventually, if not pumped from wells, a volume of water equivalent to the volume of induced recharge would return to the streams, mostly after the peak surface flow has passed.

The quantity of ground water now in storage (table 1) would be adequate to meet the present consumption rate for the next 630 years.

Quantitative hydrologic studies are needed in the areas containing extensive aquifers (fig. 12). Additional information is needed to determine the possibilities of storing part of the excess streamflow underground through artificial recharge, especially in the areas of large ground-water withdrawals. Monitoring water quality would enable early detection of pollution hazards.

Oregon Closed Basin Subregion

The Oregon Closed Basin subregion is entirely within Oregon (fig. 13). The basin is surrounded by mountains, and all drainage within the subregion is to brackish, landlocked lakes, which are 4,000 to 4,500 feet above sea level.

Annual precipitation ranges from less than 10 inches in the lower valley areas to 30 inches on the higher mountains. Maximum precipitation is in December and January; the minimum is in July and August. Most of the moisture falls as rain in the valleys and as snow on the mountains.

The surface-water yield of the subregion is 1.2 million acre-feet per year (table 1). A large part of the streamflow is derived from snowmelt in the mountains. Maximum discharge is from March to May; the minimum is from August to October.

Only one reservoir having a usable capacity of more than 1,000 acre-feet has been constructed in this subregion. Its storage capacity is 22,000 acre-feet (table 1).

Data on the chemical quality of surface waters in the subregion are sparse. The quality of water in the streams is similar to that of most mountain streams; however, the water in most of the lakes is saline, due to concentration of salts by evaporation of water. Several lakes contain water with dissolved-solids concentrations of 30,000 mg/l or more.

About 41 percent (488,000 acre-feet per year) of the surface-water yield is withdrawn for consumptive uses, but less than 25 percent (298,000 acre-feet per year) is actually consumed. Of the surface water withdrawn, 92 percent (449,000 acre-feet) is used for irrigation. The second largest use is for self-supplied industries (33,600 acre-feet per year).

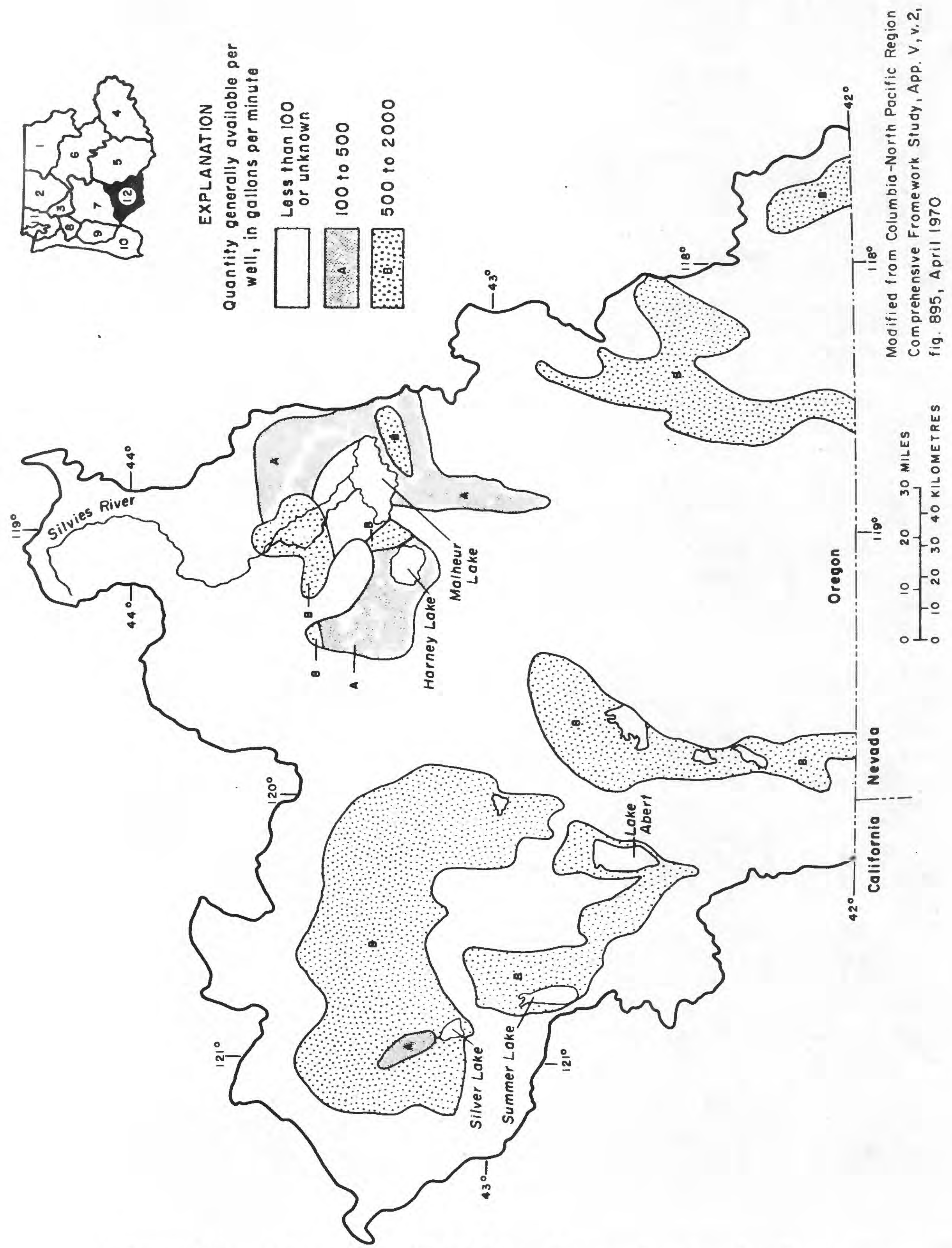


Figure 13. - General availability of ground water in the Oregon closed basin subregion.

The principal aquifers in the subregion are unconsolidated sediments and volcanic rocks (mainly basalt). These aquifers yield from 100 to 2,000 gpm of water to individual wells, and in many areas yield 500 to 2,000 gpm to wells (fig. 13).

The depth to water in the principal aquifers generally is less than 20 feet below land surface. In the higher areas, where the aquifers are less productive, the depth to water may be more than 1,000 feet below land surface.

The chemical quality of ground water varies widely. The concentration of dissolved solids is less than 1,000 mg/l in 75 to 80 percent of wells that were sampled, but the concentration is more than 5,000 mg/l in some samples. Some wells and springs yield warm to hot water.

The quantity of ground water stored in the upper 100 feet of saturated material is 56 million acre-feet (table 1), which is more than 2,000 times the storage capacity of the only surface reservoir. About 35 million acre-feet is stored in the unconsolidated sediments, the most productive aquifers.

The amount of ground water withdrawn in 1970 for consumptive uses was 68,000 acre-feet. The largest use was for irrigation (60,000 acre-feet); the second largest was for self-supplied industries (6,000 acre-feet) (table 2).

Water-resources problems that were identified by the Westwide study group are: (1) poor seasonal distribution of the surface-water supply, and (2) general problems of water requirements and water management for Indians.

Overall, the water supply is more than adequate for present demands (table 1). However, all the water that falls on the region is consumed by man's activities or by natural evapotranspiration, because there is no external drainage.

Productive aquifers underlie large parts of the subregion (fig. 13), and about 56 million acre-feet of ground water is stored in the upper 100 feet of saturated material (table 1). At the present rate of water consumption, the water in storage would be sufficient to supply this amount for the next 150 years without any recharge to the aquifers.

Lakes and marshlands, containing saline water, could be affected by extensive ground-water pumping nearby. However, pumping to date has not been adjacent to these lakes and the aquifers are so widespread, adequate amounts of ground water probably could be withdrawn to meet current seasonal demands and for new developments without affecting the lakes and marshes.

This subregion contains two small areas designated by the U.S. Geological Survey (Godwin, and others, 1971) as "known geothermal resources areas" and extensive areas designated as "areas valuable prospectively." All these areas are being examined for potential sources of geothermal water for power generation.

Quantitative hydrologic studies are needed in areas containing extensive aquifers (fig. 13). Additional information is needed on possible effects of ground-water withdrawal on the lakes and marshes. The potential for obtaining adequate ground water for thermal powerplants needs to be fully evaluated.

Exploring the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as a part of the studies.

Western Missouri River Region

The western Missouri River region, as defined for this report, includes all the Missouri River drainage in Montana, Wyoming, and Colorado (fig. 14). The western boundary of the region coincides with the Continental Divide, where the elevation ranges from about 6,000 to more than 14,000 feet above sea level. Eastward from the Continental Divide, the rugged mountains and canyons of the Rocky Mountains give way to high rolling hills and level to irregular plains. Elevations on the plains range from about 1900 feet above sea level, where the Missouri River leaves Montana, to more than 6000 feet in southeastern Wyoming.

Annual precipitation in the region ranges from 8 inches in parts of the Yellowstone River drainage in northwestern Wyoming to 120 inches in the higher mountains of northern Montana. Precipitation generally increases with elevation, but some high areas have low rates of precipitation because they are in the rain shadows of even higher mountains. In general, for equivalent elevations rainfall increases from north to south. On the other hand, the amount of winter snowfall increases from south to north. Many of the rainstorms on the plains are of short duration but high intensity, resulting in severe local floods. Heavy snow packs in the higher mountains tend to even the supply of water in streams.

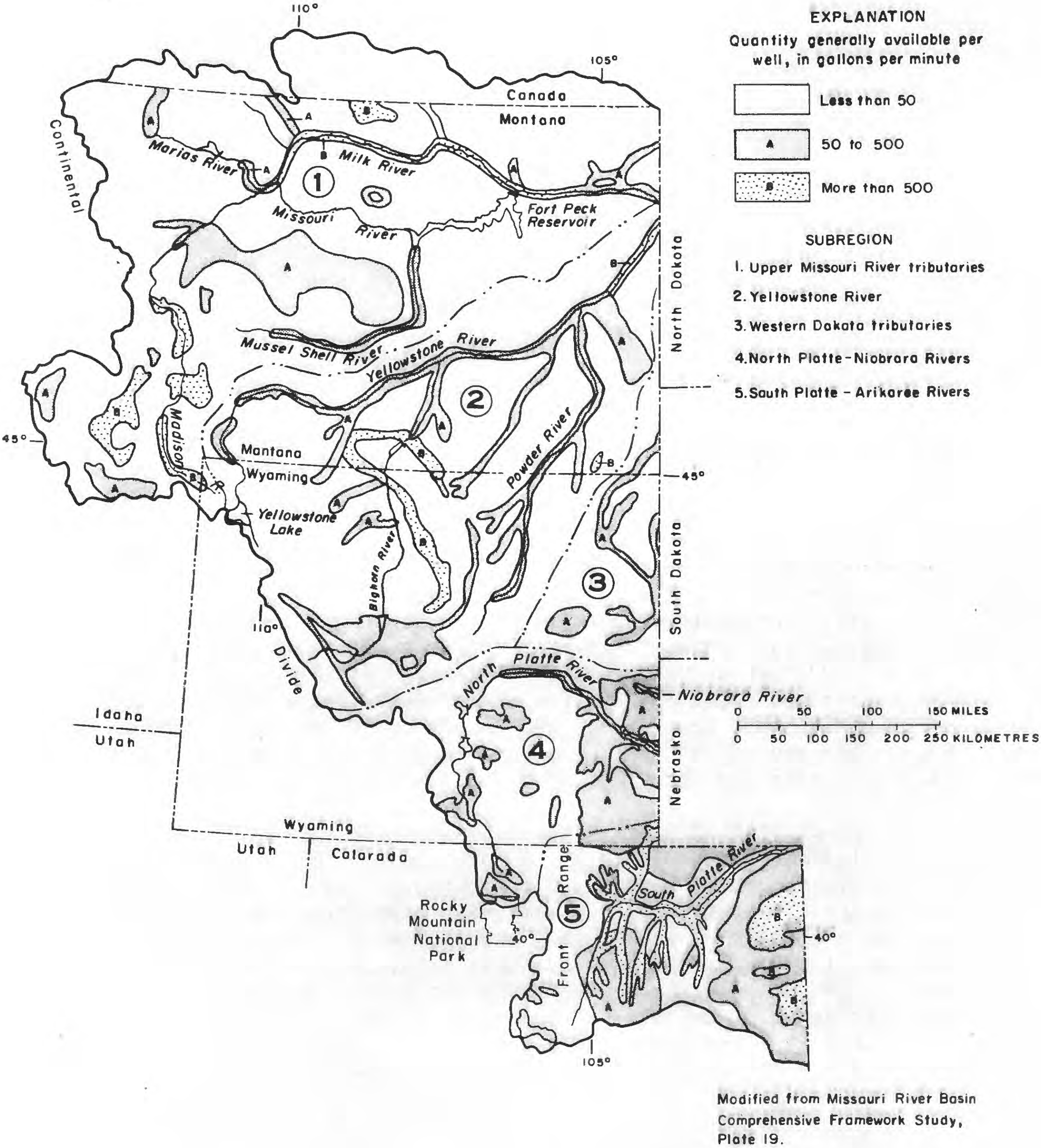


Figure 14. - General availability of ground water in the Western Missouri River region.

The region has been divided into 5 subregions to facilitate descriptions of the availability and use of water resources. Even though the subregions are somewhat similar, significant differences do exist.

Upper Missouri River Tributaries Subregion

The yield of surface water within the subregion is 9.2 million acre-feet per year. An additional 143,000 acre-feet per year is imported (table 3). Most of the streamflow is derived from snowmelt, and the maximum discharge is in June. Minimum flow is in March.

Surface reservoirs for regulation of flow have a combined storage capacity of 22.9 million acre-feet. Evaporation from the reservoirs averages 369,000 acre-feet per year.

The concentration of dissolved solids in water of the main stem of the Missouri River is less than 500 mg/l. In most of the headwaters streams, the concentration is less than 250 mg/l, but in some of the lower tributaries the concentration is 500 to 1,000 mg/l.

About 4.32 million acre-feet per year of surface water is withdrawn for consumptive uses, but only 2.72 million acre-feet per year is actually consumed. The largest use is for irrigation (4.27 million acre-feet per year); other uses are minor.

The principal aquifers in the subregion are unconsolidated sediments in the major stream valleys. These aquifers generally yield 50 to more than 500 gpm of water to individual wells. Yields of more than 500 gpm are prevalent along the valley of the main stem (fig. 14). Aquifers in consolidated sedimentary rocks (sandstone) in large upland areas yield 50 to more than 500 gpm of water to wells (fig. 14). These sandstone aquifers extend in the subsurface beneath the eastern three-quarters of the subregion, but they are deeply buried in most areas and have not been adequately explored for water. The Madison Limestone is another widespread aquifer in the subsurface, but in general it is several hundred to several thousand feet below land surface. Sparse data indicate that this limestone could yield large quantities of water to wells in many areas, but it has not been adequately explored for water.

The depth to water in the unconsolidated sediments generally is less than 50 feet below land surface. Data are not adequate to define the depth to water in the consolidated sedimentary rocks.

The concentration of dissolved solids in ground water in unconsolidated sediments in the headwaters valleys generally is less than 500 mg/l, but in some areas the concentration is as high as 1,000 mg/l. The ground water in parts of the Milk River and Mussel Shell River valleys

Table 3.--Generalized water budget for the Western Missouri River region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption			Surface water (ac-ft)	Ground water (ac-ft) 3/
				Man's activities (ac-ft per yr) 2/	Wet land and phreatophytes (ac-ft per yr)	Reservoir evaporation (ac-ft per yr)		
Upper Missouri River tributaries	143	9,200	7,280	2,720	-	369	22,900	8,700
Yellowstone River	0	9,910	9,400	929	-	370	2,590	14,800
Western Dakota tributaries	0	632	563	52	-	33	245	400
North Platte - Niobrara Rivers	7	1,780	991	875	-	180	3,060	70,000
South Platte - Arikaree Rivers	366	1,410	304	1,780	-	151	604	115,000
Totals (rounded)		22,900		6,360		1,100	29,400	209,000

1/ Data from comprehensive Framework Report, Westwide State Reports, and U.S. Geological Survey published and unpublished reports and records.

2/ Includes consumption of both surface water and ground water.

3/ Mostly storage in valley alluvium but includes a large volume in limestone and sandstone in the Yellowstone subregion and broad plains deposits in the North Platte - Niobrara and South Platte - Arikaree subregions.

contains 1,000 to 2,000 mg/l dissolved solids, and in the lower main stem valley 2,000 to 4,000 mg/l dissolved solids. The concentration of dissolved solids in the consolidated sedimentary rocks has not been adequately defined, but concentrations of more than 1,000 mg/l are common. Dissolved-solids concentration of water from the Madison Limestone ranges from less than 500 mg/l near the outcrops to 300,000 mg/l in northeast Montana. The western limit of water containing more than 100,000 mg/l coincides with the western limit of salt deposits in the Madison.

The quantity of ground water in storage in the principal aquifers of the subregion is 8.7 million acre-feet, which is only 38 percent as much as the combined storage of all the surface reservoirs (table 3). The above volume does not include ground water stored in the consolidated sedimentary rocks where they have not been adequately explored.

The amount of ground water withdrawn in 1970 for consumptive uses was 76,000 acre-feet, of which 38,000 acre-feet was actually consumed. The largest use was for irrigation (44,000 acre-feet); the second largest was for rural supplies (15,000 acre-feet).

Water-resources problems in the subregion that were identified by the Westwide study group include: (1) a need for flood control on streams; (2) a need to improve economic conditions in the Madison River basin; and (3) a need for hydrologic studies of Indian water supplies and needs.

None of these problems appear to relate to ground-water management. However, the ground-water reservoirs in unconsolidated sediments along streams, which contain 8.7 million acre-feet of water in storage (table 3), could be used to some extent for regulation of streamflow through artificial recharge. The ground-water reservoirs are nearly full under natural conditions, so it might be necessary to remove some of the water by pumping to provide for adequate storage during periods of excess streamflow. Pumping of ground water during periods of low streamflow could supplement the surface supply. Conjunctive use of surface water and ground water definitely could be considered.

One small area has been designated by the U.S. Geological Survey as a "known geothermal resources area" and much larger areas have been designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies need to be made along the major stream valleys, where aquifers capable of yielding 50 to more than 500 gpm of water to wells are common (fig. 14). Consideration could be given to possibilities for conjunctive use of ground water and surface water to achieve a better balance of supply and demand.

The Madison Limestone and related formations yield large supplies of water in many areas where they have been tested. Additional information on these aquifers is needed because their depth and transmissivity is unknown. Because water quality might be a problem where these rocks are deeply buried, the water quality needs to be known. Drilling and testing will be necessary in some areas to obtain adequate data for analysis.

Exploring the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as a part of the studies.

Yellowstone River Subregion

The Yellowstone River subregion includes all the drainage of the Yellowstone River and lies in northern Wyoming and southeastern Montana (fig. 14).

The average yield of surface water is 9.9 million acre-feet per year (table 3). Most of the streamflow is derived from snowmelt, and the maximum discharge is in June. The minimum flow is in April.

Surface reservoirs for regulation of streamflow have a combined capacity of 2.6 million acre-feet (table 3). Evaporation from the reservoirs averages 370,000 acre-feet per year.

The concentration of dissolved solids in the headwaters streams generally is less than 250 mg/l. The concentration of dissolved solids in the main stem of the Yellowstone River is 250 to 500 mg/l from its confluence with the Bighorn River to its confluence with the Missouri River. The dissolved-solids concentration of water in the Powder River is much higher than in other streams of the subregion, ranging from more than about 1,700 mg/l in the upper reaches to about 1,100 mg/l in the lower reaches.

Withdrawal of surface water for consumptive uses averages about 5.2 million acre-feet per year, but only 879,000 acre-feet per year is actually consumed. The largest use is for irrigation (4.9 million acre-feet per year). The second largest use is for public supplies (127,000 acre-feet per year).

The principal aquifers in the subregion are unconsolidated sediments in the major stream valleys and consolidated sedimentary rocks (sandstone and limestone) in upland areas. The aquifers in the unconsolidated sediments and the sandstone yield 50 to 500 gpm of water to individual wells, and the limestone aquifer yields more than 500 gpm to wells.

The depth to water in the unconsolidated sediments is less than 50 feet below land surface. The depth in other aquifers has not been adequately defined, but some flowing wells have been reported.

The concentration of dissolved solids in waters of the principal aquifers in the unconsolidated sediments ranges from less than 500 mg/l to more than 2,000 mg/l. The water of best quality is in the valleys of the upper reaches of the Bighorn and Yellowstone Rivers; the water of poorest quality is in the lower reaches of those valleys. The chemical quality of water in the consolidated sedimentary rocks has not been adequately defined.

The quantity of ground water stored in the principal ground-water reservoirs is 14.8 million acre-feet (table 3), of which 1.4 million acre-feet is in the unconsolidated sediments. The largest part of the storage indicated is in and near the outcrop area of the Madison Limestone. This formation lies at depths of several thousand feet below land surface in much of the subregion, but estimates of ground-water storage have not been published for the areas where the formation is deep.

The amount of ground water withdrawn in 1970 for consumptive uses was 101,000 acre-feet, of which 50,000 acre-feet was actually consumed (table 4). The largest use is for irrigation (60,000 acre-feet); the second largest use was for self-supplied industries (19,000 acre-feet) (table 4).

Water-resources problems in the subregion that were identified by the Westwide study group include: (1) a need for more flood control; (2) a need for additional municipal water supplies; (3) a need for large supplies of water for development of coal resources; (4) seasonal shortages of irrigation water in the Wind-Bighorn River basin; (5) a need for additional storage of water for new agricultural and industrial development; (6) a need for establishment of wild and scenic rivers; (7) a need to determine instream flow requirements for fish and wildlife, outdoor recreation, and water quality control; (8) a need to determine Indian water requirements and define Indian water rights; (9) a need to evaluate water pollution from feedlots and from irrigation return; (10) severe erosion and sedimentation problems in the Powder River basin; (11) a need for pump-back storage of water to meet peak demands for electrical power generation; and (12) environmental, social, and economic impacts of extensive coal development.

Utilization of underground storage of water through artificial recharge and pumping could provide some regulation of streams. Some of the most productive aquifers in the subregion are along the major stream valleys,

Table 4.--Estimated use of ground water in 1970 in the western Missouri River Basin

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generation	Total	
Upper Missouri River tributaries	10	15	44	7	0	76	38
Yellowstone River	9	13	60	19	0	101	50
Western Dakota tributaries	.1	.4	0	0	0	.5	.2
North Platte - Niobrara Rivers	16	1	38	29	1	85	42
South Platte - Arikaree Rivers	69	.4	836	46	0	951	476
Total	104	30	978	101	1	1,210	606

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: U.S. Geological Survey Circular 676 (1972).

and these aquifers are closely connected to the streams. These aquifers now contain about 14.8 million acre-feet of water in storage (table 3).

The possible use of ground water to supplement the water supply for Billings during periods of low streamflow could be considered.

The possibility of using ground water from deep aquifers for use in coal development could be considered, along with considerations of importing surface water from long distances. The Madison Limestone and associated formations yield large supplies of ground water in some areas, and presumably these rocks underlie most of the subregion at some depth. Also, large ground-water yields from sandstone in some areas have been reported.

Conjunctive use of ground water and surface water could be considered for all the major valleys containing productive aquifers (fig. 14).

Quantitative hydrologic studies are needed along the major stream valleys, where aquifers capable of yielding 50 to more than 500 gpm of water to wells are common (fig. 14).

Additional information on the Madison Limestone and associated formations is needed. The depth of these aquifers and their transmissivity are unknown. Because water quality might be a problem where these rocks are deeply buried, the water quality needs to be known. Drilling and testing may be necessary in some areas to obtain adequate data for analysis.

Effects of coal mining on the ground-water supply and the quality of both ground water and surface water needs to be monitored closely.

Western Dakota Tributaries Subregion

The western Dakota tributaries subregion includes the drainages of three small drainage basins in southeastern Montana and northeastern Wyoming, (fig. 14).

The average yield of surface water in the subregion is 632,000 acre-feet per year (table 3). Streamflow is derived from snowmelt and rainfall on the plains. Maximum discharge in the Little Missouri River basin is in June; the minimum is in September. The maximum discharge in the Belle Fourche River basin is in May; the minimum is in January. Maximum discharge in the Cheyenne River basin is in May; the minimum is in September.

Surface reservoirs for regulation of streamflow have a storage capacity of 245,000 acre-feet (table 3). Evaporation from the reservoirs is 33,000 acre-feet per year.

The concentration of dissolved solids in waters of the Little Missouri River range from more than 500 mg/l to less than 2,000 mg/l. The dissolved solids become more concentrated downstream. The dissolved-solids concentration of water in the Belle Fourche River ranges from more than 250 mg/l in the upper reaches to less than 1,000 mg/l in the lower reaches. The concentration of dissolved solids in waters of the Cheyenne River range from 2,000 to 4,000 mg/l.

Withdrawal of surface water for consumptive uses in the subregion averages about 123,000 acre-feet per year, but only 52,000 acre-feet per year is actually consumed. The largest use is for irrigation (38,000 acre-feet per year); the second largest use is for public supplies (7,000 acre-feet per year).

The principal aquifers in the subregion are in consolidated rocks, except for a small area of unconsolidated sediments along the Belle Fourche River valley. The yield of water to individual wells from the principal aquifers is generally less than 500 gpm (fig. 14). The Madison Limestone probably underlies the entire subregion at depths of several thousand feet, but its water-bearing properties have not been adequately evaluated. Wells tapping it possibly would yield more than 500 gpm in some areas.

The depth to water in the principal aquifers generally ranges from about 50 feet to as much as 600 feet.

Data on the quality of ground water are sparse, but concentrations of dissolved solids is expected to exceed 1,000 mg/l throughout the subregion.

The quantity of ground water stored in the principal aquifers is 400,000 acre-feet, which is nearly two times the storage capacity of surface storage. The quantity of ground water in storage listed above does not include storage in the limestone aquifer.

The amount of ground water withdrawn in 1970 for consumptive uses was only 500 acre-feet, mostly for rural use (table 4).

Water-resources problems in the subregion that were identified by the Westwide study group include: (1) a need for water for coal development; and (2) environmental, social, and economic impacts of coal development.

The ground-water resources of this subregion are small in comparison to those of most subregions. Shallow aquifers are limited to a few narrow stream valleys, and these aquifers yield only 50 to 500 gpm of water to wells (fig. 14). Little information on deep aquifers is available.

Conjunctive use of ground water and surface water could be encouraged.

Quantitative studies of the shallow hydrologic system are needed. Available information on the deep aquifers needs to be analyzed, and for areas where the potential for ground-water development looks promising, more detailed studies of the deep aquifers are needed.

Effects of coal mining on the ground-water supply and the quality of both ground water and surface water needs to be monitored closely.

North Platte-Niobrara Rivers Subregion

The North Platte-Niobrara Rivers subregion includes all the drainage of the North Platte River in Colorado and Wyoming and a small area drained by the Niobrara River in Wyoming.

The yield of surface water averages 1.8 million acre-feet per year (table 3). Most of the flow of the North Platte River is derived from snowmelt in the mountains. The maximum discharge is in June; the minimum is in January. The flow of the Niobrara River is derived from snowmelt and rainfall on the plains. The mean monthly discharge is highest in February but is nearly constant from February to April. The minimum flow is in September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 3.1 million acre-feet (table 3). Evaporation from the reservoirs averages 180,000 acre-feet per year.

The concentration of dissolved solids in waters of the North Platte River is less than 250 mg/l in the reaches above the major storage reservoirs and ranges from 250 to 500 mg/l in the remainder of the basin, except for one small area where the concentration is more than 2,000 mg/l. The dissolved-solids concentration of water in the Niobrara River basin is generally more than 2,000 mg/l.

Withdrawal of surface water for consumptive uses averages 2.66 million acre-feet per year, but only 833,000 acre-feet per year are actually consumed. The largest use is for irrigation (258,000 acre-feet per year); the second largest is for public supplies (50,000 acre-feet per year).

The principal aquifers in the subregion are unconsolidated sediments. However, each year more irrigation supplies are being developed in the consolidated sedimentary rocks. These sediments include stream alluvium along parts of the North Platte and Laramie River valleys and broad slope deposits on the upland plains. Most of these aquifers yield 50 to 500 gpm of water to individual wells, but in some parts of the North Platte valley yields of more than 500 gpm are obtained (fig. 14).

The depth to water in the principal aquifers ranges from less than 50 feet below land surface in the valleys to more than 200 feet below land surface beneath the higher plains.

The concentration of dissolved solids in ground water of the principal aquifers generally is less than 500 mg/l and in some areas less than 250 mg/l. On the other hand, the dissolved-solids concentration of water in one small area along the North Platte River above the major surface reservoirs is 500 to 1,000 mg/l.

The quantity of ground water in storage in the principal aquifers of the subregion is 70 million acre-feet, which is about 23 times the storage capacity of the surface reservoirs (table 3).

The amount of ground water withdrawn in 1970 for consumptive uses was 85,000 acre-feet, but only 42,000 acre-feet was actually consumed (table 4). The largest use was for irrigation (380,000 acre-feet); the second largest use was for self-supplied industries (29,000 acre-feet).

Water-resources problems in the North Platte-Niobrara subregion that were identified by the Westwide study group include: (1) a need for additional water for public supplies and industries; (2) a need for more flood control; (3) seasonal shortages of surface water at places in the North Platte River valley; (4) an increasing number of irrigation wells in the eastern part of the subregion, all taking water from the same aquifer; (5) a need to determine instream flow requirements for fish and wildlife and outdoor recreation and methods of meeting these requirements; and (6) a need to modify operations of mainstem reservoirs to meet localized needs for additional flat-water recreation opportunities.

Part of these water-resources problems could be alleviated to some extent by conjunctive use of ground water and surface water, including artificial recharge for underground storage of water and pumping during periods of low streamflow. Flood dangers could be lessened in some areas by diversion of excess flows to recharge facilities. Also, the levels of Glendo and Guernsey reservoirs could possibly be held at more constant levels by greater utilization of underground storage.

Ground-water resources in the eastern part of the subregion may be overdeveloped. If so, eventually the amount of pumping will be reduced, or the supply will have to be increased by artificial recharge.

Quantitative hydrologic studies are needed along the major streams and in the eastern part of the area, where broad plains deposits comprise the principal aquifer (fig. 14).

Monitoring of water levels and ground-water quality in the eastern plains area would provide data for modeling the system.

South Platte-Arikaree Subregion

The South Platte-Arikaree (or Republican) subregion includes the drainage of those streams in northeastern Colorado and a small area in southeastern Wyoming plus some minor tributaries in Colorado of the Smoky Hill River which is in Kansas.

The yield of surface water averages 1,410 acre-feet per year. An additional 366,000 acre-feet per year is imported from the Upper Colorado region and from the North Platte River basin (table 3). Most of the streamflow is derived from snowmelt in the mountains, and the maximum discharge is in June. The minimum flow is in February.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 604,000 acre-feet (table 3). Evaporation from the reservoirs averages 151,000 acre-feet per year.

The concentration of dissolved solids in headwaters streams of the South Platte River basin is less than 500 mg/l. The dissolved-solids concentration of water in the South Platte River increases downstream, to more than 1,000 mg/l.

Withdrawal of surface water for consumptive uses averages about 2.2 million acre-feet per year, but only 1.3 million is actually consumed. The largest use of surface water is for irrigation (1.8 million acre-feet per year); the second largest use is for public supplies (256,000 acre-feet).

The principal aquifers in the subregion are unconsolidated sediments, which include stream alluvium in the major stream valleys and slope deposits on the upland plains. The valley aquifers generally yield more than 500 gpm of water to individual wells and the slope deposits yield 100 to more than 500 gpm to wells (fig. 14).

The depth to water in the principal aquifers ranges from less than 50 feet below land surface in the valleys to more than 200 feet beneath the higher parts of the upland plains.

The concentration of dissolved solids in water from the slope deposits generally is less than 250 mg/l. The dissolved-solids concentration varies widely in the valley alluvium, ranging from 250 mg/l to more than 2,000 mg/l. The highest concentrations are in areas of extensive reuse of irrigation water and operation of cattle feedlots.

The quantity of ground water stored in the principal aquifers is 115 million acre-feet, which is 190 times the combined storage capacity of all the surface reservoirs (table 3).

The amount of ground water withdrawn in 1970 for consumptive uses was 1.2 million acre-feet, of which 606,000 acre-feet were actually consumed (table 4). The largest use was for irrigation (978,000 acre-feet); the second largest use was for public supplies (69,000 acre-feet) (table 4).

Water-resources problems in the South Platte-Arikaree subregion that were identified by the Westwide study group include: (1) substandard quality of public water supplies in the eastern part of the subregion; (2) a need for additional water for public and industrial water supplies especially along the Front Range corridor; (3) localized needs for additional flat-water recreation opportunities and lack of use of reservoirs for recreation in large metropolitan areas; (4) management of flood plains to reduce flood damage and provide more space for recreation; (5) conversion of irrigated land to urban use; (6) provide artificial recharge to aquifers where ground-water withdrawals are extensive; (7) protection of Rocky Mountain National Park from outside influences of water management; (8) protection of the environment versus economic growth; (9) flood control on several streams; (10) ownership of water rights on Federal lands; (11) problems of Colorado meeting South Platte River Compact requirements; (12) effects of ground-water withdrawal along the Front Range; (13) possible designation of part of the South Platte River as a wild and scenic river; and (14) a rapid increase in the number of irrigation wells in the eastern part.

The water supplies of several small communities are inferior in quality (commonly containing more than 1,000 mg/l dissolved solids), due to discharge of urban and industrial wastes, cattle feedlots, and return irrigation water. Stronger enforcement of antipollution laws is needed to protect the quality of both ground water and surface water.

Intense development of ground water in the eastern part of the subregion and in the Front Range corridor is probably depleting the ground-water supply faster than it is being replenished. Artificial recharge in these areas could reduce the rate of ground-water depletion. Excess surface flow during floods could possibly be diverted to recharge facilities in these areas, reducing the peak flow during floods and accomplishing significant recharge to selected aquifers.

During periods of low flow in the South Platte River, ground water is pumped from many wells for supplemental supplies, causing further decrease in streamflow. A systematic program of conjunctive use of ground water and surface water is needed to provide maximum benefits from the available water supply. About 115 million acre-feet of ground water is stored in the subregion, largely in the major stream valleys east of the mountains and in the eastern plains areas. Because of the complex situation during periods of low streamflow, Colorado has difficulty in meeting the requirements of the South Platte River Compact. A better coordinated program of utilizing both surface and subsurface storage could minimize the low flow problems.

Quantitative hydrologic studies are needed in areas along the major stream valleys and the eastern plains, where the aquifers are capable of yielding more than 50 gpm of water to wells (fig. 14).

Monitoring water levels and ground-water quality in all the principal aquifers would aid in evaluating what is happening in the aquifers. These data could be used to determine changes that may be needed in ground-water management.

California Region

North Coastal Subregion

The north coastal subregion includes all coastal basins in California north of the Russian River and the Klamath River drainage in Oregon (fig. 15). Most of the subregion is mountainous, with elevations ranging from sea level on the west to more than 14,000 feet on the highest peaks in the east.

The average annual precipitation ranges from 10 inches in parts of the northeast to 120 inches in the northwest part. The average is about 45 inches. The highest monthly rate of precipitation is in December and January; the lowest rate is in July and August.

The yield of surface water averages 27.1 million acre-feet per year (table 5). Most streamflow at higher elevations is derived from snowmelt and the maximum runoff is in May and June. The flow at lower elevations is derived from rainfall and the maximum flow is in January and February. The minimum flow for all areas is in September.

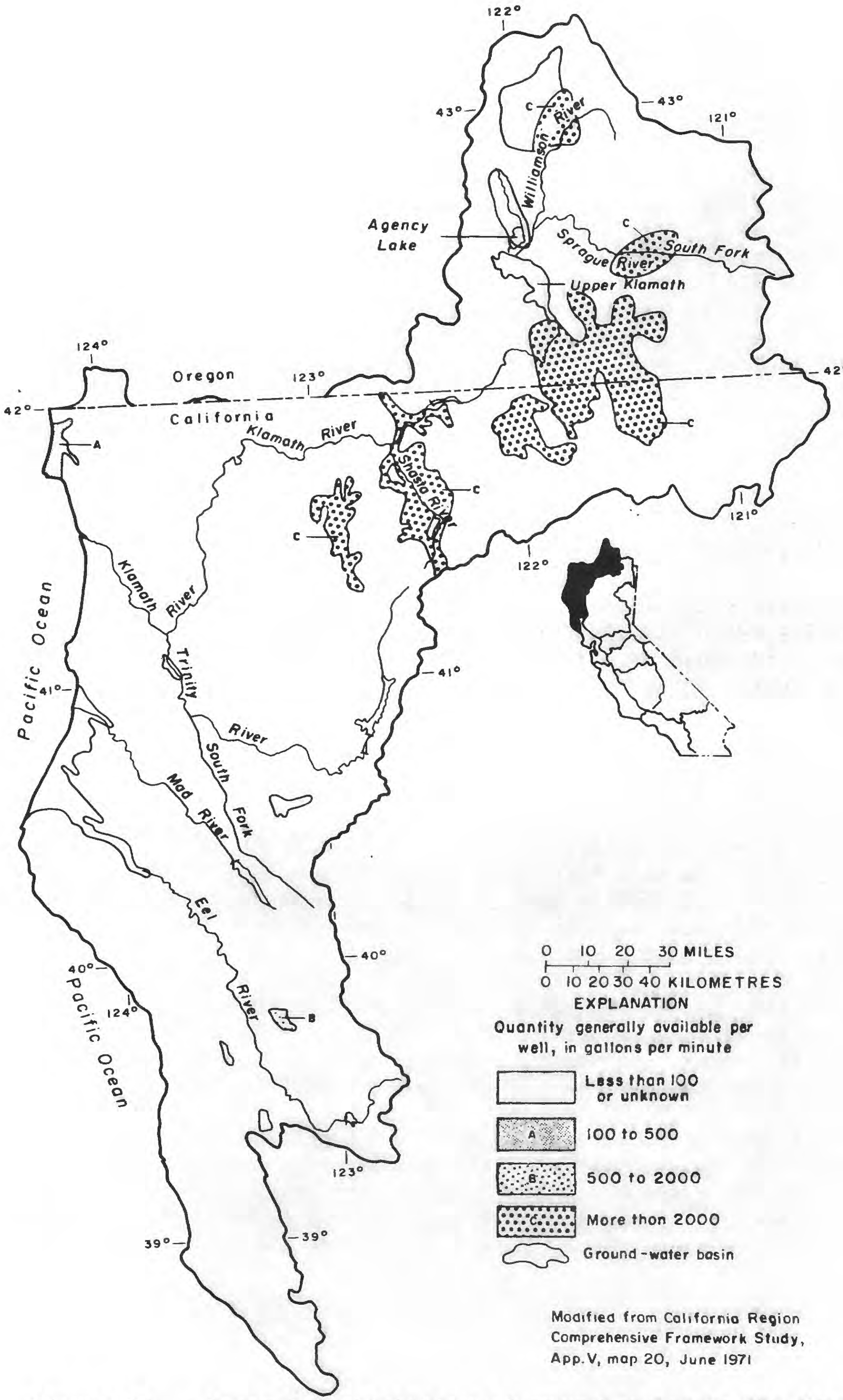


Figure 15. - General availability of ground water in the North Coastal subregion.

Table 5.--Generalized water budget for the California region [1/]

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption: Man's activities (ac-ft per yr) 2/	Consumption: Wet land and phreatophytes (ac-ft per yr)	Consumption: Reservoir evaporation (ac-ft per yr)	Surface water (ac-ft)	Ground water (ac-ft) 3/
North Coastal	0	27,100	25,300	512	-	38	2,630	700 4/
San Francisco Bay	680	3,350	3,080	797	-	30	804	1,200 4/
Central Coastal	0	1,780	1,050	790	-	30	1,340	7.600 4/
South Coastal	1,450	1,400	382	2,480	-	90	1,930	10,600 4/
Sacramento Basin	1,000	21,100	18,600	4,710	-	310	10,700	22,000
Delta-Central Sierra	21,200	1,080	19,800	1,780	-	60	1,500)	
San Joaquin Basin	180	6,060	2,640	3,240	-	140	3,000)	80,000
Tulare Basin	1,330	3,130	35	6,730	-	90	1,800)	
North Lahontan	11	1,540	1,130	68	-	20	1,400)	700 4/
South Lahontan	0	1,200	325	405	-	20	410)	
Colorado Desert	3,600	112	0	2,340	-	0	0	3,600 4/
Totals (rounded)		67,800		23,800		830	25,500	126,000

1/ Data from comprehensive Framework Report and Westwide State Report.

2/ Includes consumption of both surface water and ground water.

3/ Depth zone variable but generally the upper 200 feet below land surface.

4/ Some ground-water basins not included in total.

Surface reservoirs for regulation of streamflow have a combined capacity of 2.63 million acre-feet (table 5). Evaporation from the reservoirs is 38,000 acre-feet per year.

The concentrations of dissolved solids in waters of the streams are less than 340 mg/l, and in many streams the concentration is less than 110 mg/l. The quality of water in the Klamath River improves downstream due to inflows of low salinity water from its many tributaries.

Withdrawal of surface water for consumptive use in the subregion averages about 732,000 acre-feet per year, but only 410,000 acre-feet per year is actually consumed. The largest withdrawal is for irrigation (638,000 acre-feet per year); the second largest is for public supplies (67,300 acre-feet per year).

The principal aquifers in the subregion are unconsolidated sediments and volcanic rocks in stream valleys and broad basins between mountain ranges. In some of the larger basins, the aquifers generally yield more than 1,000 gpm of water to individual wells (fig. 15), and yields as large as 4,000 gpm have been reported. Figure 15 shows some basins where the yield is 500 gpm, some where the yield is 300 gpm, and others where only the outline of the basin is shown, because the yield is less than 300 gpm or has not been reported.

The depth to water in the principal aquifers ranges from land surface to about 185 feet below land surface. Flowing wells are common in some of the valleys.

The concentration of dissolved solids in waters of the principal aquifers generally is less than 500 mg/l. However, the concentration exceeds 4,800 mg/l locally.

The quantity of usable water stored in the principal aquifers is about 700,000 acre-feet (table 5), which is less than one-third the storage capacity of surface reservoirs in the subregion.

The amount of ground water withdrawn in 1970 for consumptive uses was 180,000 acre-feet, of which 102,000 acre-feet was consumed (table 6). The largest use was for irrigation (151,000 acre-feet); the second largest use was for public supplies (14,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) a need for more flood control in the Eel River basin; (2) a decrease in fish runs in some of the coastal streams; and (3) a need to retain free-flowing rivers.

Table 6.--Estimated use of ground water in 1970 in the California region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generation	Total	
North Coastal	14	8	151	7	0	180	102
San Francisco Bay	128	20	320	131	0	599	338
Central Coastal	67	16	1,090	36	0	1,210	682
South Coastal	867	29	1,230	248	336	2,710	1,530
Sacramento Basin	175	25	4,000	60	0	4,260	2,400
Delta-Central Sierra	82	9	1,490	66	0	1,650	930
San Joaquin Basin	100	19	2,780	60	0	2,960	1,670
Tulare Basin	239	28	5,820	32	0	6,120	3,450
North Lahontan	.7	.9	6	2	0	10	6
South Lahontan	54	8	570	15	0	647	365
Colorado Desert	26	10	300	6	0	342	193
Total	1.753	173	17,800	663	336	20,700	11,700

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: U.S. Geological Survey Circular 676 (1972).

Ground-water management alternatives do not relate directly to any of these problems, except that in some instances underground storage of surplus surface water could provide more ground-water discharge to streams during periods of low streamflow. About 25.3 million acre-feet of water per year flows out to the ocean from the subregion.

In large areas of the Klamath River basin, aquifers are capable of yielding more than 1,000 gpm of water to wells and these aquifers are connected closely to the streams. Water artifically recharged to these aquifers would return to the streams eventually, and much of the increased ground-water recharge would be during periods of normal low streamflow.

This subregion contains areas designated by the U.S. Geological Survey (Godwin, and others, 1971) as "known geothermal resources areas." Geothermal water has been used to some extent for space heating or as a heat exchange source for heating water of better chemical quality, which is used for space heating. Additional development of geothermal resources seems to be a distinct possibility.

Quantitative hydrologic studies are needed in the areas containing the most productive aquifers (fig. 15).

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

San Francisco Bay Subregion

The San Francisco Bay subregion includes all basins draining into San Francisco Bay and several basins draining directly into the Pacific Ocean (fig. 16). One-third of the subregion is classed as valley lands.

Average annual precipitation ranges from 12 inches in the southeast to 14 inches in the south bay area and to 80 inches on the higher mountains of the Coast Range north of the bay area. The average for the subregion is 30 inches. Mean monthly precipitation reaches a maximum in January and a minimum in July and August. Most of the moisture falls as rain.

The principal streams are the Russian and Napa Rivers. The yield of surface water is 3.35 million acre-feet. An additional 680,000 acre-feet flows in from other subregions (table 5). Maximum discharge of streams is in January; the minimum is in October, when many are dry.

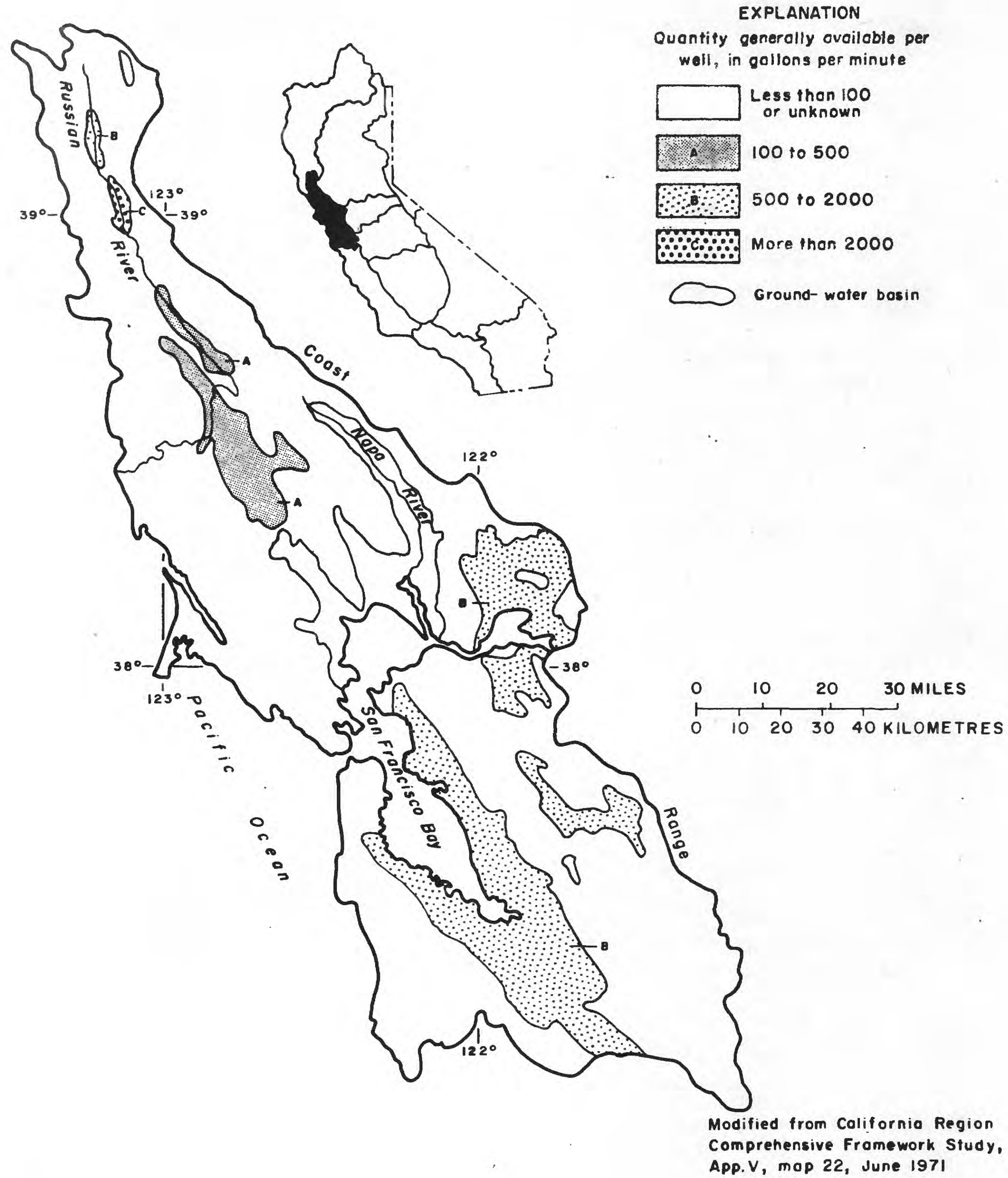


Figure 16. - General availability of ground water in the San Francisco Bay subregion.

Surface reservoirs for regulation of flow have a combined storage capacity of 804,000 acre-feet (table 5). Evaporation from reservoirs averages 30,000 acre-feet per year.

The concentration of dissolved solids in surface waters ranges from 100 to 500 mg/l in the Napa River and to as much as 1,000 mg/l in some of the streams draining into the bay from the east.

Surface water withdrawn for consumptive uses is about 819,000 acre-feet per year, all of which is consumed or flows into the bays or the ocean. The largest use is for public supplies (584,000 acre-feet per year); the second largest is for self-supplied industries (193,000 acre-feet per year).

The principal aquifers in the subregion are unconsolidated sediments in intermontane valleys and broad sedimentary basins adjacent to the bays. These aquifers generally yield 100 to more than 500 gpm of water to wells. In most of the bay area, the aquifers yield 300 to 500 gpm to wells (fig. 16). The aquifers in some ground-water basins yield less than 100 gpm or the average yield has not been adequately determined.

The depth to water in the principal aquifers generally is less than 260 feet below land surface, and flowing wells have been reported in parts of all but one of the ground-water basins.

The concentration of dissolved solids in ground water generally is less than 1,000 mg/l, but locally it exceeds 11,000 mg/l in the Napa Valley.

The quantity of ground water stored in the upper 200 feet below land surface in the principal aquifers is 1.2 million acre-feet, which is only a little more than the storage capacity of surface reservoirs. However, some of the aquifers are more than 200 feet thick, and the quantity of ground water in storage is more than indicated above.

The amount of ground water withdrawn in 1970 for consumptive uses was 599,000 acre-feet, of which 338,000 acre-feet was actually consumed. The largest use was for irrigation (320,000 acre-feet); the second largest use was for self-supplied industries (131,000 acre-feet), but use for public supplies was nearly the same (128,000 acre-feet) (table 6).

Water-resources problems that were identified by the Westwide study group include: (1) a need for additional flood control in the Russian River basin; (2) a need for protection of water quality in San Francisco Bay, in estuaries, and in the delta area above the bay; and (3) possible use of reclaimed waste water for recreation and for maintaining greenbelts.

Overall, the water supply (including inflow) is adequate for present needs, and 3.08 million acre-feet per year flows into San Francisco Bay or the Pacific Ocean (table 5).

Extensive aquifers capable of yielding 100 to more than 500 gpm of water to wells are present in the Russian River basin (fig. 16) and are closely connected to streams. These aquifers could be used for more storage of water underground, by diversion of water from streams during flood flows to artificial recharge facilities. The artificial recharge would induce additional ground-water discharge to the streams, after a time-lag, tending to make the discharge of the streams more uniform.

Ground water is used extensively for public, industrial, and irrigation supplies in a large area east and south of the bay, which is underlain by a widespread aquifer capable of yielding 300 to 500 gpm of water to wells (fig. 16). If withdrawal of water from this acquifer continues to increase, an increase in artificial ground-water recharge may become necessary, if additional supplies can be obtained, to sustain the present and projected rates of withdrawal.

The subregion contains one large area designated by the U.S. Geological Survey (Godwin, and others, 1971) as a "known geothermal resources area" and an even larger area designated as "areas valuable prospectively." The only commercial use of geothermal resources for electrical power generation in the Nation is in this subregion.

Quantitative hydrologic studies are needed in areas containing productive aquifers (fig. 16). Additional information is needed to determine the possibilities of artificial recharge especially in the areas of heavy ground-water withdrawals.

Monitoring water quality in the subregion is needed to detect changes in both the surface water and ground-water resources. Monitoring water levels in wells is needed in the heavily pumped areas.

Exploring of the geothermal areas is needed to evaluate the potential for additional development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies. Private companies have been very active in exploration of the geothermal areas, and their activity is expected to continue as long as the potential for energy development looks favorable.

Central Coastal Subregion

The central coastal subregion (fig. 17) includes all coastal basins between the San Francisco Bay subregion (fig. 16) and the South Coastal subregion (fig. 18). The subregion extends inland from the Pacific Ocean an average of about 50 miles, to the crest of the Coast Range.

Annual precipitation ranges from 6 inches per year in intermontane basins of the southeast to 60 inches on the upper slopes of the Coast Range in the northwest. The average annual precipitation for the entire subregion is about 20 inches. Maximum precipitation is in January; the minimum is in July and August. Virtually all the moisture falls as rain.

The yield of surface water averages 1.78 million acre-feet per year (table 5). Most of the streamflow is derived from rain and ground-water discharge. The maximum discharge is in January; the minimum is in September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 1.34 million acre-feet (table 5). Evaporation from the reservoirs averages 30,000 acre-feet per year.

The concentration of dissolved solids in waters of the principal streams ranges from 500 to 1,500 mg/l. Excessive concentrations of sulfate, fluoride, and boron limit the uses of some water.

The amount of surface water withdrawn for consumptive uses is 190,000 acre-feet per year, but only 106,000 acre-feet per year is actually consumed. The largest use is for irrigation (107,000 acre-feet per year); the second largest use is for public supplies (45,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in valleys and coastal plains. These aquifers yield from 100 to more than 1,000 gpm of water to individual wells. The aquifers in some basins yield less than 100 gpm or the yield has not been adequately determined (fig. 17).

The depth to water in the principal aquifers generally is less than 250 feet below land surface, and flowing wells have been reported in some valleys.

The concentration of dissolved solids in the ground water generally is less than 800 mg/l, but locally the concentration is as high as 11,000 mg/l.

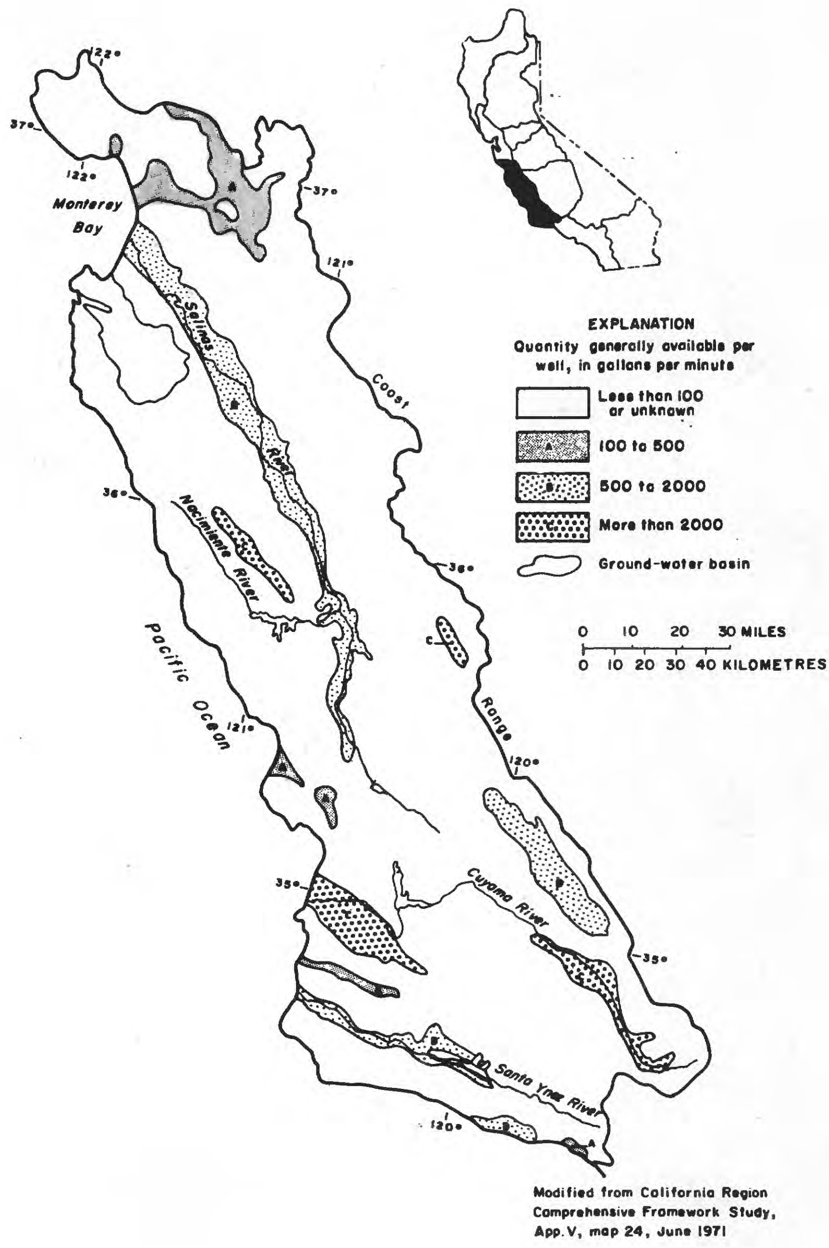


Figure 17. - General availability of ground water in the Central Coastal subregion.

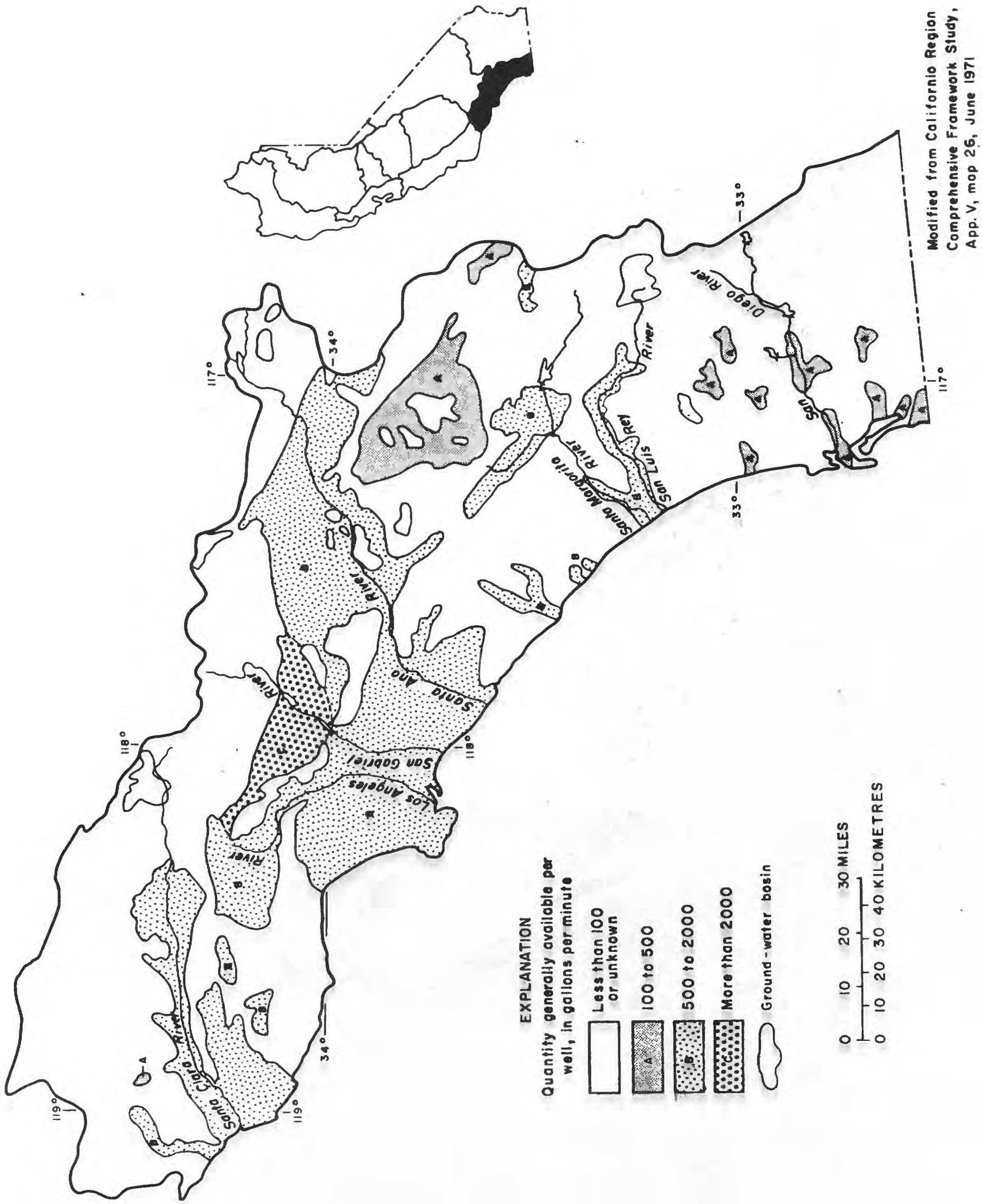


Figure 18. - General availability of ground water in the South Coastal subregion.

The quantity of ground water stored in the upper 200 feet below land surface is 7.6 million acre-feet. In some valleys the aquifers are much thicker than 200 feet, and the quantity of ground water is correspondingly greater than indicated above.

The amount of ground water withdrawn in 1970 for consumptive uses was 1.21 million acre-feet, of which 682,000 acre-feet was actually consumed. The largest use was for irrigation (1.09 million acre-feet); the second largest use was for public supplies (67,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) a need for more flood control; (2) a need for data on large-scale desalting of sea water; (3) water pollution in the Salinas River basin and in Monterey Bay; and (4) competition for water among irrigation, public supplies, and industries.

Flood control projects in the subregion could be tied to artificial recharge to the ground-water reservoirs in some areas. Sea-water intrusion has been noted at several localities along the coast, and additional ground-water recharge in these localities could prevent or reduce the severity of sea-water intrusion.

Water pollution in the Salinas River basin needs to be eliminated as rapidly as possible. This basin contains the most extensive aquifer in the subregion. Withdrawal of ground water in the subregion in 1970 was 1.21 million acre-feet, so severe pollution of the ground water would have an enormous impact on the economy.

An area east of the Cuyama River contains an extensive aquifer capable of yielding 500 to 1,000 gpm of water to wells but the water is inferior in quality. This water probably could be used for cooling at thermal power plants. The plain is sparsely populated, which might add to its attractiveness as a potential location for thermal power plants. However, the plain is adjacent to the active San Andreas fault, which might make the area unacceptable for power plants, especially nuclear plants.

The water of inferior quality could be used, alternatively, as a source of feed water for desalting plants, which would make the water acceptable for most uses.

Quantitative hydrologic studies should be made in all the areas containing extensive aquifers (fig. 17) where such studies have not been completed. These studies should include the areas containing water of inferior quality, as well as those containing fresh water. Special emphasis should be given to possibilities of artificial recharge.

South Coastal Subregion

The south coastal subregion (fig. 18) includes all the basins in California south of the Central Coastal subregion (fig. 17). Elevations range from sea level to a little more than 10,000 feet above sea level on the highest peaks.

Average annual precipitation ranges from 10 inches in the interior valleys to 40 inches at higher altitudes. The average for the subregion is 18.4 inches per year. Maximum precipitation is in February; the minimum is in July. Most of the moisture falls as rain.

The yield of surface water is 1.4 million acre-feet per year. An additional 1.45 million acre-feet per year is imported from other subregions (table 5). Most of the local streamflow is derived from rainfall and from ground-water discharge. Runoff reaches a maximum in March and a minimum in September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 1.93 million acre-feet (table 5). Evaporation from the reservoirs averages 90,000 acre-feet per year.

The concentration of dissolved solids in the locally derived water varies widely, depending on the flow characteristics of the streams, quality and quantity of imported water, reuse of water, and the disposal of waste water into the water courses. The concentration is lowest when flow is highest, and the concentration is highest when flow is lowest. The quality deteriorates downstream because of use and return to the streams and addition of wastes. Water imported from the Colorado River generally contains higher concentrations of dissolved solids than the local streams.

Withdrawal of surface water for consumptive uses in the subregion averages 1.69 million acre-feet per year, but only 947,000 acre-feet per year is actually consumed. The largest use is for public supplies (1.15 million acre-feet per year); the second largest is for irrigation (537,000 acre-feet per year).

The principal aquifers in the south coastal subregion are unconsolidated sediments in valleys and coastal plains. These aquifers yield 100 to more than 1,000 gpm of water to individual wells. A few ground-water basins yield less than 100 gpm to wells, or the yield has not been adequately determined (fig. 18).

The depth to water in the principal aquifers ranges from land surface to 800 feet below land surface. Part of the wells flow in some of the basins.

The concentration of dissolved solids in waters of the principal aquifers generally is less than 1,000 mg/l. However, the concentration locally exceeds 36,000 mg/l.

The quantity of ground water stored in the upper 200 feet below land surface is 10.6 million acre-feet, which is more than 40 times the storage capacity of all the surface reservoirs (table 5).

The amount of ground water withdrawn in 1970 for consumptive uses was 2.71 million acre-feet, of which 1.53 million acre-feet was actually consumed. The largest use was for irrigation (1.23 million acre-feet); the second largest was public supplies (867,000 acre-feet) (table 6).

Water-resources problems that were identified by the Westwide study group include: (1) a need for additional flood control; (2) a need to evaluate the potential for using reclaimed waste water for recreation and greenbelts; and (3) a need for data on large-scale desalting of sea water.

Withdrawal of ground water in the subregion in 1970 was 2.71 million acre-feet (table 6). In order to sustain a high rate of ground-water withdrawal, additional artificial recharge may be necessary. Consequently, any plans for flood control in the subregion probably would need to consider possibilities for artificial recharge along with flood control.

Use of reclaimed waste water for recreation and greenbelts could cause problems of chemical pollution of ground water. In selecting potential sites for using reclaimed waste water for recreation or greenbelts, the risk of ground-water pollution would need to be considered. On the other hand, sea water is encroaching inland in some areas and reclaimed waste water could possibly be recharged into acquifers in these areas to prevent seawater encroachment, either by injection through wells or by applying excess water to carefully selected greenbelts.

Quantitative hydrologic studies are needed in areas containing extensive aquifers (fig. 18), where such studies have not been completed. Special emphasis need to be given to studies involving the possible use of flood waters and reclaimed waste water for artificial ground-water recharge, to offset heavy ground-water withdrawals and encroachment of sea water.

Sacramento Basin Subregion

The Sacramento Basin subregion (fig. 19) includes all the drainage of the Sacramento River upstream from the San Francisco Bay subregion (fig. 16). In addition it includes the closed basin of Goose Lake to

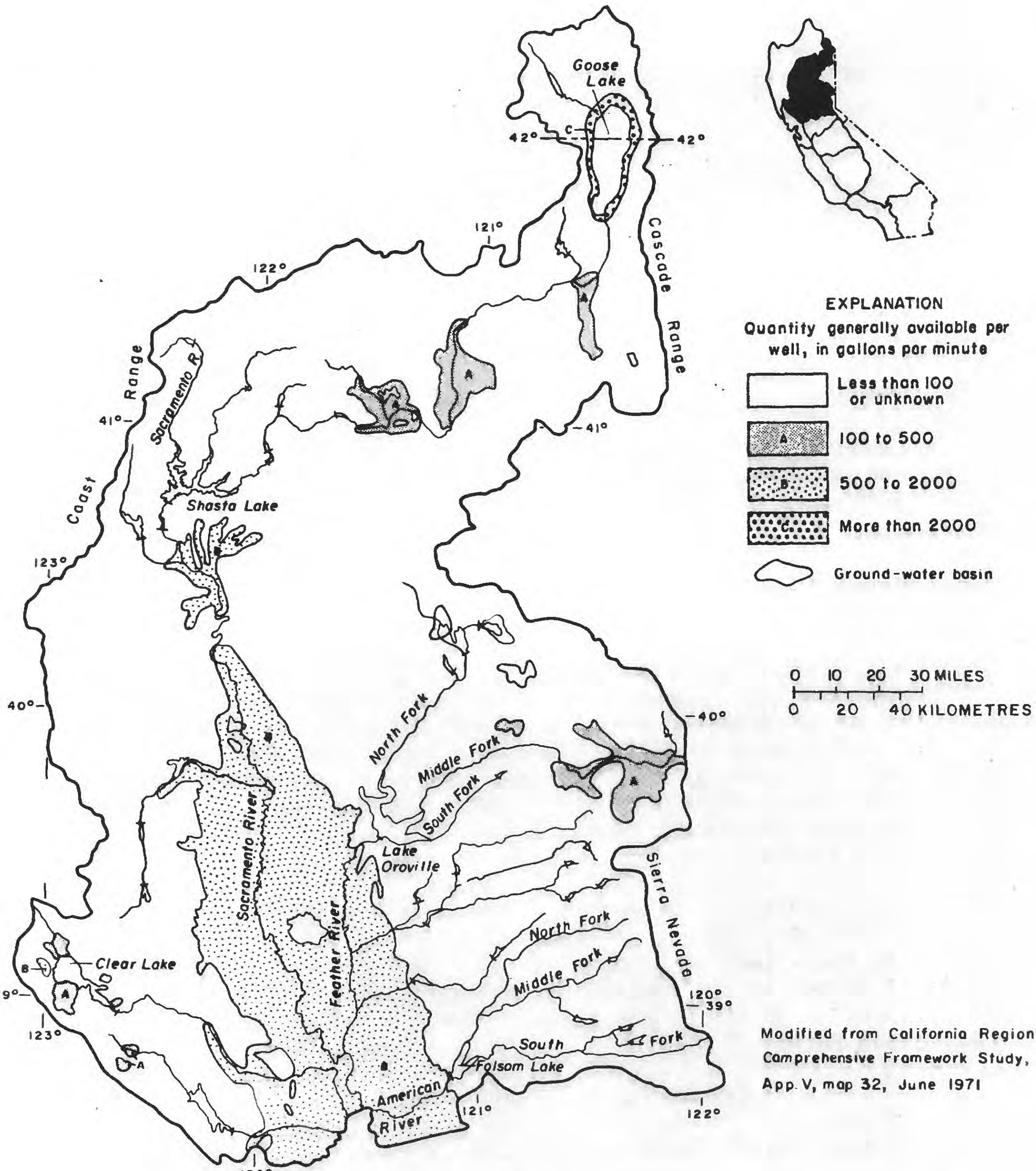


Figure 19. - General availability of ground water in the Sacramento Basin subregion.

the northeast (fig. 19). The subregion lies between the Coast Range on the west and the Cascade and Sierra Nevada Ranges on the east. About 34 percent of the subregion consists of valleys, the largest of which is the broad Sacramento River valley in the south central part. Elevations range from near sea level to more than 10,000 feet on the highest peaks along the east side.

Average annual precipitation ranges from 8 inches in one valley of the northeast to 90 inches on some of the high slopes of the Sierra Nevada. Maximum precipitation is in January; the minimum is in July and August. Most of the moisture falls as rain at lower elevations and as snow at higher elevations.

The yield of surface water within the subregion averages 21 million acre-feet per year. An additional 1.0 million acre-feet per year is imported from adjacent subregions (table 5). Streamflow is derived from rain at lower elevations, from snowmelt at higher elevations, and from ground-water discharge. The base flow (ground-water discharge) in the Cascade Range and associated lava plateau is better sustained than anywhere in the California Region, because of extensive, highly fractured volcanic rocks. At lower elevations, maximum streamflow coincides with maximum precipitation, and minimum flow coincides with minimum precipitation. At high elevations, maximum flow coincides with the maximum rate of snowmelt (June), and the minimum flow is ground-water outflow occurring after the disappearance of the mountain snowpack (September and October). At intermediate elevations, runoff increases as winter precipitation increases, remains high until the snowmelt period is past, and declines rapidly thereafter.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 10.7 million acre-feet (table 5). Evaporation from reservoirs averages 310,000 acre-feet per year.

The chemical quality of waters in the Sacramento River and its tributaries generally is excellent upstream from Shasta Lake. Below that point, the quality deteriorates downstream to some extent, because of successive withdrawals and returns of water, but the quality of the water is still fairly good where it leaves the subregion. The concentrations of dissolved solids is not known.

Withdrawal of surface water for consumptive uses is 4.13 million acre-feet per year, but only 2.31 million acre-feet per year is actually consumed. The largest use is for irrigation (4.00 million acre-feet per year); the second largest use is for public supplies (117,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in intermontane valleys and volcanic rocks. These aquifers generally yield 100 to more than 1,000 gpm of water to individual wells. The aquifers in some of the ground-water basins yield less than 100 gpm to wells or the average yield has not been determined (fig. 19).

The maximum depth to water in the principal aquifers is a little more than 300 feet below land surface. Flowing wells are common in some of the basins.

The concentration of dissolved solids in ground water from the principal aquifers generally is less than 500 mg/l. Locally, the concentration may exceed 2,700 mg/l.

The quantity of ground water stored in the upper 200 feet below land surface is more than 22 million acre-feet, which is 2 times the storage capacity of all the surface reservoirs (table 5). The largest part of the ground water is stored in the Sacramento Valley. (fig. 19).

The amount of ground water withdrawn in 1970 for consumptive uses was 4.26 million acre-feet, of which 2.40 million acre-feet was consumed (table 6). The largest use was for irrigation (4.0 million acre-feet); the second largest use was for public supplies (175,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) a need for more flood control on some tributaries to the Sacramento River; and (2) a need to optimize recreation potentials at Central Valley Project control structures.

Overall, the water supply in the subregion is more than adequate for needs within the subregion, and 18.6 million acre-feet per year flows out of the subregion, mostly as controlled flow for use in other subregions.

Consideration should be given to diverting part of the flood flows on tributary streams to artificial recharge facilities. After a time lag, ground-water discharge to streams, as a result of artificial recharge, would increase, tending to provide a more uniform flow in the streams.

Even though ground-water withdrawals in the subregion are large (4.26 million acre-feet in 1970), the withdrawals are not creating serious problems, except locally. A potential exists for additional use of ground water for new developments.

The Goose Lake area, a topographically closed basin in the northeastern part of the subregion, contains an extensive aquifer capable of yielding more than 1,000 gpm of water to wells (fig. 19). This area has not been adequately studied, but it appears to offer opportunity for additional development. The area possibly would be suitable for thermal power generation sites.

This subregion contains small areas designated by the U.S. Geological Survey as "known geothermal resources areas" and large areas designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies are needed in areas containing extensive aquifers (fig. 19), where such studies have not been completed. Additional information is needed to determine the possibility of developing large supplies of ground water in the Goose Lake area for new developments, such as thermal power plants.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

Delta-Central Sierra Subregion

The delta-central Sierra subregion includes the drainage of the lower part of the Sacramento River and its tributaries and the lower part of the San Joaquin River and its tributaries (fig. 20). The western half of the subregion is a broad valley area; the eastern half is mountainous. Elevations range from sea level on the west to 10,000 feet on the highest mountains on the east.

Average annual precipitation ranges from 10 inches on the valley floor to 70 inches on the high mountains. Average precipitation for the entire subregion is about 25 inches. Maximum precipitation is in January; the minimum is in July and August. Most of the moisture falls as rain at lower elevations and as snow at higher elevations.

The yield of surface water within the region averages 1.08 million acre-feet per year. An additional 21.2 million acre-feet per year flows into this subregion from adjacent subregions (table 5). Most of the streamflow at higher elevations (above 5000 feet) is derived from snowmelt, and most of the flow below 5000 feet is derived from rainstorms and ground-water discharge. The discharge of streams originating in the mountains increases sharply from early December to a peak in March; then decreases sharply in April, May, and June to a minimum in September. The discharge of streams originating at lower

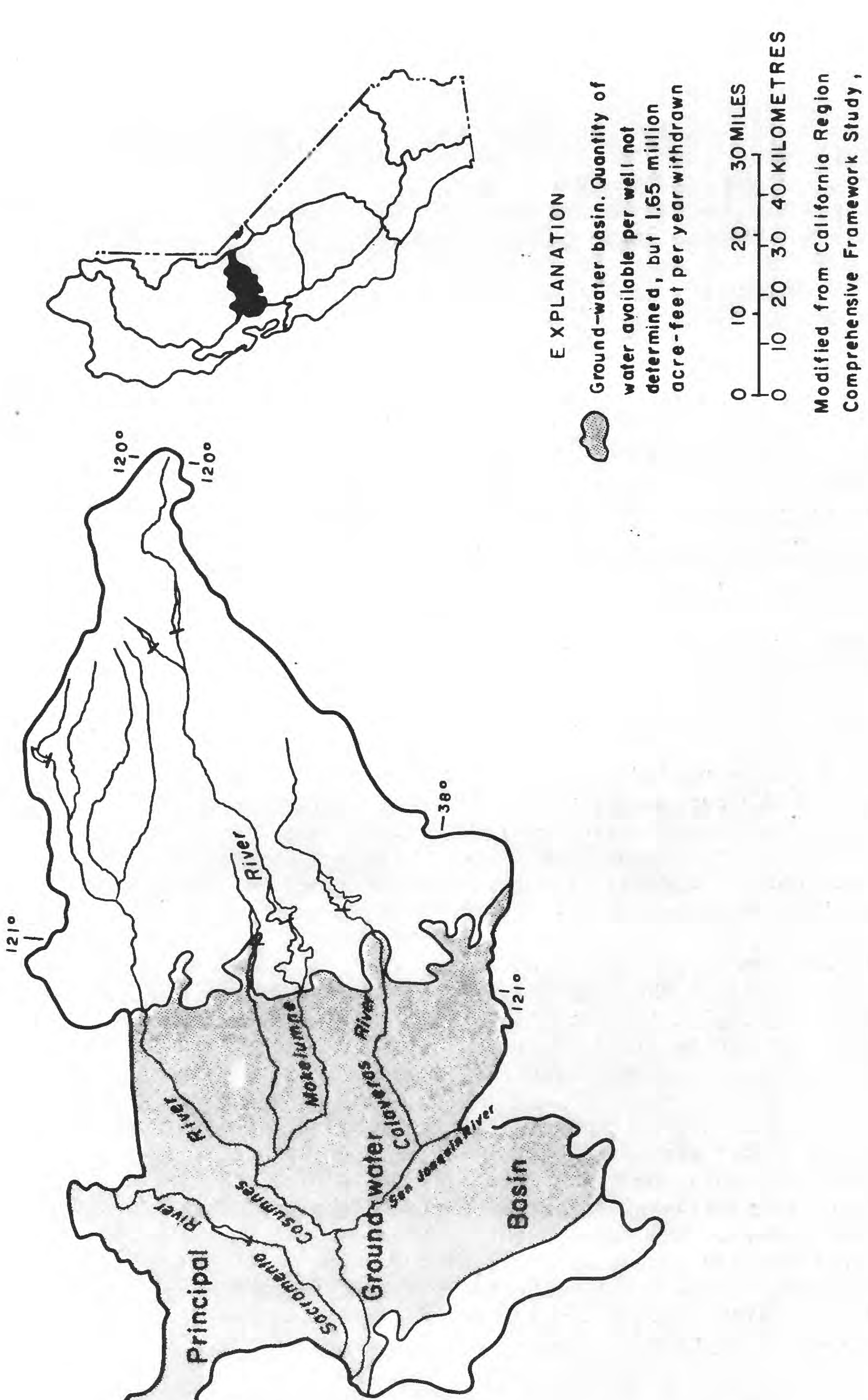


Figure 20. - General availability of ground water in the Delta-Central Sierra subregion.

elevations directly reflect the seasonal variations in precipitation, with maximum flow in January.

Surface reservoirs for regulation of streamflow in the subregion have a combined capacity of 1.5 million acre-feet (table 5). Evaporation from the reservoirs averages 60,000 acre-feet per year.

The concentration of dissolved solids in waters of the streams is unknown. The chemical quality of surface water is as follows: (1) the chemical quality of the San Joaquin River is fair to poor, (2) that of the Sacramento River is good, and (3) that of the Sierra Nevada streams is generally excellent. The chemical quality of water in the lower delta areas is influenced by return flow water of poor quality and incursions of saline water from the bay.

The amount of surface water withdrawn for consumptive uses in the subregion averages 1.52 million acre-feet per year, but only 854,000 acre-feet per year is actually consumed. The largest use is for irrigation (1.49 million acre-feet per year); the second largest use is for self-supplied industries (18,200 acre-feet per year).

The principal aquifers are unconsolidated sediments in the northern part of a single aquifer system extending into the San Joaquin and Tulare valleys. The yield of wells in this aquifer system is not known.

The depth to water in the principal aquifers is not known. However, the maximum measured depth to water in the overall aquifer system is 842 feet and the minimum depth is 2 feet.

The concentration of dissolved solids in ground water of the overall aquifer system ranges from 64 to 10,700 mg/l.

The quantity of ground water in storage in the upper 200 feet of the aquifer system is 80,000 acre-feet (table 5).

The amount of ground water withdrawn in 1970 for consumptive uses was 1.65 million acre-feet, of which 930,000 acre-feet was actually consumed. The largest use was for irrigation (1.49 million acre-feet); the second largest use was for public supplies (82,000 acre-feet) (table 6).

Water-resources problems that are identified by the Westwide study group include: (1) a need for additional flood control; (2) a need to optimize recreation potentials at Central Valley Project control structures; (3) a need to increase low summer flows in streams;

(4) a need to release adequate flows of fresh water from the Central Valley Project system for salinity control on the delta.

The only alternatives in ground-water management that might be considered would be use of flood water for artificial recharge of ground water. The recharge water would return to the streams eventually, or it could be withdrawn by pumping as needed. Additional recharge in some areas would increase the flow of streams in summer.

Quantitative hydrologic studies of the principal ground-water basin are needed (fig. 20), where such studies have not been completed. The final phase of such studies needs to include development of an analog or a digital model of the entire ground-water basin, in this and the San Joaquin and Tulare subregions, and analysis of the entire hydrologic system to evaluate the interactions of the many components of this complex system.

San Joaquin Basin Subregion

The San Joaquin basin subregion lies between the crest of the Coast Range on the west and the Sierra Nevada on the east. It borders the delta-central Sierra subregion on the north and the Tulare Basin subregion on the south (fig. 21). The San Joaquin River flows northwestward in a broad alluvial valley. Elevations range from a few feet above sea level to more than 14,000 feet above sea level in the highest part of the Sierra Nevada.

Average annual precipitation ranges from 8 inches on the lower part of the valley floor to 80 inches on the highest mountains in the southeast part. The average for the entire subregion is about 28 inches. Maximum precipitation is in January; the minimum is in August. Most of the moisture falls as rain at elevations below 5000 feet and as snow above that elevation.

The yield of surface water is 6.06 million acre-feet per year. An additional 180,000 acre-feet per year flows into the subregion (table 5). Most of the streamflow is derived from snowmelt at elevations above 5000 feet and from rain below that elevation. Maximum runoff in Sierra Nevada streams is in May and the minimum is in October. In the Coast Range, maximum runoff is in February and the minimum is June to October, when most of the streams are dry.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 3.0 million acre-feet (table 5). Evaporation from the reservoirs averages 140,000 acre-feet per year.

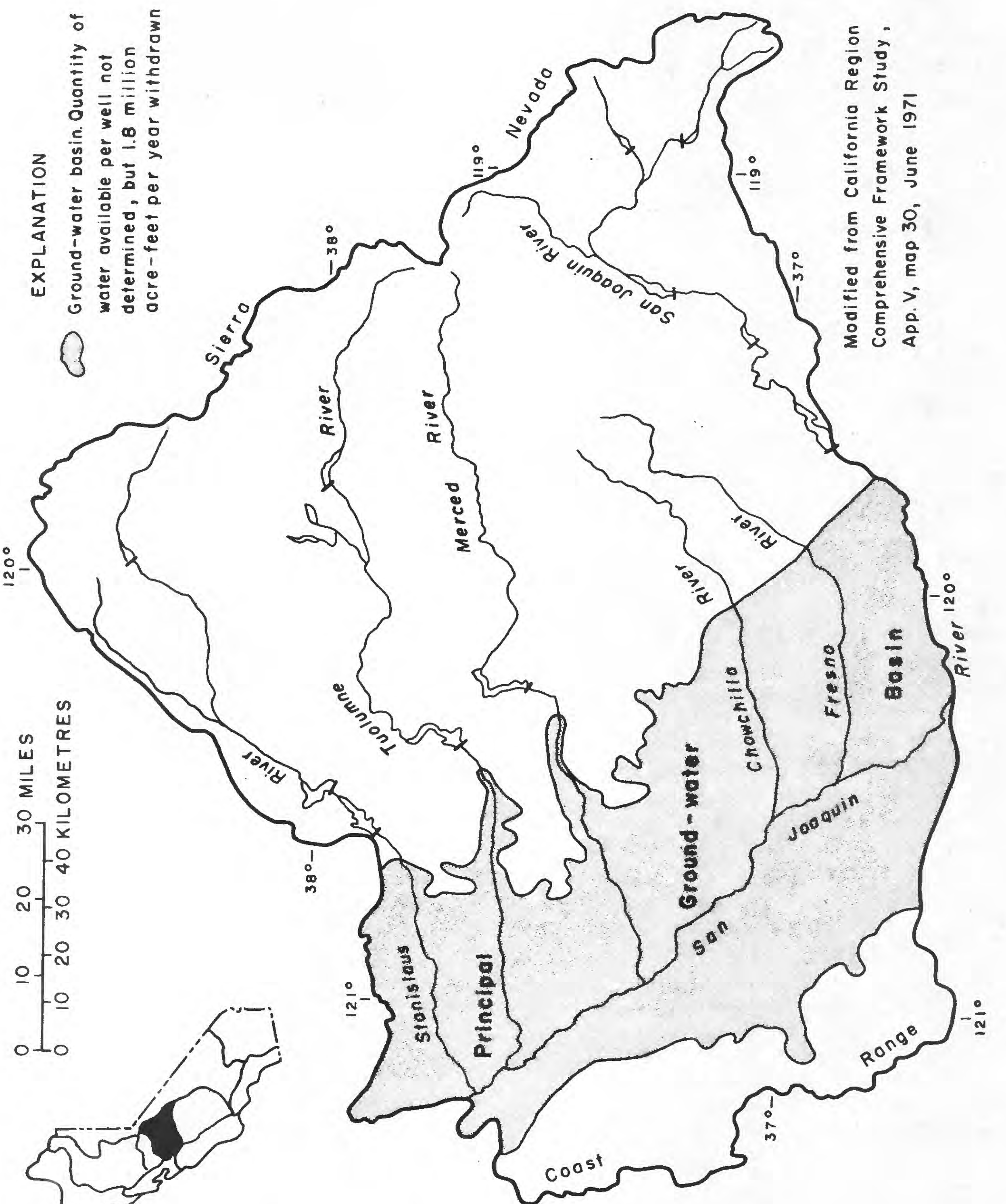


Figure 21. - General availability of ground water in the San Joaquin subregion.

The chemical quality of water in streams fed by snowmelt is excellent, until the streams reach the valley floor and start receiving waste water from towns and irrigated fields. Streams originating at lower elevations in the Sierra Nevada and the Coast Range contain higher concentrations of dissolved solids than the high mountain streams.

Withdrawal of surface water for consumptive uses averages about 2.80 million acre-feet per year, but only 1.57 million acre-feet per year is actually consumed. The largest use is for irrigation (2.78 million acre-feet per year). The second largest use is for public supplies (11,000 acre-feet).

The principal ground-water basin or reservoir in the San Joaquin basin subregion is continuous with that in the delta-central Sierra subregion (figs. 20 and 21) and was described in that section of the report.

The amount of ground water withdrawn in 1970 for consumptive uses was 2.96 million acre-feet, of which 1.67 million acre-feet was consumed. The largest use was for irrigation (2.78 million acre-feet); the second largest use was for public supplies (100,000 acre-feet).

Water-resources problems identified by the Westwide study group include: (1) a need for additional flood control on some streams; (2) a need to optimize recreation potentials at Central Valley Project control structures; (3) a need to increase low summer flows in streams; and (4) a need to release adequate flows of fresh water from the Central Valley Project system for salinity control.

Overall, the water supply in the subregion is more than adequate to meet the present demands (table 5). However, ground-water withdrawals exceed ground-water recharge by about 150,000 acre-feet per year. Part of this ground-water deficit probably could be reduced by diversion of part of presently uncontrolled flood flow to artificial recharge facilities. This procedure would also alleviate some of the danger of floods. In some areas, an increase in ground-water recharge would also result in higher flows in streams during summer. Withdrawal of ground water in the subregion in 1970 was 2.96 million acre-feet, which demonstrates that aquifers in the principal ground-water basin are recharged readily from surface-water sources.

Quantitative hydrologic studies are needed in the area containing the principal ground-water basin (fig. 21), where such studies have not been completed. The final phase of such studies need to include development of an analog or a digital model of the entire ground-water basin, in this and the delta-central Sierra and Tulare basin subregions, and analysis of the entire hydrologic system to evaluate the interactions of the many components of this complex system.

Tulare Basin Subregion

The Tulare basin is virtually a topographically closed basin, lying between the Coast Range on the west and south and the Sierra Nevada on the south and east (fig.22). Elevations range from a little less than 300 feet above sea level in the lower parts of the valley area to 14,496 feet on the highest peaks in the Sierra Nevada.

Average annual precipitation ranges from 5 inches on the valley floor near the south end of the subregion to 60 inches in the high mountains of the northeast part. The average for the entire subregion is about 15 inches.

Maximum precipitation is in January and February; the minimum is in July and August. Most of the moisture falls as rain at elevations below 5000 feet and as snow above 5000 feet.

The yield of surface water is 3.13 million acre-feet per year. An additional 1.33 million acre-feet is imported from other subregions (table 5). Most of the flow of streams in the Sierra Nevada is derived from snowmelt, and maximum runoff is in May. The minimum flow is in September. Streams in the Coast Range derive most of their flow from rain, and maximum runoff is in March. These streams do not flow during part of the year. The streams from both sides of the basin lose water by infiltration into the ground, where they leave the mountains and traverse the alluvial fans.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 1.8 million acre-feet (table 5). Evaporation from the reservoirs averages 90,000 acre-feet per year.

The chemical quality of water in streams that drain the Sierra Nevada is of excellent quality, and even in the lower reaches of the rivers, the quality is not seriously affected by man's activities. The chemical quality of water in the small, intermittent streams that drain the Coast Range generally is poor.

Withdrawal of surface water for consumptive uses in the subregion averages about 5.86 million acre-feet per year, but only 3.28 million acre-feet per year is actually consumed. The largest use is for irrigation (5.82 million acre-feet per year); the second largest use is for public supplies (26,400 acre-feet per year).

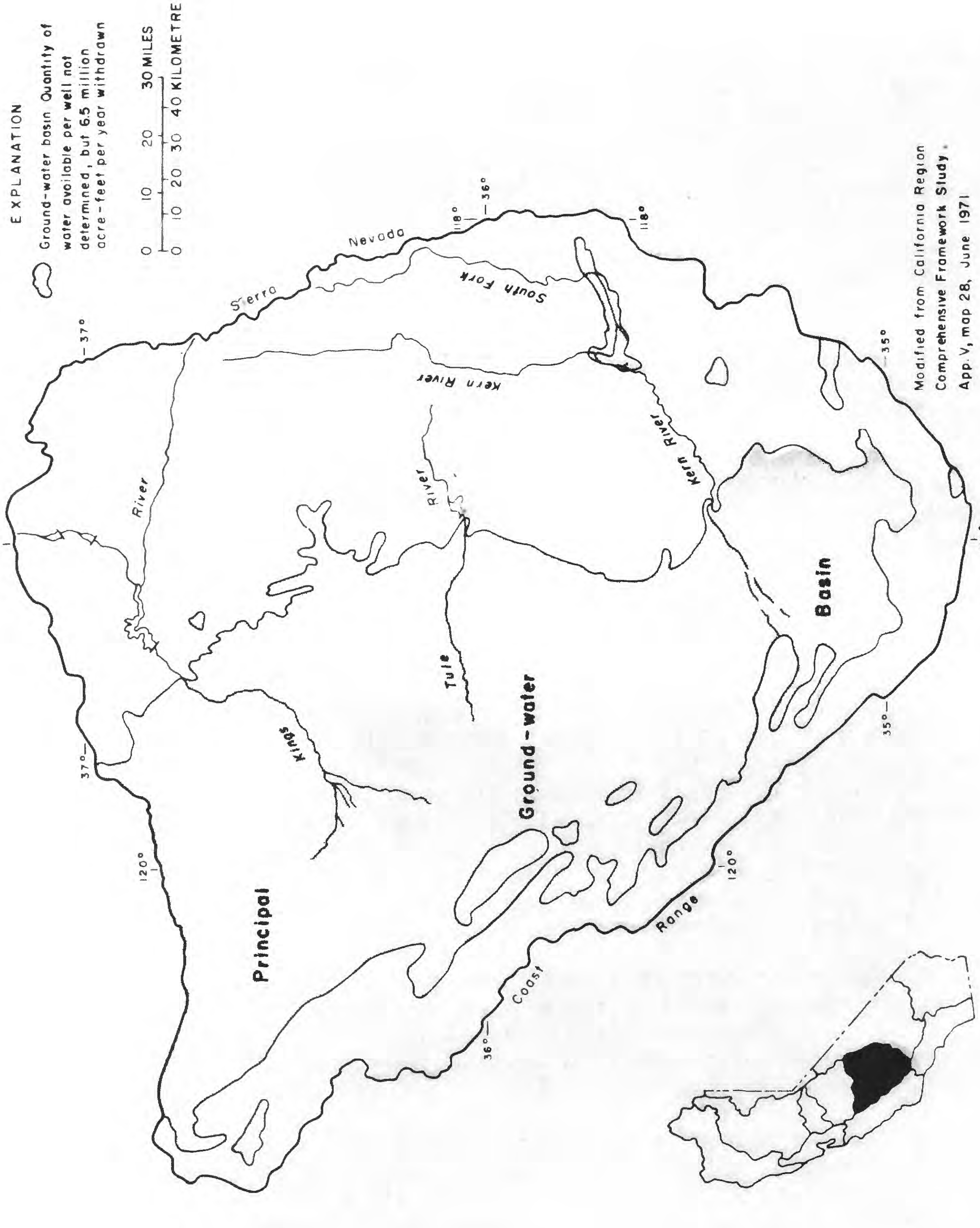


Figure 22. - General availability of ground water in the Tulare Basin subregion.

The principal ground-water basin is continuous with that in the delta-central Sierra and San Joaquin subregions (figs. 20 to 22), and it was described in the section of the report on the delta-central Sierra subregion.

The amount of ground water withdrawn in 1970 for consumptive uses was 6.12 million acre-feet, of which 3.45 million acre-feet was actually consumed. The largest use was for irrigation (5.82 million acre-feet); the second largest use was for public supplies (239,000 acre-feet) (table 6).

The only water-resource problem identified by the Westwide study group is a need for additional flood control in the San Joaquin River Valley. However, the Westwide State report for California indicates that ground-water depletions exceed ground-water recharge in the subregion by 1.80 million acre-feet per year.

Plans for flood control in the subregion should consider the possibility of diverting part of the flood flows to artificial recharge facilities. The aquifers in the principal ground-water basin accept recharge readily. This procedure could eliminate part of the ground-water deficit and alleviate part of the flood danger at the same time.

Quantitative hydrologic studies are needed in the area containing the principal ground-water basin (fig. 22), where such studies have not been completed. The final phase of such studies need to include development of an analog or a digital model of the entire ground-water basin, in this and the delta-central Sierra and San Joaquin subregions, and analysis of the entire hydrologic system to evaluate the interactions of the many components of this complex system.

North Lahontan Subregion

The north Lahontan subregion is an area of internal drainage, lying east of the drainage basins of the San Joaquin and Sacramento Rivers and Goose Lake and north of Mono Lake basin (fig. 23). Most of the subregion is mountainous, but contains a few large valleys. Elevations of most of the subregion are between 4000 and 6500 feet.

Average annual precipitation ranges from 4 inches along parts of the Nevada border to 70 inches along the crest of the Sierra Nevada; the average for the subregion is 22 inches. Maximum precipitation is in January; the minimum is in July and August. Most of the moisture falls as snow on the higher mountain slopes.

The yield of surface water averages 1.54 million acre-feet per year; an additional 11,000 acre-feet per year flows into the subregion

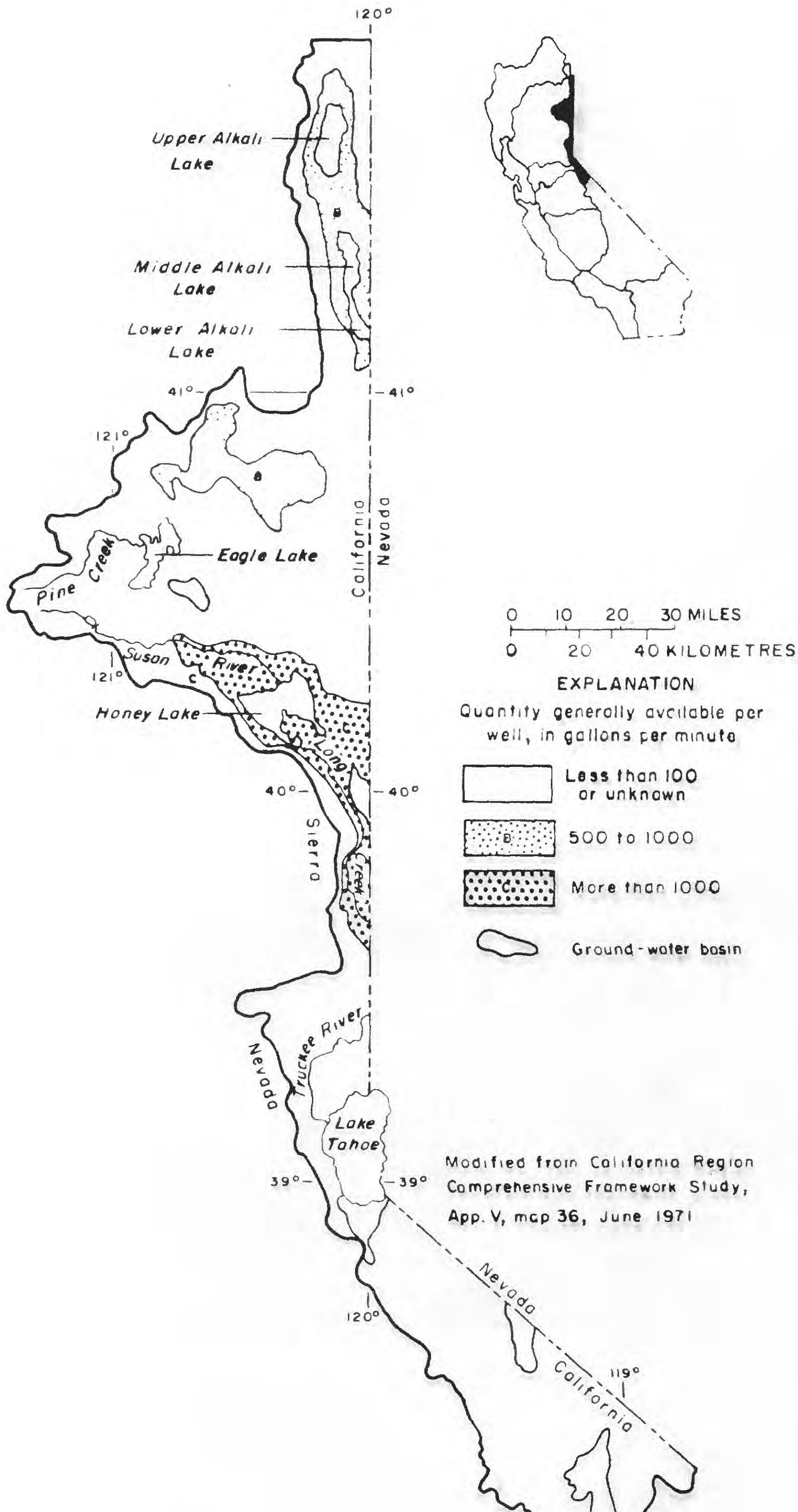


Figure 23. - General availability of ground water in the North Lahontan subregion.

(table 5). Most of the streamflow is derived from snowmelt, and the maximum discharge of streams is from April to June, depending on the elevation of the watershed. Minimum flow is in October.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 1.40 million acre-feet (table 5). Evaporation from the reservoirs averages 20,000 acre-feet per year.

The concentration of dissolved solids in the streamflow derived from snowmelt was reported as "low" in the Comprehensive Framework Study.

Withdrawal of surface water for consumptive uses averages about 110,000 acre-feet per year, but only 61,500 acre-feet per year is actually consumed. The largest use is for irrigation (107,000 acre-feet per year); the second largest use is for public supplies (2,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in the larger valleys. These aquifers generally yield 500 to more than 1,000 gpm of water to individual wells (fig. 23). The most productive and widespread aquifer is in Honey Lake valley, where the average yield of wells is about 1,150 gpm.

The maximum measured depth to water in the principal aquifers is 192 feet; the depth generally is less than 75 feet. Some flowing wells have been reported.

The concentration of dissolved solids in the ground water ranges from 64 to 2,030 mg/1, and much of the water contains less than 200 mg/1 dissolved solids.

The quantity of ground water stored in the principal aquifers has not been determined.

The amount of ground water withdrawn in 1970 for consumptive uses was only 10,000 acre-feet, of which 6,000 acre-feet was actually consumed (table 6).

The Westwide study group did not identify specific water-resources problems. For the most part, the subregion is sparsely populated, and water resources have not been extensively developed. The yield of surface water (1.54 million acre-feet per year) is more than adequate to meet present demands in the subregion, and 1.13 million acre-feet of water per year flows naturally or is exported into other subregions (table 5).

Extensive aquifers capable of yielding 500 to more than 1,000 gpm of water to wells are present in the vicinity of Alkali Lakes and Honey Lake, which are in topographically closed basins. The quantity of ground water stored in the subregion has not been adequately defined, but it probably is several million acre-feet. In 1970, only 10,000 acre-feet of ground water was withdrawn for consumptive uses (table 6).

A potential for extensive new developments based on ground-water supplies exists in the subregion. The combination of large ground-water supplies and sparse population suggest that parts of the subregion would be suitable for siting of thermal power plants.

Small areas in the subregion have been designated by the U.S. Geological Survey as "known geothermal resources areas" and much larger areas have been designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies need to be made in the areas containing the principal aquifers (fig. 23). Additional information is needed to determine possible effects on the lakes and possible changes in chemical quality of the ground water, if heavy pumping was initiated.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

South Lahontan Subregion

The south Lahontan subregion lies east of the San Joaquin basin, Tulare basin, and south coastal subregions (fig. 24). The subregion is characterized by high mountains and intermontane valleys. All drainage is internal, either within the subregion or in Nevada. Elevations range from 282 feet below sea level in Death Valley (the lowest point in the United States) to more than 11,000 feet above sea level on some of the mountain peaks.

Average annual precipitation ranges from 2 inches on the valley floors in the southeastern part to 50 inches along the crest of the Sierra Nevada. The average for the subregion is about 8 inches per year. Most of the moisture falls as snow on the higher mountains. Maximum precipitation is in December and January; the minimum is in June and July.

The yield of surface water is 1.2 million acre-feet per year (table 5). Most of the streamflow is derived from snowmelt, and maximum discharge

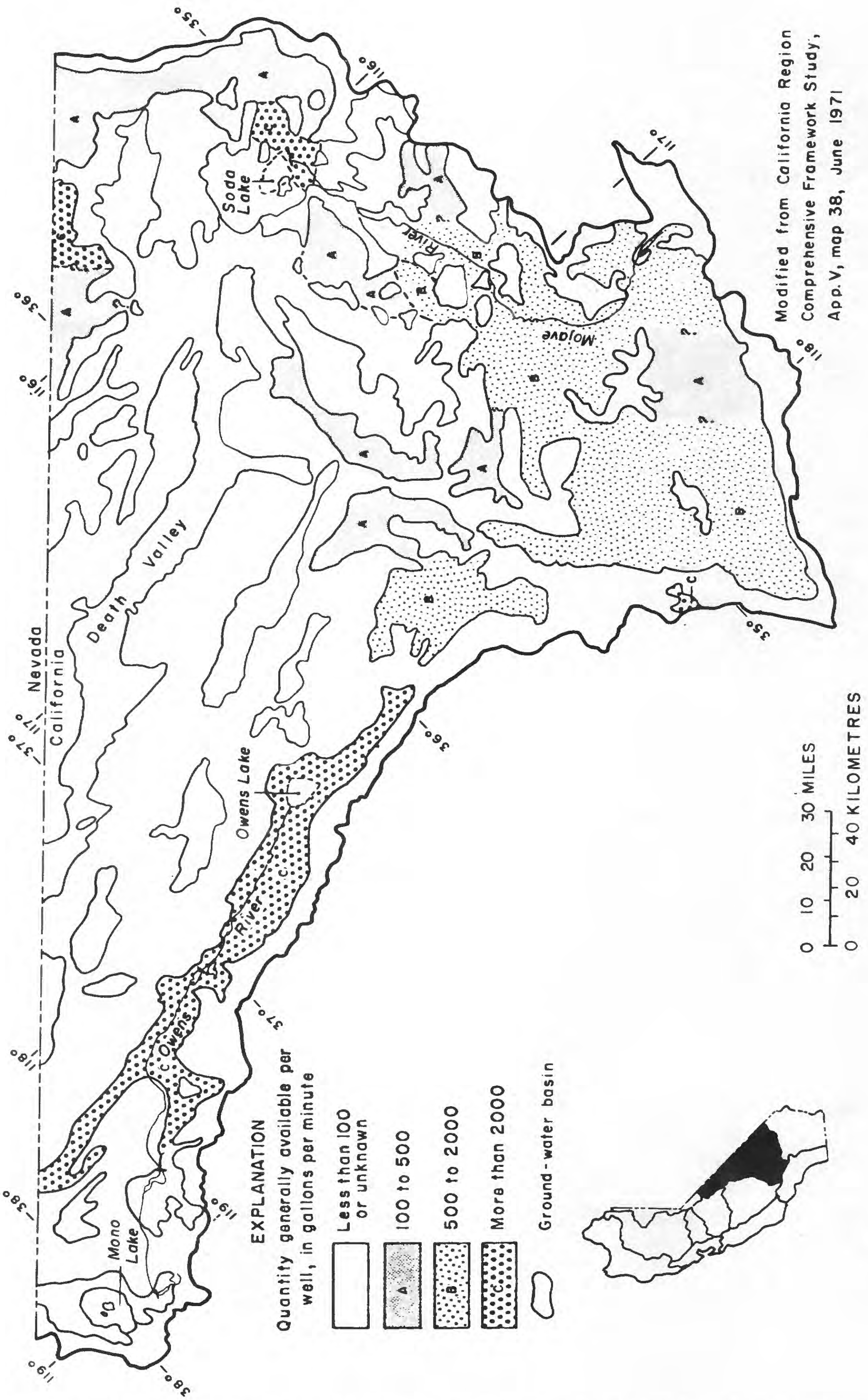


Figure 24. - General availability of ground water in the South Lahontan subregion.

is in March or June, depending on location within the subregion. The minimum flow is in October.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 410,000 acre-feet (table 5). Evaporation from the reservoirs averages 20,000 acre-feet per year.

The concentration of dissolved solids in streams was not reported in the Comprehensive Framework Study, only that the water generally is excellent in quality.

The quantity of surface water withdrawn for consumptive uses averages 70,500 acre-feet per year, but only 39,500 acre-feet per year is actually consumed. The largest use is for irrigation (62,900 acre-feet per year); the second largest use is for public supplies (4,000 acre-feet per year). Most of the flow of the Owens River is exported from the subregion by aqueduct to Los Angeles for public supplies.

The principal aquifers are unconsolidated sediments in the intermontane valleys. These aquifers generally yield 100 to more than 1,000 gpm of water to individual wells in the larger valleys (fig. 24). The most productive aquifer is in the Owens River valley, where ground water commonly is pumped into the Los Angeles aqueduct to supplement the supply of surface water.

The maximum measured depth to water is 975 feet below land surface; the maximum depth in Owens Valley is 127 feet, and some wells flow.

The concentration of dissolved solids in the ground water varies widely, ranging from less than 100 to more than 400,000 mg/l. In Owens Valley, the range is 100 to 400 mg/l.

The quantity of ground water stored in the principal aquifers has not been determined.

The amount of ground water withdrawn in 1970 for consumptive uses was 647,000 acre-feet, of which 365,000 acre-feet was actually consumed (table 6). The largest use was for irrigation (570,000 acre-feet); the second largest use was for public supplies (54,000 acre-feet).

The Westwide study group did not identify specific water-resources problems. Most of the subregion is sparsely populated, so ground-water withdrawal is concentrated in a few relatively small areas. Total withdrawal in 1970 was 647,000 acre-feet (table 5), which is about 300,000 acre-feet more than ground-water recharge.

Extensive aquifers in the vicinity of Soda Lake, capable of yielding 100 to more than 1,000 gpm of water to wells (fig. 24), contain water of inferior chemical quality. This water probably could be used for cooling at thermal power plants

The water of inferior quality could be used, alternatively, as a source of feed water for desalting plants, which would make the water acceptable for most uses. However, a demand for desalted water does not exist in the area at present.

A large area in the subregion has been designated by the U.S. Geological Survey as "known geothermal resources areas" and an even larger area has been designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies are needed in all the areas containing extensive aquifers (fig. 24), where such studies have not been completed. These studies need to include the areas containing water of inferior quality, as well as those containing fresh water.

Possibilities of additional artificial recharge in the heavily pumped areas are worthy of additional study. Some storm runoff possibly could be detained at artificial recharge facilities, rather than letting it flow to playas, where it evaporates.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

Colorado Desert Subregion

The Colorado Desert subregion occupies the southeastern part of California. Part of the subregion is tributary to the Colorado River; the remainder has internal drainage (fig. 25). The dominant feature of the subregion is the Colorado River, which forms the eastern boundary. Elevations range from 274 feet below sea level in the Salton Sea to more than 8000 feet in the mountains. The subregion is characterized by broad desert valleys and scattered mountain ranges.

Average annual precipitation ranges from less than 3 inches on much of the desert floor to 40 inches in the mountains. The average for the subregion is 5.5 inches per year. Maximum precipitation is in January; the minimum is in May and June. Most of the moisture falls as rain on the desert and as snow on the higher mountains.

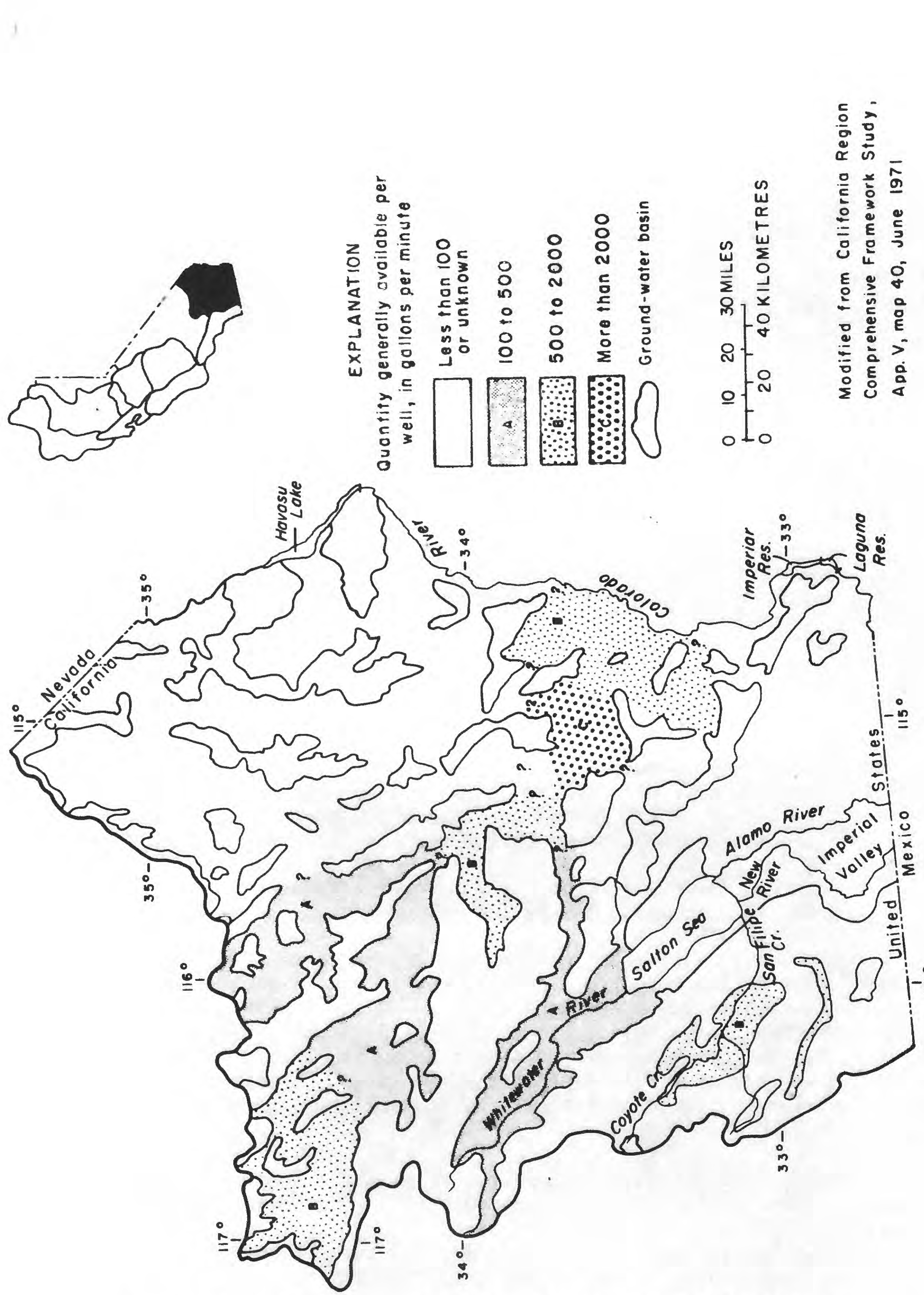


Figure 25. - General availability of ground water in the Colorado Desert subregion.

The yield of surface water averages 112,000 acre-feet per year. An additional 3.6 million acre-feet per year is imported from the Colorado River. Most of the runoff is derived from snowmelt and winter rains in the mountains. Maximum runoff is in March or April, depending on location within the subregion. Surface reservoirs for regulation of streamflow have not been constructed.

The concentration of dissolved solids in water imported from the Colorado River averages about 900 mg/l. Water derived from snowmelt in the mountains is good. Waste water from irrigation contains 2,000 to 4,000 mg/l dissolved solids where it enters the Salton Sea. The concentration of dissolved solids in the Salton Sea increased from about 34,000 to about 36,000 mg/l from 1965 to 1969, due to concentration of salts by evaporation of water.

The quantity of surface water withdrawn for consumptive uses averages about 3.84 million acre-feet per year, and 2.15 million acre-feet per year is actually consumed. The largest use is for irrigation (3.80 million acre-feet per year); the second largest use is for public supplies (26,100 acre-feet per year).

The principal aquifers are unconsolidated sediments in the broad valleys. These aquifers commonly yield 100 to more than 1,000 gpm of water to individual wells (fig. 25). The yield of wells has not been determined for much of the valley areas.

The maximum measured depth to water in the principal aquifers is 644 feet. The depth generally is less than 300 feet, and flowing wells have been reported in some areas.

The concentration of dissolved solids in the ground water ranges from less than 100 to more than 300,000 mg/l. In some valleys, none of the water contains less than 1,000 mg/l dissolved solids.

The quantity of ground water stored has been determined for only one valley, which contains 3.6 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 342,000 acre-feet, of which 193,000 acre-feet was consumed. The largest use is for irrigation (300,000 acre-feet); the second largest use was for public supplies (26,000 acre-feet) (table 6).

The only water-resource problem that was identified by the Westwide study group was increasing salinity of water in the Colorado River, the source of much of the water supply for the subregion.

Because the yield of surface water is small (112,000 acre-feet per year), almost all the present water demands are met by imports (3.60 million acre-feet per year) and pumping of ground water (342,000 acre-feet in 1970).

In some valleys, extensive aquifers capable of yielding more than 100 gpm of water to wells (fig. 25) contain water of inferior chemical quality. These aquifers, which are in sparsely populated areas, possibly could be used as sources of cooling water for thermal power plants.

Imperial Valley contains five tracts designated by the U.S. Geological Survey (Godwin, 1971) as "known geothermal resources areas" and large tracts designated as "areas valuable prospectively."

Quantitative hydrologic studies are needed in areas containing extensive, productive aquifers (fig. 25), where such studies have not been completed. These studies need to include the areas containing water of inferior quality, as well as those containing fresh water.

Possibilities of additional artificial recharge in the heavily pumped areas are worthy of additional study. Some storm runoff possibly could be intercepted and diverted to recharge facilities before it reaches playas, where it would evaporate.

Exploring of the geothermal areas is needed to evaluate the potential for developing geothermal energy. These studies would include detailed mapping and analysis of the hydrologic system and the temperature anomalies. Several private companies and the U.S. Bureau of Reclamation have made preliminary studies of Imperial Valley, including some test drilling, and the Bureau of Reclamation, in cooperation with the Office of Saline Water, is conducting an experiment in desalting the hot brine available from wells.

Great Basin Region

The Great Basin region occupies a large area of internal drainage in Nevada, Utah, Idaho, and Wyoming (fig. 26). The region is characterized by alternating mountain ranges and valleys (basins). Most of the mountain ranges trend north or northeast, with crests nearly straight or curved. The ranges are 40 to 80 miles long and 5 to 15 miles wide. Through most of the region, the ranges are regularly spaced 15 to 25 miles apart. Typically, the range crests are 3,000 to 5,000 feet above the floors of adjacent valleys. Many of the crests are more than 10,000 feet above sea level in central and eastern Nevada. Elsewhere the altitude of the crests generally is

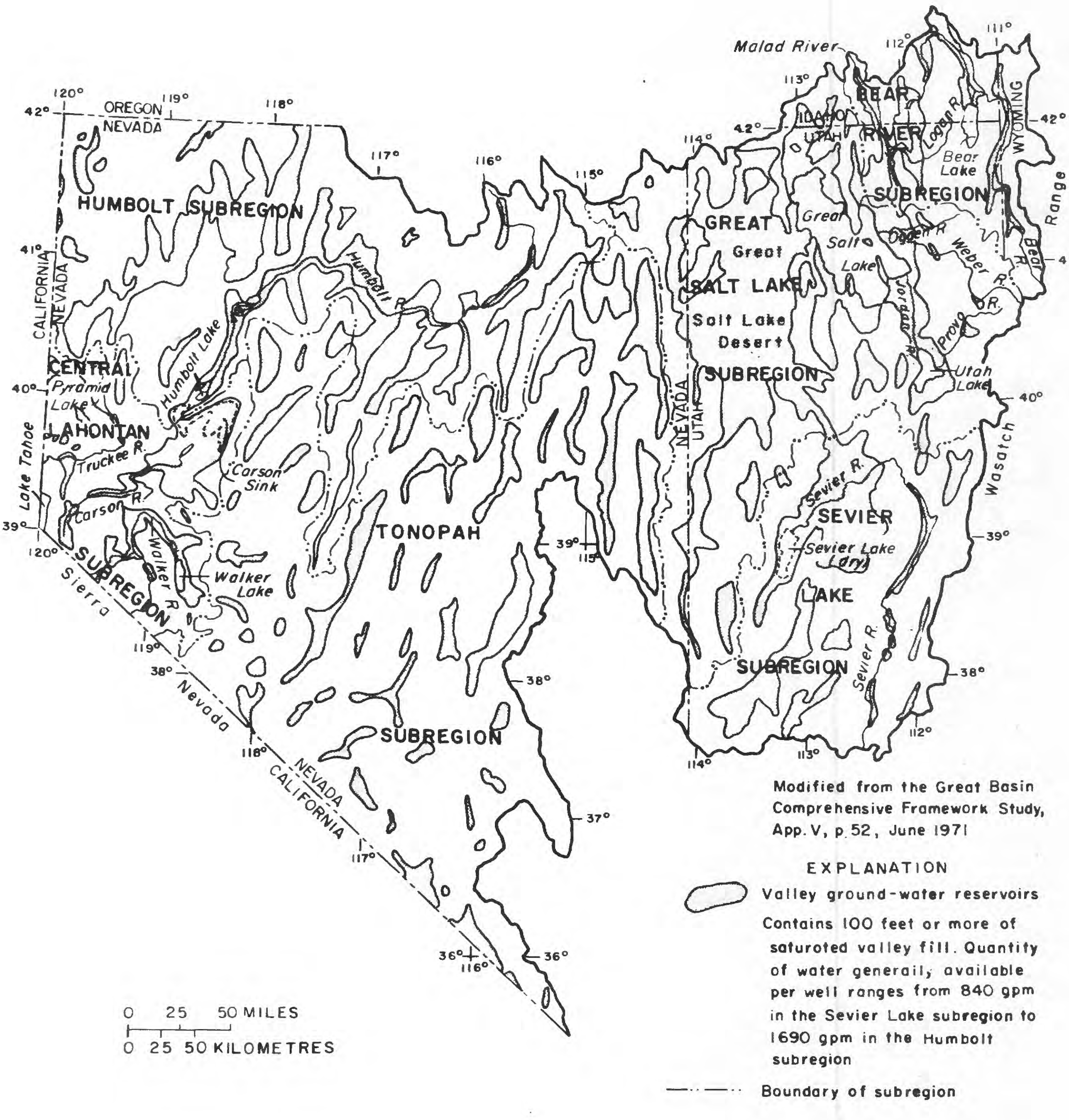


Figure 26. - General availability of ground water in the Great Basin region.

less than 9,000 feet. The valley floors range from 2,100 feet above sea level in southern Nevada to about 7,000 feet in central Nevada.

Average annual precipitation ranges from 4 inches or less in Great Salt Lake Desert, in part of the Humboldt subregion, and in the southern part of the Tonopah subregion to about 60 inches in the higher mountains of the Bear River and Great Salt Lake subregions. The average for the entire region is about 11 inches. In winter the principal source of precipitation is associated with moist air moving across the area from the Pacific Ocean, and most of the winter precipitation is snow. The rate of winter precipitation decreases from north to south. In summer the principal source of moisture is the Gulf of Mexico, resulting in thundershower activity, especially in July and August. The rate of summer precipitation decreases from southeast to northwest.

Bear River Subregion

The Bear River is the principal stream of the Bear River subregion. The surface-water yield of the subregion averages 2.1 million acre-feet per year (table 7). Surface-water inflow to the subregion is an additional 19,000 acre-feet per year. Most of the streamflow is derived from snowmelt, and maximum runoff is usually in June; the minimum is usually in fall or winter. However, low flows are strongly affected by artificial controls.

Lakes and surface reservoirs for regulation of flow have a combined storage capacity of 1.63 million acre-feet, largely in Bear Lake (table 7). Evaporation from the reservoirs averages 167,000 acre-feet per year.

The concentration of dissolved solids in the upper part of the Bear River in Wyoming ranges from 100 to 500 mg/l. The concentration in the Malad River ranges from 1,200 to 4,600 mg/l. Because of inflow of saline water from various sources, the concentration of dissolved solids in the outflow of Bear River to Great Salt Lake ranges from 250 to 3,800 mg/l.

The quantity of surface water withdrawn for consumptive uses averages about 2.37 million acre-feet per year, and 1.14 million acre-feet per year is actually consumed. The largest withdrawal is for irrigation (1.98 million acre-feet per year); the second largest use is for public supplies (40,000 acre-feet per year).

The principal aquifers are unconsolidated sediments and volcanic rocks in the valley areas (fig. 26). These aquifers yield as much

Table 7.--Generalized water budget for the Great Basin region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption: Man's activities (ac-ft per yr) 2/	Consumption: Wet land and phreatophytes (ac-ft per yr)	Consumption: Reservoir evaporation (ac-ft per yr) 3/	Surface water (ac-ft) 4/	Ground water (ac-ft) 5/
Bear River	19	2,100	838	1,200	346	167	1,630	12,000
Great Salt Lake	85	1,900	19	1,340	401	303	1,130	65,000
Sevier Lake	9	910	3	801	237	70	522	25,000
Humbolt	25	850	20	741	335	20	281	43,600
Central Lahontan	1,120	108	0	855	166	63	656	16,100
Tonopah	20	290	0	350	40	1	2	130,000
Totals (rounded)		6,160		5,290	1,520	624	4,220	292,000

1/ Data from comprehensive Framework Report.
2/ Includes consumption of both surface water and ground water.
3/ Does not include evaporation from terminal lakes.
4/ Active storage capacity in 1965, including 1.206 MAF usable storage in Bear Lake and 240,000 ac-ft that is Nevada part of Lake Tahoe.
5/ Upper 100 feet of saturated material.

as 4,650 gpm of water to individual wells, and the average yield is 1,060 gpm per well.

The water table in the principal aquifers is essentially at land surface in the lower parts of the Bear River valley and the depth below land surface to the water table generally increases away from the river in relation to the slope of the land surface.

Ground water in the principal aquifers contains less than 1,000 mg/l dissolved solids in most areas. In a few small areas the ground water contains more than 1,000 mg/l dissolved solids.

The quantity of recoverable ground water in the upper 100 feet of the principal aquifers is 12 million acre-feet (table 7), which is seven times the storage capacity of all surface reservoirs, including Bear Lake. In most areas the principal aquifers are much more than 100 feet thick, and the quantity of recoverable ground water in storage is correspondingly more than 12 million acre-feet.

The amount of ground water withdrawn from the principal aquifers by pumping in 1970 was 134,000 acre-feet, of which 64,000 acre-feet was actually consumed (table 8). The largest use was for irrigation (89,000 acre-feet); the second largest use was for public supplies (35,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) a need for a policy decision on interbasin transfers of water; (2) a need for additional irrigation development; (3) seasonal shortages of water in the Smiths Fork River; and (4) a need for an interstate compact for division of water between Utah, Wyoming, and Idaho.

Overall, the supply of water is more than adequate; 838,000 acre-feet of water per year flows out of the subregion to Great Salt Lake (table 7). Additional water could be stored in either surface or subsurface reservoirs to provide better seasonal distribution of the supply. At the present time, about 12 million acre-feet of ground water is stored in the upper 100 feet of saturated material comprising the principal aquifers. These aquifers could be readily managed for storage of water by providing for artificial recharge during periods of excess surface flow and withdrawing water through wells during low surface flow. In 1970, only 134,000 acre-feet of ground water was withdrawn for consumptive uses (table 8). By using underground storage and conjunctive use of ground water and surface water, considerable new development would be possible.

Table 8.--Estimated use of ground water in 1970 in the Great Basin region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generated	Total	
Bear River	35	3	89	8	0	135	64
Great Salt Lake	105	46	102	57	0	310	148
Sevier Lake	13	12	311	2	0	338	161
Humbolt	7	1	157	4	0	169	81
Central Lahontan	12	5	26	14	4	61	29
Tonapah	5	.8	168	19	0	193	92
Total	177	68	853	103	4	1,205	575

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: USGS Circular 676 (1972)

Quantitative hydrologic studies are needed in areas containing the principal aquifers (fig. 26). Special consideration needs to be given to possible effects of underground storage and removal of ground water on the level of Bear Lake and the possibilities of artificial recharge. Special studies are needed in areas where ground water feeds marshes and subirrigated croplands to evaluate the effects that ground-water development might have on these areas.

Great Salt Lake Subregion

The principal stream systems in the Great Salt Lake subregion are those of the Weber and Jordan Rivers. The surface-water yield is 1.90 million acre-feet per year, and an additional 85,000 acre-feet of water per year is imported, primarily from the Upper Colorado region (table 7). Most of the streamflow is derived from snowmelt, and maximum runoff is in May or June. Minimum runoff is in winter (December to February, depending on location).

Surface reservoirs for regulation of streamflow have a combined storage capacity of 1.13 million acre-feet (table 7). Evaporation from the reservoirs averages 303,000 acre-feet per year.

The concentration of dissolved solids averages 120 mg/l in the upper part of the Weber River and the average concentration in the Jordan River, which originates from Utah Lake, is 1,150 mg/l. The quality of water in all the streams deteriorates downstream, due to return flow and reuse of water. The water in the northern part of Great Salt Lake is saturated with soluble salts.

The amount of surface water withdrawn for consumptive uses averages about 1.93 million acre-feet per year, and 1.19 million acre-feet per year is actually consumed. The largest use is for irrigation (1.73 million acre-feet per year); the second largest use is for public supplies (214,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in the valley areas. These aquifers yield as much as 4,500 gpm to individual wells, and the average yield is about 900 gpm per well (figure 26).

Ground-water levels in the principal aquifers are above or near land surface in the lower parts of most valleys. The depth below land surface to the water table increases away from the low areas in relation to the slope of the land surface.

Most of the water from wells and springs in the subregion contains less than 1,000 mg/l dissolved solids, except in the Great Salt Lake

Desert, the lower reaches of valleys that drain directly to Great Salt Lake, and local areas adjacent to thermal springs, where the concentration of dissolved solids ranges from 1,000 to more than 35,000 mg/l.

The quantity of recoverable ground water in the upper 100 feet of the unconsolidated sediments is 49.9 million acre-feet, which is 44 times the storage capacity of all the surface reservoirs (table 7). In most areas the saturated material is much more than 100 feet thick, and the quantity of ground water in storage is correspondingly more than 49.9 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 310,000 acre-feet, of which 148,000 acre-feet was actually consumed (table 8). The largest use was for public supplies (105,000 acre-feet); the second largest use was for irrigation (102,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) a need for more water for public supplies and industries along the front of the Wasatch Range; (2) a need for a policy decision on interbasin transfers of water; (3) the possibility of using water supply to control urban growth; (4) the effect of water use on inflow to Great Salt Lake; (5) a need for more flood control on the Jordan River; (6) possible use of the Jordan River flood plain for recreation; and (7) potential increase of water supply through weather modifications.

The ground-water resources along the front of the Wasatch Range have not been fully developed. In 1971, ground-water withdrawal in Salt Lake County was 125,000 acre-feet. Electric analog model analyses of the hydrologic system in the county made by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources (Hely, Mower, and Harr, 1971a, b) show that withdrawals from existing withdrawal centers could be increased to 150,000 acre-feet per year with no serious adverse effects. Increasing withdrawals from the same centers to 200,000 acre-feet per year might create a water-quality problem. The practical limit of continuous withdrawals is between 150,000 and 200,000 acre-feet per year (a possible increase of 25,000 to 75,000 acre-feet per year in withdrawals). Planned ground-water development based on proper spacing of pumping centers, efficient well design and construction, and use of artificial recharge could raise the potential increase in withdrawals to 75,000 acre-feet per year or more without serious adverse effects.

A large volume of ground water is available for additional development in the East Shore area of Great Salt Lake. A study by the Bureau of Reclamation and the Geological Survey indicates that subsurface flow to Great Salt Lake from the Weber-Delta area is about 20,000 acre-feet per year. Much of this water could be intercepted by wells in carefully planned ground-water developments.

Considerably more than the 95,000 acre-feet per year of ground water described above would be available along the Wasatch front for a limited time by mining. To what extent artificial recharge would be possible with floodwater in the lower stream reaches has not been evaluated.

Ground-water basins in the western part of the subregion contain saline water in and near the Great Salt Lake Desert and in the lower ends of valleys that drain directly to Great Salt Lake. The saline ground water is unsuitable for most uses without desalting.

The use of ground water and surface water in the subregion needs to be more closely coordinated. Thus, greater benefits would be realized from the total water resources of the subregion. If a more unified approach to water management does not meet the water demands in the future, importation of water or weather modification will be necessary.

It is interesting to note that 43 percent of the water consumed is by evapotranspiration in wetlands and phreatophyte areas and by reservoir evaporation.

Several areas in the subregion have been designated by the U.S. Geological Survey as "areas valuble prospectively."

Quantitative hydrologic studies are needed in the areas containing the principal aquifers (fig. 26), where such studies have not been completed. Special consideration needs to be given to possibilities of increasing the ground-water recharge from flood flows of streams.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

Sevier Lake Subregion

The Sevier River is the principal stream in the subregion. The yield of surface water is 910,000 acre-feet per year; an additional

9,000 acre-feet per year is imported from adjacent subregions (table 7). Most of the streamflow is derived from snowmelt, and maximum runoff is in May; minimum flow is in September.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 522,000 acre-feet (table 7). Evaporation from the reservoirs averages 70,000 acre-feet per year.

The concentration of dissolved solids in water of the upper part of the Sevier River and its tributaries generally is less than 400 mg/l. The concentration increases downstream, due to return flow from irrigation and to inflow of saline ground water. In the lower reaches of the river, the water generally contains 1,000 to 1,500 mg/l dissolved solids.

The amount of surface water withdrawn for consumptive uses averages about 1.06 million acre-feet per year, and 740,000 acre-feet is actually consumed. Virtually all the surface water diverted is used for irrigation.

The principal aquifers are unconsolidated sediments in the valley areas. These aquifers yield as much as 3,500 gpm to individual wells; the average yield is 840 gpm per well (figure 26).

The water table in the principal aquifers is at land surface in the lower parts of most valleys. The depth below land surface to the water table increases away from the low areas in relation to the slope of the land surface.

Most of the ground water in the principal aquifers contains less than 1,000 mg/l dissolved solids. The concentration of dissolved solids in ground water of some small areas is more than 1,000 mg/l.

The quantity of ground water stored in the upper 100 feet of the principal aquifers is 21.7 million acre-feet, which is 41 times the combined storage capacity of all the surface reservoirs in the subregion (table 7). In most areas the aquifers are much more than 100 feet thick, and the quantity of ground water in storage is correspondingly more than 21.7 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 338,000 acre-feet, and 161,000 acre-feet was actually consumed. The largest use was for irrigation (311,000 acre-feet); the second largest use was for public supplies (13,000 acre-feet) (table 8).

Only one water-resource problem was identified by the Westwide study group, and it is general in nature: the need for a policy decision on interbasin transfers of water and whether or not interbasin transfers are needed.

Table 7 shows that water consumption exceeds the yield of surface water and imports in the subregion. About 32 percent of the consumption is evapotranspiration from wetlands and phreatophyte areas (237,000 acre-feet per year) and evaporation from reservoirs (70,000 acre-feet per year).

The perennially available water supply of the subregion could be increased only by additional recovery of water lost to excessive evapotranspiration, importation of water, weather modification, or more efficient use of water. The effective water supply could be increased within specific time limits by ground-water mining. The ground water stored in the upper 100 feet of saturated material in the principal aquifers (21.7 million acre-feet) is adequate to supply all the water consumed by man's activities for 32 years at the 1970 level of development. In the process of extracting this water much of the water lost to excessive evapotranspiration would be recovered. Stated another way, water use could be doubled for more than 32 years by extracting the ground water stored in the upper 100 feet of saturated material.

Some of the ground water, especially in the vicinity of Sevier Lake, is too saline for most uses without desalting. However, the saline water might be usable for some industrial applications.

With improvement in irrigation efficiency and by mining of ground water, costly importation of additional water does not seem necessary for many years, when the economic base of the subregion could be greatly expanded.

Quantitative hydrologic studies are needed in the areas containing major ground-water reservoirs (fig. 26). Special consideration needs to be given to possibilities of better water management through expanded conjunctive use of ground water and surface water.

Two tracts of land in the subregion have been designated by the U.S. Geological Survey as "known geothermal resources areas." Exploring of these geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

Humboldt Subregion

The Humboldt River is the principal stream in the subregion. The yield of surface water is 850,000 acre-feet per year; an additional 25,000 acre-feet per year flows into the subregion from adjacent areas (table 7). Most of the runoff is derived from snowmelt, and maximum runoff is in June; minimum flow is in October.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 281,000 acre-feet (table 7). Evaporation from the reservoirs averages 20,000 acre-feet per year.

The weighted average concentration of dissolved solids in water of the upper part of the Humboldt River is less than 300 mg/l. The chemical quality of the water deteriorates downstream, due to irrigation return flow and ground-water discharge. In the lower part of the Humboldt River the concentration of dissolved solids in the water generally is between 500 and 600 mg/l. The water has a high concentration of dissolved solids by the time it flows into Humboldt Lake.

The amount of surface water withdrawn for consumptive uses averages about 800,000 acre-feet per year, and 660,000 acre-feet per year is actually consumed. The largest use is for irrigation (700,000 acre-feet per year, including use by nonirrigated wet meadows); the second largest use is for public supplies (12,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in the valleys. These aquifers yield as much as 4,000 gpm of water to individual wells; the average yield is 1,690 gpm per well (figure 26).

The water table in the principal aquifers is at land surface in the lower parts of most valleys. The depth below land surface to the water table increases away from the low areas in relation to the slope of the land surface.

Most of the ground water in the principal aquifers contains less than 1,000 mg/l dissolved solids. However, the concentration of dissolved solids is much higher in parts of some valleys, especially near thermal springs and large playas.

The quantity of ground water stored in the upper 100 feet of the principal aquifers is 43.6 million acre-feet, which is 155 times the storage capacity of all surface reservoirs (table 7). In most areas the aquifers are much more than 100 feet thick, and the quantity of ground water in storage is correspondingly more than 43.6 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 169,000 acre-feet (table 8). The largest use was for irrigation (157,000 acre-feet); the second largest use was for public supplies (7,000 acre-feet) (table 8).

Water-resources problems that were identified by the Westwide study group include: (1) a need for more flood control in the Humboldt River basin; (2) localized needs for additional flat-water recreation opportunities; and (3) a need to study and possibly designate wild and scenic rivers.

Ground-water management relates indirectly to the first two problems. Under favorable conditions, part of the flood flow in streams could be diverted to artificial recharge facilities and stored underground until needed. Also, storage of water underground through artificial recharge could permit more uniform storage of water in surface reservoirs, thus enhancing the recreation potential of the reservoirs.

Table 7 shows that total consumption of water in the subregion is 761,000 acre-feet per year, compared to a surface-water yield plus surface inflow of 875,000 acre-feet. This comparison implies that new developments to the extent of consumption of 114, 000 acre-feet of water per year is theoretically possible on a sustained basis, and recovery of the water lost to excessive evapotranspiration in wetlands and phreatophyte areas could add an additional 335,000 acre-feet per year to the sustained supply.

The large supply of ground water now stored in the upper 100 feet of saturated material in the principal aquifers (43.6 million acre-feet) (fig. 26) is adequate to provide water in the amount now consumed by man's activities for more than a hundred years. However, this amount of ground water could not be withdrawn without adverse effects on streamflow. In the process of extracting this water, some of the water now lost to consumption in wet and phreatophyte areas would be salvaged. To take a more realistic view of the situation with respect to time, by mining the ground water in the upper 100 feet of saturated material, water use could be tripled for more than 50 years, if the people of Nevada so desired.

The subregion contains tracts of land designated by the U.S. Geological Survey as "known geothermal resources areas" and large tracts designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies are needed in all the large ground-water basins containing productive aquifers (fig. 26). Special consideration needs to be given to unified management of the Humboldt River and adjoining ground-water reservoirs. Also, consideration needs to be given to intercepting storm flows in areas favorable for artificial recharge, to prevent the water from entering playas and evaporating.

Exploring of geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

Central Lahontan Subregion

Principal streams in the subregion are the Truckee, Carson, and Walker Rivers. The yield of surface water in Nevada alone is about 108,000 acre-feet per year; an additional 1.12 million acre-feet flows into the subregion from the California region (table 7). Most of the streamflow is derived from snowmelt in the Sierra Nevada, and maximum runoff is in June; minimum flow is in September.

Surface reservoirs for regulation of streamflow, excluding Lake Tahoe, have a combined storage capacity of 656,000 acre-feet (table 7). Evaporation from the reservoirs averages 63,000 acre-feet per year.

The concentration of dissolved solids in the upper reaches of principal streams and their tributaries generally is less than 120 mg/l. The chemical quality of water deteriorates downstream, due mostly to return flow and reuse of water. The concentration of dissolved solids in Pyramid and Walker Lakes, the major terminal lakes in the subregion, is about 5,100 and 8,500 mg/l, respectively.

The amount of surface water withdrawn for consumptive uses averages about 1.35 million acre-feet per year, and 826,000 acre-feet per year is actually consumed. The largest use is for irrigation (1.32 million acre-feet per year), which is essentially the only use of surface water.

The principal aquifers are unconsolidated sediments in the valleys. These aquifers yield as much as 4,400 gpm of water to individual wells; the average well yield is 1,550 gpm (fig. 26).

The water table in the principal aquifers is at land surface in the lower parts of most valleys. The depth below land surface to the water table increases away from the low areas in relation to the slope of the land surface.

Most of the ground water in the principal aquifers contains less than 1,000 mg/l of dissolved solids. Exceptions are near or beneath large playas, such as Carson Sink, and near thermal springs.

The quantity of ground water stored in the upper 100 feet of the principal aquifers is 16.1 million acre-feet, which is 24 times the storage capacity of all surface reservoirs in the subregion (table 7). In most areas the aquifers are much more than 100 feet thick, and the quantity of ground water in storage is correspondingly more than 16.1 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 61,000 acre-feet, and 29,000 acre-feet was actually consumed. The largest use was for irrigation (26,000 acre-feet); the second largest use was for self-supplied industries (mining - 14,000 acre-feet) (table 8).

Water-resources problems that were identified by the Westwide study group include: (1) a need for an interstate compact for the Carson, Truckee, and Walker Rivers; (2) possible alternatives in management of the water resources of the Walker River basin to protect or enhance the environmental quality of the basin; and (3) possible alternatives in management of the water resources of the Truckee and Carson River basins to protect or enhance the environmental quality of the basins. Of particular concern are methods of maintaining the levels of Pyramid and Walker Lakes without drastic curtailments in consumptive uses of water. At the present time, inflow to these lakes is much less than evaporation, causing the lakes to decrease in size and the concentration of dissolved solids in the water to increase.

Conjunctive use of ground water and surface water in the river valleys and more efficient irrigation practices probably would permit more flow into the terminal lakes.

The largest ground-water basin of the subregion is in the Carson Sink area (Carson Desert) (fig. 26). However, much of the ground water in this area is saline. The water might be usable for some industrial applications or support of improved wildlife habitat.

Small tracts in the subregion were designated by the U.S. Geological Survey as "known geothermal resources areas" and larger tracts were designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies of the principal ground-water basins (fig. 26) are needed. Special emphasis needs to be given to interrelations of streams and aquifers in the stream valleys and to wetlands and aquifers in the terminal lakes and playas.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic system and the temperature anomalies. Drilling and special testing will be needed as part of the study.

Tonopah Subregion

The Tonopah subregion, the largest of the six subregions in the Great Basin region, does not contain a major stream. Many minor streams rise in the mountain ranges and flow onto alluvial fans at the foot of the mountains, where most of the water infiltrates into the ground. The yield of surface water in the subregion averages 290,000 acre-feet per year; an additional 20,000 acre-feet flows into the subregion from the California region. Most of the streamflow is derived from snowmelt and spring discharge.

Surface reservoirs for regulation of streamflow have a storage capacity of only 2,000 acre-feet (table 7).

The concentration of dissolved solids in stream water has not been studies extensively. The few sampling stations indicate the water generally contains less than 200 mg/l dissolved solids.

The amount of surface water withdrawn for consumptive uses averages about 316,000 acre-feet per year, and 258,000 acre-feet per year is actually consumed. The largest use is for irrigation (312,000 acre-feet per year), which is essentially the only use for surface water.

The principal aquifers are unconsolidated sediments. These aquifers yield as much as 3,300 gpm of water to individual wells; the average yield is 1,260 gpm (fig. 26).

The water table is at or near land surface in the lowest parts of many valleys. However, because of intervalley flow of ground water in parts of the subregion, the depth to the water table is several hundred feet beneath the lowest parts of several valleys. In general the depth below land surface to the water table increases away from the lowest parts of the valleys in relation to the slope of the land surface.

Most of the ground water in the principal aquifers contains less than 1,000 mg/l dissolved solids. However, in the vicinity of large playas in some valleys, the shallow ground water contains 10,000 to 35,000 mg/l.

The quantity of ground water stored in the upper 100 feet of the principal aquifers is 50.6 million acre-feet, which is 25,000 times the capacity of surface storage (table 7). In most areas the aquifers are much more than 100 feet thick, and the quantity of ground water in storage is correspondingly more than 50.6 million acre-feet.

No water-resources problems were identified by the Westwide study group, but one development potential was considered - use of large reserves of ground water for operation of thermal powerplants.

Most of the subregion is sparsely populated, and it could accommodate thermal powerplants without many of the environmental problems associated with some subregions. The subregion contains several large ground-water basins (fig. 26), where the aquifers are capable of yielding more than 800 gpm of water to wells. The upper 100 feet of saturated material in the principal aquifers contains 50.6 million acre-feet of water in storage (table 7). Most of the basins are not favorable for agricultural development because of short growing seasons and cold nights, so the competition for water is minimal.

By uniformly lowering the water table 100 feet throughout the principal ground-water basins, 1.5 million acre-feet of water per year could be withdrawn for more than 30 years, even if there were no ground-water recharge. Because the average saturated thickness of the aquifers is much more than 100 feet, a large supply of ground-water would still remain after 30 years.

The subregion does not contain large supplies of fossil fuels that could be used for thermal powerplants, but it is crossed by large-capacity natural-gas pipelines, and more pipelines are planned if the large supplies of natural gas in low-permeability rocks of the western States can be feasibly extracted.

Several mines are being operated in the subregion, and the ground-water supply should be more than adequate for this mineral industry.

Two small tracts in the subregion have been designated by the U.S. Geological Survey as "known geothermal resources areas" and several larger tracts were designated as "areas valuable prospectively" (Godwin, and others, 1971).

Quantitative hydrologic studies are needed in all the principal ground-water basins (fig. 26). Special consideration needs to be given to possibilities of intercepting storm runoff before it reaches the playas, where it mostly evaporates, and using the water for artificial recharge.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. These studies would include mapping and analysis of the hydrologic systems and the temperature anomalies. Drilling and special testing will be needed as part of the studies.

Upper Colorado Region

Green River Subregion

The Green River subregion includes all the drainage basin of the Green River and its tributaries (fig. 27). Also included is the Great Divide Basin, a topographically closed basin in Wyoming. This subregion lies in southwestern Wyoming, northwestern Colorado, and north-eastern Utah. The subregion is characterized by high mountains, broad geologic and topographic basins, plateaus, and deep narrow canyons. The Green River is the largest stream.

Average annual precipitation ranges from less than 6 inches at places along the Green River in the rain shadow of high mountains to more than 40 inches on the highest mountain ranges. Most of the moisture falls as snow on the mountains. Maximum precipitation is in winter, except in the lower elevations of the sourthern part, where the maximum precipitation is in July and August.

The yield of surface water is 5.46 million acre-feet per year (table 9). Most of the streamflow is derived from snowmelt, and maximum runoff is usually in June; minimum runoff is in late fall or early winter (November to February), depending on location and manmade regulations.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 4.29 million acre-feet (table 9). Evaporation from reservoirs averages 121,000 acre-feet per year.

The concentration of dissolved solids in the headwaters streams commonly is less than 200 mg/l. The concentration of dissolved solids increases downstream, due to return flow from irrigated lands and solution of soluble minerals from extensive deposits of clay-bearing and evaporite-bearing rocks. The average concentration of dissolved solids in the Green River increases from about 320 to 460 mg/l from a few miles above the Wyoming-Utah State line to a few miles below the confluence of the Price River. The San Rafael River contains an average of 1,624 mg/l dissolved solids near Green River, Utah.

The amount of surface water withdrawn for consumptive uses averages about 2.35 million acre-feet per year, but only 883,000 acre-feet per year is actually consumed. About 110,000 acre-feet per year is diverted

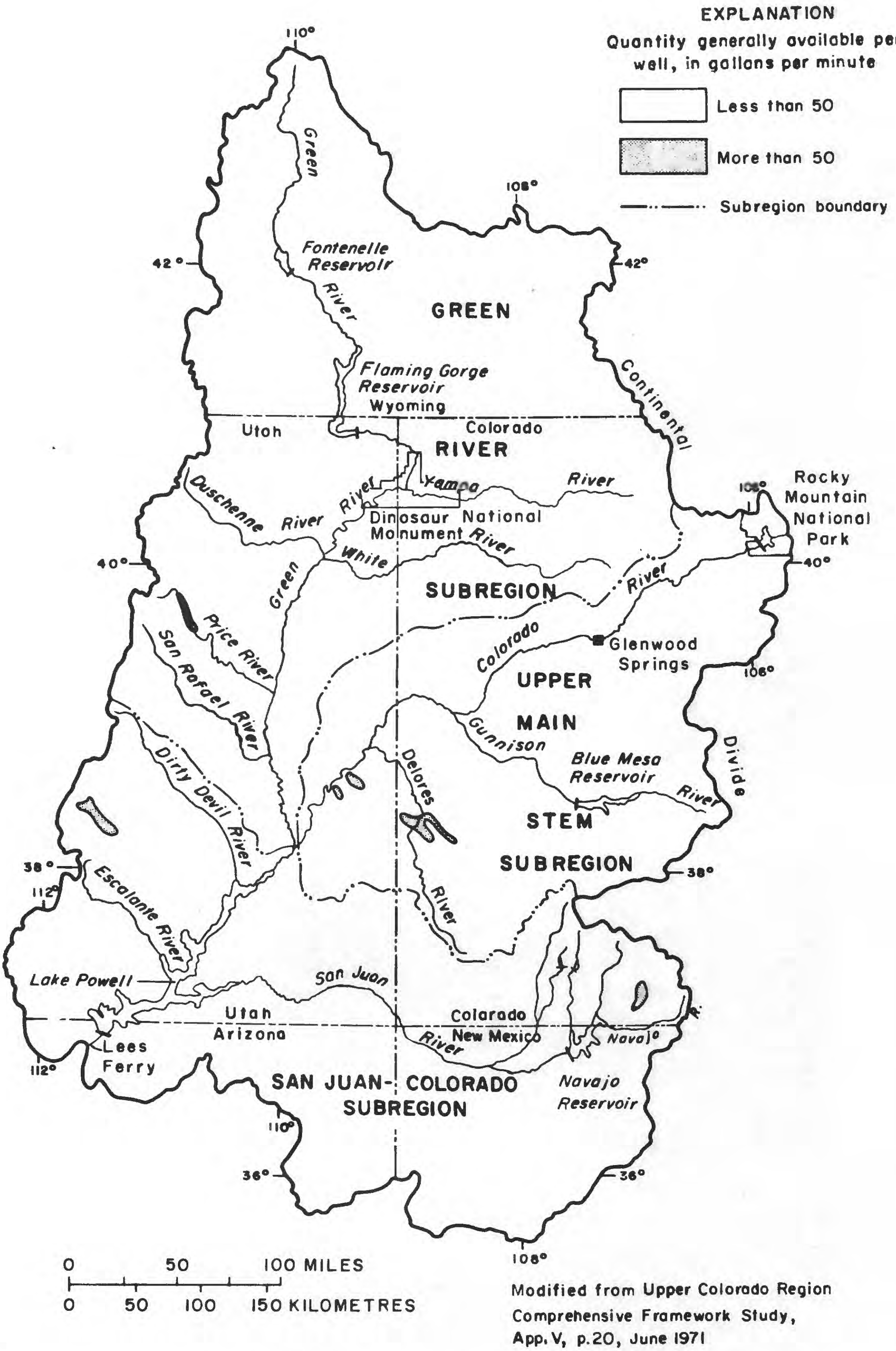


Figure 27. - General availability of ground water in the Upper Colorado region.

Table 9.--Generalized water budget for the Upper Colorado Region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
				Consumption				
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Man's activities (ac-ft per yr) 2/	Wet land and phreato-phytes (ac-ft per yr)	Reservoir evaporation (ac-ft per yr)	Surface water (ac-ft)	Ground water (ac-ft)
Green River	0	5,460	4,510	914	-	121	4,290	-
Upper Main Stem	0	6,810	5,820	1,060	-	29	2,070	-
San Juan - Colorado	9,810	2,610	11,400	425	-	632	27,100	-
Totals (rounded)		15,000		2,400		782	33,500	88,000 3/

1/ Data from comprehensive Framework Report, Westwide State Reports, and U.S. Geological Survey Water Resources Data Reports.

2/ Includes consumption of both surface water and ground water.

3/ Water stored in the upper 100 feet of saturated thickness.

out of the subregion for use in the Great Basin region. The largest use is for irrigation (2.18 million acre-feet per year); the second largest use is for self-supplied industries (50,000 acre-feet per year), largely the minerals industries. Water that is not consumed returns to the river or infiltrates into the ground-water reservoirs.

The principal aquifers are unconsolidated sediments in narrow stream valleys and consolidated sedimentary rocks between the valleys. The most widespread aquifers are sandstone, which generally yield less than 50 gpm of water to individual wells (fig. 27). However, in some areas wells yield 50 to 500 gpm. Recent studies of oil-shale deposits south of the White River in Colorado have shown that yields of 50 to 500 gpm of water from highly fractured rocks are common (Ficke, Weeks, and Welder, 1974).

Water levels in the principal aquifers range from above land surface in some of the tributary valleys south of the White River to more than 200 feet below land surface in other areas.

The concentration of dissolved solids in water from wells and springs generally ranges from 500 to 3,000 mg/l, and in some areas the concentration is more than 3,000 mg/l. Ground water of best quality generally is in the more humid mountainous areas; ground water of poorest quality generally is in the more arid areas and where the rocks are predominantly shale.

The quantity of recoverable ground water stored in the rocks of the subregion has not been determined. The estimate for the region is 88 million acre-feet, but recent studies in the Piceance Creek basin of northwestern Colorado indicates much more recoverable water in that area than previously estimated (Ficke, Weeks, and Welder, 1974).

The amount of ground water withdrawn in 1970 for consumptive uses was 62,000 acre-feet, of which 31,000 acre-feet were actually consumed (table 10). The largest use was for irrigation (33,000 acre-feet); the second largest use was for public supplies (13,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) problems associated with development of extensive coal and oil shale deposits; (2) water supply for mining trona in Wyoming; (3) water supplies for thermal powerplants; (4) seasonal shortages of irrigation water; (5) competition for water for various uses; (6) a need for more flood control; (7) effects of water-resource development in the upper basin on water quality in the lower basin and delivery of water to Mexico; (8) a need to determine and provide for instream flow requirements for fish and wildlife and outdoor recreation; (9) possible designation of wild and scenic rivers and their

Table 10.--Estimated use of ground water in 1970 in the Upper Colorado Region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generation	Total	
Green River	13	3	33	9	4	62	31
Upper Main Stem	7	3	10	5	0	25	13
San Juan - Colorado	11	8	23	4	0	46	23
Total	31	14	66	18	4	133	67

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: U.S. Geological Survey Circular 676 (1972).

effects on water-resources development; (10) whether or not additional agricultural development is needed or desirable; (11) possible export of water for public supplies and industries in the North Platte River basin; (12) a need to improve recreation opportunities; (13) a need for air-quality monitoring; (14) a need to invalidate power and reclamation withdrawals in Dinosaur National Monument; (15) a need to utilize potential hydropower sites to produce energy without pollution; and (16) a need to determine Indian water requirements and assure adequate water supplies.

Productive aquifers in the subregion generally were believed to be localized along some of the major stream valleys (fig. 27), at the time of the Regional Framework Study. Additional drilling and testing have demonstrated that yields of more than 50 gpm per well can be expected in two fairly large areas - one containing unconsolidated sediments in the upper Green River basin, the other containing oil shale in the Piceance Creek basin, south of the White River. The area in the upper Green River basin has not been explored extensively, because the demand for water has been met from surface sources. The aquifers in the Piceance Creek basin have been explored largely in conjunction with exploration of the oil shale, and those studies are still in progress.

Ground water in the oil shale presents a problem in mining, because it will be necessary to dewater the aquifers in much of the area in order to mine safely. On the other hand, a large water supply will be required for a large oil-shale industry. Part of the ground water is fresh and can be used directly as process water but part is saline, having very limited use in the oil-shale industry. Disposal of saline water that must be pumped during mining presents a serious problem. If released directly to streams, the streams would be polluted, adding to the already severe salt loading of the Colorado River. Other possibilities for disposing of the saline water include storage in ponds and solar evaporation or desalting by one of several techniques now possible. Ponding and solar evaporation would require a water surface area of several thousand acres, and the water would be lost from the supply system. A desalting process would permit direct use of the water, or it could be released to surface streams to augment the surface supply without adding to the salt load. Another possible alternative would be injection of the saline water into aquifers remote from mines and already containing saline water. This procedure has limited application because of large pressure increases in the receiving aquifer. Injection of saline water would retain it in the general area, until more saline water could be utilized in the oil-shale industry.

The ground-water supply in the Piceance Creek basin is adequate to meet all the requirements for an oil-shale industry for many years, but desalting might be required for part of the water in a few years. The rate of water production for dewatering of the mines would decrease with time, so an outside source of water will be required eventually for a large-scale industry. Without additional surface storage of water, seasonal shortages of water from streams is to be expected. However, the seasonal shortages of surface water possibly could be compensated by maximum rates of pumping ground water during low streamflow and minimum ground-water pumping during high streamflow.

Some of the tributary valleys to the Green River experience shortages of streamflow for present levels of irrigation. Where productive aquifers are present (fig. 27), these shortages could be eliminated by conjunctive use of ground water and surface water, by pumping ground water to supplement the surface supply during periods of low streamflow and recharging the aquifers during periods of excess streamflow.

Large areas are underlain by sandstone aquifers, which generally yield less than 50 gpm of water to wells. However, these aquifers could produce adequate water for small public supplies or small industries.

Quantitative hydrologic studies are needed in the few areas containing productive aquifers.

A detailed study of the Piceance Creek basin, including a digital model of the system, is nearing completion. However, available test wells do not provide complete coverage of the basin. Any future drilling and testing needs to be monitored and analyzed. Also when dewatering, mining, and processing of oil shale begin, hydrologic effects need to be closely monitored, and the digital model modified as necessary to improve the prediction capabilities under actual operating conditions.

Upper Main Stem Subregion

The upper main stem subregion includes the Colorado River and its tributaries upstream from the confluence of the Colorado and Green Rivers. This subregion is characterized by high mountains, plateaus, and deep canyons. Altitudes range from about 3,600 feet above sea level at Lake Powell to more than 14,000 feet on several mountains along the Continental Divide, the eastern boundary of the subregion.

Precipitation ranges from less than 10 inches per year in the lowest areas to more than 40 inches on the higher mountains. Most of the moisture falls in winter as snow at higher altitudes. The Colorado River, which heads near the Continental Divide, is the principal stream. The yield of surface water is about 6.81 million acre-feet per year (table 9). This is the largest yield of any subregion in the upper Colorado region, even though this is the smallest of the subregions. Most of the streamflow is derived from snowmelt, and maximum runoff is in June; minimum flow is in January. Much surface water (380,000 acre-feet in 1970) is diverted from this subregion to areas east of the Continental Divide, through 17 transmountain diversion facilities.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 2.07 million acre-feet (table 9). Evaporation from the reservoirs averages 29,000 acre-feet per year.

The concentration of dissolved solids in streams of the higher watersheds commonly is less than 20 mg/l. The concentration increases downstream, due to return flow and solution of soluble minerals in the rocks. The average concentration of dissolved solids in water of the main stem increases from 290 mg/l near Glenwood Springs, Colorado, to 650 mg/l a few miles above the confluence of the Delores River in Utah. The average concentration in the lower part of the Gunnison River is 630 mg/l.

The amount of surface water withdrawn for consumptive uses in the subregion averages about 2.57 million acre-feet per year, and 1.05 million acre-feet per year is actually consumed. The largest use is for irrigation (2.25 million acre-feet per year); the second largest use is equal for public supplies and self-supplied industries (42,000 acre-feet per year each).

The principal aquifers are unconsolidated sediments in the major stream valleys and consolidated sedimentary rocks (mostly sandstone) between the valleys. Generally, the aquifers in this subregion yield less than 50 gpm of water to individual wells, but in some areas yields of 50 to more than 500 gpm are obtained (fig. 27).

The depth to ground water ranges from less than 50 feet in stream valleys to more than 500 feet below land surface in some of the high plateau areas in the southwestern part of the subregion.

The concentration of dissolved solids in ground water generally is less than 1,000 mg/l. However, the concentration exceeds 3,000 mg/l in some small areas.

The quantity of recoverable ground water stored in the upper 100 feet of saturated material has not been estimated, but the combined storage in all three subregions is 88 million acre-feet, which is more than two times the storage capacity of all the surface reservoirs in the region (table 9).

The amount of ground water withdrawn in 1970 for consumptive uses was 25,000 acre-feet, of which 13,000 acre-feet was actually consumed. The largest use was for irrigation (10,000 acre-feet); the second largest use was for public supplies (7,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) possible designation of wild and scenic rivers in areas where water-resource development might be contempleted; (2) a need for construction of surface-storage structures, which have been authorized but not funded; (3) effects of water-resource development in the upper basin on water quality in the lower basin and delivery of water to Mexico; (4) a need for multipurpose development in upper tributaries of the Gunnison River; (5) whether or not additional agricultural development is needed or desirable; (6) localized needs for additional flat-water recreation opportunities; (7) a need for additional flood control; (8) a need to utilize potential hydropower sites to produce energy without pollution; (9) a possible need for water from the Colorado River for oil-shale development; (10) a need for public water supplies and waste disposal; (11) a need to modify reservoir management to improve the recreation potential; (12) a need for flood plain management for erosion and sedimentation; (14) detraction from the natural beauty of Rocky Mountain National Park by operation of facilities for water diversion and weather modification; (15) a need for policy decisions on interbasin transfer of water; and (16) a need for water for cooling at thermal powerplants.

None of the problems listed could be resolved readily by alternate methods of ground-water management. Only a few relatively small areas contain productive aquifers (fig. 27), and these areas are limited to major stream valleys. The aquifers in these areas could be utilized for conjunctive use of ground water and surface water by pumping from the aquifers when surface water is in short supply and recharging the aquifers when excess surface water is available.

Saline ground-water discharges to the Colorado River through a few large springs. Removal of the salt from the spring water, by desalting or total removal of the water from the surface-water system, would help alleviate the problem of salt loading of the Colorado River.

Quantitative hydrologic studies need to be made in the few areas containing productive aquifers. Special studies need to be made in the vicinity of saline springs, including drilling and hydraulic testing, to better define the hydrologic system and to devise methods of controlling the discharge of salts to the Colorado River.

San Juan-Colorado Subregion

The San Juan-Colorado subregion includes all the drainage of the Colorado River and its tributaries from the confluence of the Colorado and Green Rivers to Lees Ferry, a short distance downstream from Lake Powell. The subregion is characterized by high mountains, plateaus, and deep canyons. Elevations range from about 3100 feet above sea level at Lees Ferry to more than 14,000 feet on the highest peaks in the northeastern part of the subregion.

Average annual precipitation ranges from less than 6 inches along the lower parts of the Colorado and San Juan Rivers to more than 40 inches on the higher mountains in the northeast part of the subregion. Most of the moisture falls as snow on the mountains.

Other than the main stem of the Colorado River, the San Juan River is the principal stream. The yield of surface water is about 2.61 million acre-feet per year. An additional 9.81 million acre-feet per year flows into the subregion from adjacent subregions, mainly as flow in the Colorado River (table 9). Most of the streamflow is derived from snowmelt, and maximum runoff is in May; minimum flow is in January.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 27.1 million acre-feet (table 9). Evaporation from the reservoirs averages 632,000 acre-feet per year.

The concentration of dissolved solids in streams of the high watersheds commonly is less than 200 mg/l, although mine drainage increases the salinity of water in some high mountain streams. The concentration increases downstream, due to return flow and solution of soluble minerals in the rocks. The average concentration of dissolved solids in water of the San Juan River is 160 mg/l near the Colorado-New Mexico line and it increases to 460 mg/l several miles downstream from the New Mexico-Utah State line. At Lees Ferry, Arizona, the point of outflow from the subregion, the concentration of dissolved solids in the Colorado River averages 586 mg/l.

The amount of surface water withdrawn for consumptive uses averages about 840,000 acre-feet per year, and 402,000 acre-feet per year is actually consumed. The largest use is for irrigation (789,000 acre-feet per year); the second largest use is for public supplies (24,000 acre-feet per year).

The principal aquifers are local deposits of unconsolidated sediments in stream valleys and consolidated sedimentary rocks (mostly sandstone). Only two small areas are shown in figure 27 where the aquifer yields more than 50 gpm of water to individual wells. However, some thick beds of sandstone in the eastern part of the subregion are known to yield more than 50 gpm to wells, and they probably would yield as much or more than 500 gpm. In some large areas, beds of sandstone alternate with beds of shale, and if wells were drilled to depths of 2,000 to 3,000 feet in these areas and the casing perforated in all the beds of sandstone, yields as large as 3,500 gpm could possibly be obtained (Baltz and West, 1967). In one area of New Mexico, in the southern part of the subregion, yields of a few hundred to a few thousand gallons per minute from mineral test holes have been reported, but the area has not been adequately tested for a hydrologic analysis.

The depth to ground water generally is less than 100 feet below land surface in northeastern Arizona and northwestern New Mexico. On either side of the Colorado River and beneath several high plateaus, the depth to water generally is 500 to 1,000 feet below land surface and may exceed 1,000 feet in some areas.

The concentration of dissolved solids in water from wells and springs in the western part of the subregion generally is less than 1,000 mg/l, but in some large areas the concentration may be as high as 3,000 mg/l. In the eastern part of the subregion, the concentration of dissolved solids generally ranges from 1,000 to 3,000 mg/l but may exceed 3,000 mg/l locally.

The quantity of recoverable ground water stored in the upper 100 feet of saturated material in the subregion has not been estimated, but the combined storage in all three subregions is 88 million acre-feet, which is more than two times the storage capacity of all the surface reservoirs in the region (table 9).

The amount of ground water withdrawn in 1970 for consumptive uses was 46,000 acre-feet, of which 23,000 acre-feet was actually consumed. The largest use was for irrigation (23,000 acre-feet); the second largest use was for public supplies (11,000 acre-feet) (table 10).

Water-resources problems in the San Juan-Colorado subregion that were identified by the Westwide study group include: (1) a need to determine water requirements on Indian reservations and provide for meeting the requirements; (2) a need for a policy decision on construction of upper basin projects that have been authorized but not constructed; (3) the effects of water use in the upper basin on the quality of water in the lower basin and on meeting obligations of water delivery to Mexico; (4) a need for more water of better quality to meet the requirements for public supplies;

(5) a need for large supplies of water for coal development, including thermal electric plants, in the San Juan River basin; (6) whether or not additional agricultural development is needed or desirable; (7) a need for more recreation facilities in the San Juan River basin; (8) a need to improve economic conditions in the San Juan River basin, possibly by increasing irrigation; (9) a need for more flood control on some streams; (10) localized needs for additional flat-water recreation opportunities; (11) uncontrolled development and use of surface water and adjacent lands; (12) a need to implement the second stage of the San Juan-Chama Project; (13) a need for regulation of flow in the Navajo River for fish and wildlife and outdoor recreation; (14) high rate of erosion and sedimentation in many areas; (15) a need for a policy decision on interbasin transfers of water; (16) possible designation of the Escalante River as a wild and scenic river; and (17) air pollution from thermal powerplants along the San Juan River.

In general, the aquifers in the major river valleys are thin and therefore, they cannot be utilized extensively, either as a sole source or supply or for conjunctive uses of ground water and surface water. The largest potential for ground-water development probably is a system of sandstone aquifers in the eastern and southern parts of the San Juan basin (not shown on fig. 27). In these areas, adequate supplies of ground water for some industries possibly could be developed. However, these ground-water sources have not been adequately evaluated for use in making development decisions.

The possible large reserves of ground water in sandstone aquifers in the east and south parts of the San Juan basin need to be explored adequately to assess the potential for extensive ground-water development. Extensive drilling and hydraulic testing will be required.

Lower Colorado Region

Lower Main Stem Subregion

The lower main stem subregion includes the Colorado River drainage from Lee Ferry, Arizona, to the Mexican boundary except for the Little Colorado River basin, most of the Gila River basin, and the California part of the Colorado River basin (fig. 28). The subregion includes parts of Arizona, Nevada, and Utah. It is characterized by discontinuous mountain ranges, intermontane valleys, high plateaus, and deep canyons, including Grand Canyon. Elevations range from 75 feet along the Mexican border to nearly 12,000 feet in the mountains west of Lake Mead.

Figure 28. - General availability of ground water in the Lower Colorado region.

Average annual precipitation ranges from 5 inches or less along the Colorado River below Lake Mead to 25 inches or more on high plateaus. The higher mountains and plateaus receive most precipitation in winter, largely as snow; the low valleys receive most precipitation in summer as intense rains for short periods during thunderstorms.

The principal stream in the subregion is the Colorado River. The local yield of surface water is about 900,000 acre-feet per year. An additional 11.9 million acre-feet per year flows into the subregion from adjacent subregions (table 11).

Surface reservoirs for regulation of streamflow have a storage capacity of 28.6 million acre-feet (table 11). Streamflow in the main stem of the Colorado is the most completely regulated of any major river in the Western United States. Evaporation from the reservoirs averages 1.23 million acre-feet per year.

The concentration of dissolved solids in the Colorado River, the only perennial stream, exceeds 500 mg/l where the river enters the subregion, and ranges from 600 to 900 mg/l at major diversion points. The chemical quality of the river water is affected by return flow and by natural discharge of saline springs upstream.

The amount of surface water withdrawn for consumptive uses averages about 1.98 million acre-feet per year, and 1.43 million acre-feet per year is actually consumed. The largest use is for irrigation (1.82 million acre-feet per year); the second largest use is for public supplies (34,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in the major valleys. These aquifers generally yield several hundred gallons per minute of water to individual wells (figure 28).

The depth to ground water ranges from near land surface in the lowest parts of major valleys to a few hundred feet below land surface around the margins of large valleys or in heavily pumped areas. The depth generally is less than 500 feet below land surface in all the large valleys.

The concentration of dissolved solids in ground water in the principal aquifers ranges from less than 100 to more than 100,000 mg/l. However, in most of the aquifers the concentration of dissolved solids is less than 1,000 mg/l.

The quantity of ground water stored in the upper 100 feet of saturated material is 109 million acre-feet, which is nearly four times the storage capacity of all the surface reservoirs (table 11).

Table 11.--Generalized water budget for the Lower Colorado Region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption: Man's activities (ac-ft per yr) 2/	Consumption: Wet land and phreatophytes (ac-ft per yr)	Consumption: Reservoir evaporation (ac-ft per yr)	Surface water (ac-ft)	Ground water (ac-ft) 3/
Lower Main Stem	11,900	900	7,150	1,800	660	1,230	28,600	109,000
Little Colorado	0	516	305	96	-	39	66	250,000
Gila	15	1,800	0	3,710	-	159	3,200	114,000
Totals (rounded)		2,220		6,510		1,430	31,900	473,000

1/ Data from comprehensive Framework Report.

2/ Includes consumption of both surface water and ground water.

3/ In upper 100 feet of saturated material. A total of 1.43 billion acre feet are in storage at depths to 1,200 ft.

The amount of ground water withdrawn in 1970 for consumptive uses was 535,000 acre-feet, of which 371,000 acre-feet was actually consumed. The largest use was for irrigation (420,000 acre-feet); the second largest use was for public supplies (77,000 acre-feet) (table 12).

Water-resources problems that were identified by the Westwide study group include: (1) a possible need for designation of wild and scenic rivers; (2) localized needs for additional flat-water recreation opportunities; (3) a need to evaluate the full recreation potential of the Central Arizona project; (4) an increasing need for water for public supplies and for industries, including thermal power plants; (5) possible modification of reservoir management to improve the recreation potential; (6) increasing salinity of both surface water and ground water; (7) a need for pollution control at Lake Mead in Nevada, and possible use of sewage effluent to establish greenbelts; (8) effects of sanitary land fills on water quality; (9) a need for water supplies for visitors at special sites on public land in Arizona; and (10) high water losses due to thick growths of phreatophytes.

Ground water has been used extensively for irrigation, public supplies, and self-supplied industries (table 12) in local areas, especially in the vicinity of Las Vegas, Nevada, and Yuma, Arizona. As a result of large withdrawals of ground water in some localities, ground-water levels have declined severely. On the other hand, the ground-water supplies in some large basins have hardly been touched. The ground water in these basins (fig. 28) is available for local use, or it could be transported to basins having large water demands. The quantity of ground water available in the upper 100 feet of saturated material in all the basins is 109 million acre-feet (table 11) and at the present rate of consumption (1.8 million acre-feet per year) would be adequate to supply water from this zone for 60 years.

Deterioration in water quality results from natural discharge of saline ground water and from return flow of irrigation water. The most severe problem of ground-water quality is in the Wellton-Mohawk project area in the lower part of the Gila River valley. Plans are being made to desalt the more saline ground water, thus improving the supply of fresh water and preventing additional salt loading of the Colorado River. Similar improvements in water quality probably could be achieved in other parts of the subregion.

Waste water from the Las Vegas, Nevada, metropolitan area and from mineral processing plants nearby has caused a severe problem of pollution between Las Vegas and Lake Mead. This area is also the natural discharge point for ground water in the vicinity of Las Vegas; consequently, it contains the highest natural salinity of ground water in the valley. The pollution problem could be alleviated by desalting the

Table 12.--Estimated use of ground water in 1970 in the Lower Colorado Region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generation	Total	
Lower Main Stem	77	10	420	24	4	535	371
Little Colorado	6	6	21	16	4	53	37
Gila	200	32	3,980	147	41	4,400	3,060
Total	283	48	4,420	187	49	4,990	3,470

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: U.S. Geological Survey Circular 676 (1972).

saline waste waters and the saline ground water or removing the saline waters from the hydrologic system by pumping it to tightly sealed evaporation ponds.

The sewage effluent could be treated and used to maintain greenbelts. Much of the nitrate and phosphate probably would be retained in the soil zone and would be consumed by plants in the greenbelts. By applying excess water to greenbelts west of Las Vegas, where the depth to the water table increases westward, much of the nitrates and phosphates would be used by vegetation and the excess water would provide recharge to the aquifer. The water table slopes from west to east in the area, so eventually the waste water of improved quality would reach the pumping centers in Las Vegas and would be mixed with the naturally circulating ground water to provide a larger supply of ground water of acceptable quality.

Some species of phreatophytes possibly could be controlled locally by pumping enough ground water to lower the water table below the level at which phreatophytes can raise the water efficiently (probably a depth of 10 to 20 feet below land surface). Gradual lowering of the water table would permit some well-established species of phreatophytes to survive for wildlife habitat, but they would not consume large quantities of water. Even if it were necessary to "irrigate" selected stands of phreatophytes for wildlife habitat, the savings in water consumption could be large.

Quantitative hydrologic studies should be made in all the larger ground-water basins, where such studies have not been completed. Studies in the Las Vegas valley need to be expanded to include research on artificial recharge with sewage effluents in greenbelts and the character and movement of the water after it reaches the water table. Additional studies of water quality improvement through selective desalting of saline ground water need to be made in all the irrigated areas.

Little Colorado Subregion

The Little Colorado subregion includes all the drainage basin of the Little Colorado River. This subregion lies in northeastern Arizona and northwestern New Mexico (fig. 28). It is characterized by low to high mountains, high plateaus and mesas, and broad valleys. Elevations range from 2700 feet above sea level at the mouth of the Little Colorado River to more than 12,000 feet on the highest peaks in the west-central part of the subregion.

Average annual precipitation ranges from less than 6 inches at places along the Little Colorado River to more than 25 inches on the upper parts of the San Francisco peaks. Winter precipitation is light and consists of about 50 percent snow. Summer precipitation consists of frequent rains of moderate to high intensity but short duration associated with thunderstorms.

The principal stream is the Little Colorado River. The surface yield of water averages 516,000 acre-feet per year (table 11). Maximum runoff is in April, but runoff in August is nearly equal. Minimum runoff is in December.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 66,000 acre-feet (table 11). Evaporation from the reservoirs averages 39,000 acre-feet per year.

The concentration of dissolved solids in headwaters streams of the Little Colorado River and its tributaries generally is less than 500 mg/l. The concentration in the Little Colorado River increases downstream, due to return flow and solution of soluble minerals in the rocks. However, the concentration is reduced at several points along the course of the river by inflow of less saline water from tributary streams. The dissolved-solids concentration of water in the Little Colorado River at its confluence with the Colorado River averages about 1,500 mg/l, due to inflow of spring water containing about 2,500 mg/l dissolved solids.

The amount of surface water withdrawn for consumptive uses averages about 72,000 acre-feet per year, and 58,600 acre-feet per year are actually consumed. The largest use is for irrigation (68,800 acre-feet per year); the second largest use is for rural supplies (3,200 acre-feet per year).

The principal aquifers are consolidated sedimentary rocks (mostly sandstone but some limestone); minor aquifers are unconsolidated sediments along the major stream valleys. The aquifers generally yield less than 200 gpm of water to individual wells, but locally yield as much as 2,000 gpm.

The depth to ground water is less than 200 feet below land surface in the areas of major developments and from 200 to more than 500 feet below land surface in other areas.

The concentration of dissolved solids in ground water varies widely, but generally is less than 3,000 mg/l. South of the Little Colorado River and in two large areas in the northwest and northeast parts of the subregion, the concentration generally is less than 1,000 mg/l.

The quantity of ground water stored in the upper 100 feet of saturated material is 250 million acre-feet (table 11). However, much of this water is in rocks having low permeabilities, and it cannot be recovered readily through wells.

The amount of ground water withdrawn in 1970 for consumptive uses was 53,000 acre-feet, of which 37,000 acre-feet was actually consumed (table 12). The largest use was for irrigation (21,000 acre-feet); the second largest use was for self-supplied industries (16,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) a need to improve the local economy of the subregion; (2) increasing salinity of both surface water and ground water; (3) a possible need for designating some wild and scenic rivers; (4) a need to determine Indian water requirements, inventory the water supply on their reservations, and attempt to find ways of meeting the water requirements; (5) high erosion rates on large areas and sedimentation in reservoirs; (6) salt loading of the Colorado River; (7) a need for additional water of better chemical quality for municipal supplies in New Mexico; (8) uncontrolled development and use of surface water and adjacent lands; and (9) a need for better flood control on tributaries in New Mexico.

The most productive aquifers are limited to a few small areas, mostly in the upper part of the Little Colorado River basin. In general, the ground-water resources are fully developed in these areas, so the possibilities for additional ground-water development are limited. In some areas of heavy withdrawal, the ground-water supply probably could be supplemented through artificial recharge during brief periods of storm runoff.

Springs discharge saline water to streams in the subregion at a few places. The saline-water discharge could be intercepted and desalted, either by surface collection of the water or by withdrawal from wells. Withdrawal through wells completed in the source aquifers could keep the water table below the streambed levels, thus preventing discharge of saline water. In some cases it might be possible to pump a small volume of very saline water and prevent it from contaminating a larger volume of fresh water, before the mixture discharges from saline springs.

Quantitative hydrologic studies need to be made in the few areas of heavy ground-water withdrawals and in the vicinity of saline springs. An area along the Zuni River valley from Zuni Pueblo, New Mexico, to the Arizona line needs to be explored to determine the potential for ground-water development. The unconsolidated sediments in this area have not been adequately explored to provide information on the ground-water situation. The general topographic and geologic situation suggest that some exploration, including test-well drilling, is justified.

Gila Subregion

The Gila subregion includes most of the drainage of the Gila River and a few topographically closed basins in central and southeastern Arizona and southwestern New Mexico (fig. 28). It is characterized by discontinuous mountain ranges, high plateaus, and intermontane valleys. Elevations range from 520 feet above sea level at the lower end of the subregion to nearly 12,000 feet on the highest mountains.

Precipitation ranges from less than 8 inches in the lower valleys of the southwest to more than 30 inches on the higher mountains. The subregion has two distinct precipitation seasons - one in summer and one in winter. Much of the winter precipitation falls as snow above an elevation of 4000 feet.

The principal stream is the Gila River. The yield of surface water is 1.8 million acre-feet per year. An additional 15,000 acre-feet per year is imported from the Little Colorado Subregion (table 11). Maximum runoff is in March in the streams at higher elevations and in August in streams at lower elevations. Minimum runoff is in June at both high and low elevations.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 3.2 million acre-feet (table 11). Evaporation from the reservoirs averages 159,000 acre-feet per year.

The concentration of dissolved solids in surface water varies widely. In the upper part of the Gila River and its tributaries, the concentration generally is less than 500 mg/l and commonly is less than 200 mg/l. The concentration of dissolved solids increases downstream, due to return flow and solution of soluble minerals in the rocks. The dissolved-solids concentration in the Gila River increases from 250 to 1,370 mg/l in a 1.13-mile reach downstream from the Arizona-New Mexico line. The concentration of dissolved solids in the upper reaches of the Salt and Verde Rivers generally is less than 500 mg/l. The concentration in the Verde River does not change much downstream, but the concentration in the Salt River increases to an average of 630 mg/l, with a range of 400 to 790 mg/l. Municipal and industrial effluents in the Phoenix area further increases the concentration of dissolved solids to an average of 3,100 mg/l by the time the last of the flow is diverted from the river for irrigation.

The amount of surface water withdrawn for consumptive uses averages about 1.23 million acre-feet per year, and 650,000 acre-feet per year are actually consumed. The remainder of the surface water is lost through evaporation from reservoirs (159,000 acre-feet per year) and infiltration into the ground. Outflow from the subregion is limited to minor floodflows in the lower part. The largest use of surface water is for irrigation (about 936,000 acre-feet per year); the second largest use is for public supplies (about 123,000 acre-feet per year).

The principal aquifers are unconsolidated sediments in the valleys. These aquifers yield a few hundred to a few thousand gallons per minute of water to individual wells (fig. 28).

The depth to ground water in the major valleys ranges from less than 200 feet to more than 500 feet below land surface. The depth is least in the central parts of the valleys, especially in stream valleys, and greatest along the margins of the valleys.

The concentration of dissolved solids in ground water ranges from 100 to more than 100,000 mg/l, but the water in most of the principal aquifers contains less than 1,000 mg/l dissolved solids. Water quality varies both laterally and vertically within some aquifers, depending on variations in the composition of sediments and the quality of recharge water. The water of poorest quality is in the Gila River valley, where the concentration of dissolved solids is more than 1,000 mg/l in large areas.

The quantity of ground water stored in the upper 100 feet of saturated material is 114 million acre-feet, which is 35 times the combined storage capacity of all the surface reservoirs in the subregion (table 11). In the major valleys the thickness of saturated material is much more than 100 feet, and the quantity of ground water in storage is correspondingly more than 114 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 4.4 million acre-feet, of which 3.06 million acre-feet was actually consumed (table 12). The largest use was for irrigation (3.98 million acre-feet); the second largest use was for public supplies (200,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) possible reuse of public water supplies (sewage effluent) to supplement the generally short supply; (2) possible improvement in water supply by watershed management, especially by control of phreatophytes; (3) increase in flood damages, due to encroachment of phreatophytes into stream channels; (4) management of flood plains to minimize flood damages; (5) adverse effects of stream channelization on wildlife habitat; (6) a need for more water for mining and processing copper ores; (7) increasing salinity of both surface water and ground water; (8) a possible need to designate wild and scenic rivers; (9) high erosion and sedimentation rates in some areas; (10) increasing demands for public and industrial water supplies, including water for thermal power plants; (11) effects of converting land to urban uses; (12) a need to develop the full recreation potential of the Central Arizona Project; (13) localized needs for additional lake and reservoir recreation opportunities; (14) effects of sanitary land fills on quality of water; (15) possible effects of pumping ground water on streamflow; (16) a need for water for construction and for visitors at special sites on public land in Arizona; and (17) a need to protect several rare and endangered species of animals.

Sewage effluent from the larger cities could be used directly, after treatment, for some uses, or it could be stored underground through artificial recharge for later recovery and use. Some of the water could be used to maintain greenbelts, at the same time artificial recharge is being accomplished, by adding excess water to the greenbelts. Much of the nitrates and phosphates would be adsorbed in the soil zone and used by plants and additional amounts would be adsorbed by unsaturated materials above the water table. If the waste water was recharged at considerable distances from ground-water withdrawal centers where the water table is relatively deep, the water would mix with the stored ground water and eventually return to the pumping centers at acceptable quality for most uses.

Some species of phreatophytes possibly could be controlled by controlling ground-water levels. Gradual lowering of the water table by pumping ground water would permit many of the well-established phreatophytes to survive for wildlife habitat, but they would not consume large quantities of water. Control of phreatophytes in this manner would reduce their encroachment into stream channels and reduce the threat of floods. Even if it were necessary to "irrigate" selected stands of phreatophytes to maintain wildlife habits, the savings in water consumption could still be large.

In addition to reducing flood damages by flood-plain management, damages could be further reduced by diverting storm runoff to artificial recharge facilities near the sources of flow. This procedure also would tend to offset the declining water levels in some areas of heavy pumping.

Obtaining additional water supplies for mining and processing of copper ores may not be as much of a problem as preventing ground-water pollution by escape of mill effluents. Most of the copper mining is adjacent to large ground-water basins, where ground water is available by "mining." However, in some basins the competition for water is strong, and the water-table is being lowered severely.

Artificial recharge from storm runoff should be considered for areas where water levels are declining. Most of the storm runoff in topographically closed basins is dissipated back to the atmosphere, by evaporation from wetted soils or from playas, without reaching points of withdrawal for beneficial uses. Recharge in these basins possibly could be increased by accumulating the storm runoff in recharge facilities near its source. Coarse, unconsolidated material in the channels of the larger ephemeral streams permits rapid infiltration of water during infrequent periods of storm runoff. Recharge probably could not be increased significantly in valleys containing through-going ephemeral stream channels.

Artificial recharge with water of better chemical quality than the water in the ground-water reservoir would tend to improve the overall quality of ground water by dilution. Part of the water normally stored in surface reservoirs could be stored underground, which would improve the quality of the ground water, reduce evaporation losses, and reduce the concentration of dissolved solids in the surface supply by reducing evaporation.

The most likely methods of increasing the water supply of the subregion include: (1) importation, (2) weather modification, and (3) an increase in artificial recharge from storm runoff. The Central Arizona Project probably will provide the maximum import of water that will be permissible for many years. Weather modification is still in the experimental stage. Artificial recharge from storm runoff would add only a small increment of water. However, withdrawal of ground water from storage at the present rate could be spread over larger areas, reducing the severity of concentrated withdrawal now practiced. Withdrawal centers could be dispersed by transporting the water to the areas of concentrated use, or the users could be dispersed through strong land management.

The many large subdivisions of land in Arizona tend to disperse water use, but unfortunately, too frequently the subdividers fail to consider availability of water for the subdivisions. Consequently, some subdivisions become local importers of water at great cost to home owners. This situation could be avoided by permitting subdivisions only where water is readily available.

Quantitative hydrologic studies are needed in all the large ground-water basins, where such studies have not been completed. Special consideration needs to be given to possibilities of artificial recharge to augment the usable water supply and conservation of water through more underground storage to reduce reservoir evaporation losses. Control of phreatophytes through control of ground-water levels also could be emphasized.

Other special studies need to include: (1) evaluation of possible methods of improving the chemical quality of water, (2) a search for better methods of waste-water disposal, or reuse and (3) effects of sanitary land fills on water quality.

Northern Rio Grande Region

Rio Grande-Colorado Subregion

The Rio Grande-Colorado subregion includes the drainage basin of the Rio Grande in Colorado and an adjacent area of internal drainage (fig. 29). The subregion is characterized by a large valley bounded on three sides by mountains. Elevations range from an average of 7700 feet above sea level in the valley to more than 14,000 feet on the higher peaks.

Average annual precipitation is 7 to 10 inches on the valley floor and more than 30 inches on some of the highest mountains. Much of the moisture falls as snow in the mountains during winter, but maximum monthy precipitation is rain in August.

The principal stream is the Rio Grande. The yield of surface water averages 1.50 million acre-feet per year (table 13). Maximum runoff is in May or June; minimum runoff is in January or February.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 400,000 acre-feet (table 13).

The concentration of dissolved solids in streams generally is less than 500 mg/1.

The amount of surface water withdrawn for consumptive uses averages 1.26 million acre-feet per year, and 633,000 acre-feet is actually consumed. Essentially all the surface water diverted is used for irrigation.

The principal aquifers are unconsolidated sediments, which occupy the entire valley area. These aquifers yield a few hundred to a few thousand gallons per minute of water to individual wells.

The depth to ground water is less than 12 feet below land surface under most of the valley floor. The depth is a little more around the margins of the valley, where alluvial fan slopes are steep. Flowing wells are common in the valley.

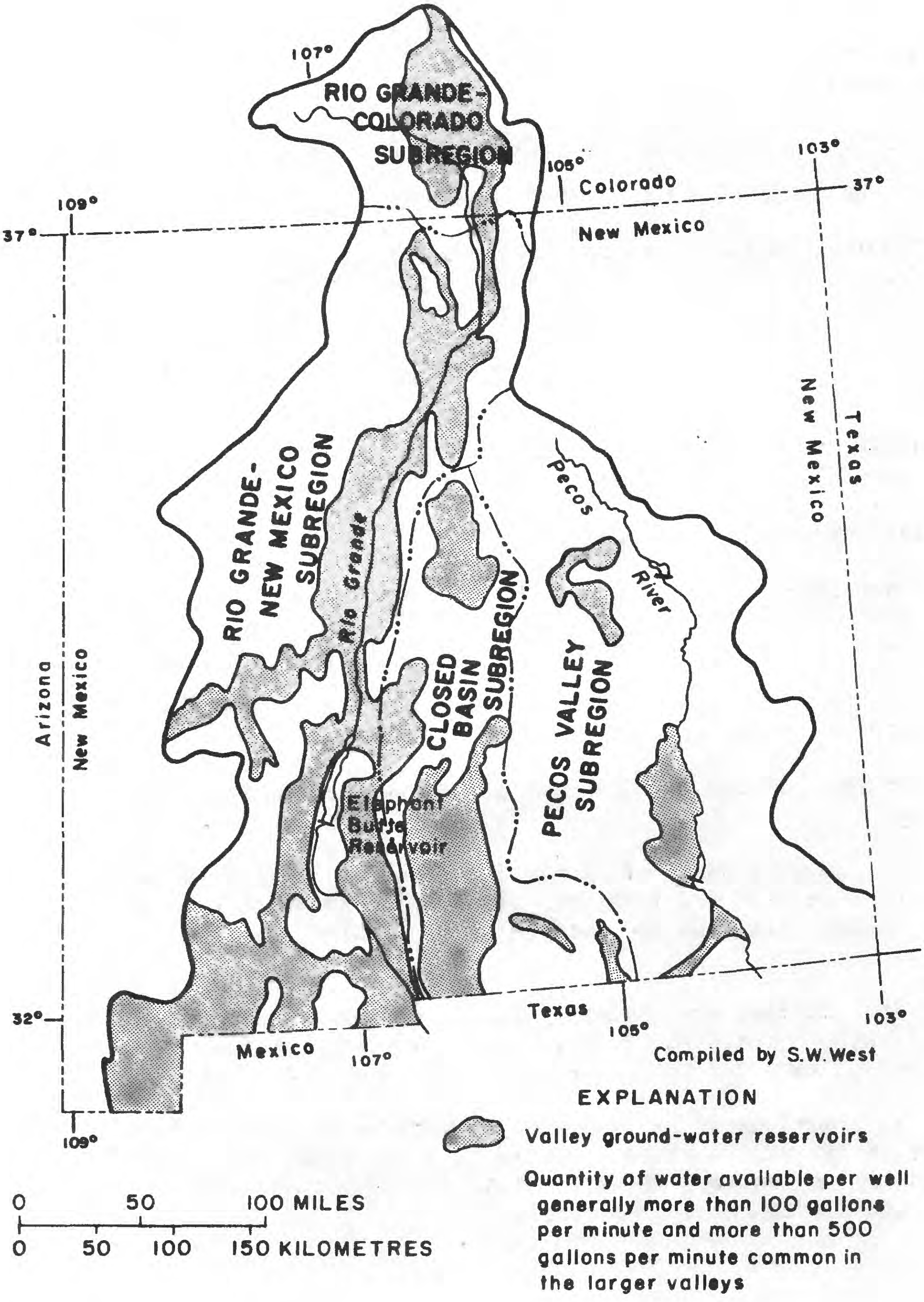


Figure 29. - General availability of ground water in the northern part of the Rio Grande region.

Table 13.--Generalized water budget for the northern Rio Grande region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption: Man's activities (ac-ft per yr) 2/	Consumption: Wet land and phreatophytes (ac-ft per yr)	Consumption: Reservoir evaporation (ac-ft per yr)	Surface water (ac-ft)	Ground water (ac-ft) 3/
Rio Grande - Colorado	0	1,500	500 4/	993	1,000	-	400	2,000,000
Rio Grande - New Mexico	500	1,380	387	530	546	262	4,110	2,250,000
Pecos Valley	9	592	181	354	185	41	312	24,000
Closed basins	0	48 5/	0	112	50 6/	0	0	236,000 7/
Totals (rounded)		3,470		1,990	1,780	303	4,820	4,510,000

1/ Data from published and unpublished records and reports of the New Mexico State Engineer Office and from U.S. Geological Survey.

2/ Includes consumption of both surface water and ground water.

3/ Total saturated thickness containing fresh water (less than 1,000 mg/l dissolved solids).

4/ Includes some ground-water underflow.

5/ Some runoff from mountainous areas, which infiltrates into the ground or evaporates in playas.

6/ Evaporation from playas in Estancia Basin only.

7/ Includes both fresh (less than 1,000 mg/l dissolved solids) and slightly saline (1,000 to 3,000 mg/l dissolved solids) water.

The concentration of dissolved solids in ground water generally is less than 500 mg/l. In some areas, where the water table is essentially at land surface, the dissolved solids have been concentrated in the water due to evapotranspiration. In these areas the concentration locally is about 14,000 mg/l.

The quantity of fresh (less than 1,000 mg/l dissolved solids) ground water stored in the principal aquifers is 2 billion acre-feet, which is 5,000 times the storage capacity of all the surface reservoirs (table 13). The quantity in the upper 100 feet of saturated material is 20 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 679,000 acre-feet (table 14). The largest use was for irrigation (669,000 acre-feet); the second largest use was equally divided between public supplies and self-supplied industries (4,000 acre-feet each). In comparison, 1,000,000 acre-feet was consumed by evapotraspiration from wetlands and phreatophyte areas, where the water table is less than 12 feet below land surface.

Water-resources problems that were identified by the Westwide Study group include: (1) a need to preserve wildlife refuge; (2) possible effects of lowering ground-water levels on a large sand dune area; (3) a need for more flood control; (4) failure of Colorado to meet Rio Grande compact commitments; and (5) a need for channel improvement, as described in the Bureau of Reclamation San Luis Valley project proposal.

The Closed Basin Division, San Luis Valley Project, proposed by the U.S. Bureau of Reclamation (1963), contemplates salvaging about 101,000 acre-feet of water annually, of which 86,000 acre-feet would be pumped ground water (mostly from an area of 109,000 acres) and 15,000 acre-feet would be surface water. According to the Bureau of Reclamation plan, the accrued debit of Colorado would be offset in about 35 years.

If 86,000 acre-feet of water can be recovered for new uses annually from an area of 109,000 acres, prospects are good for recovering a million acre-feet a year from the 1.5 million acres where the water table is less than 8 feet below the land surface. A million acre-feet of water per year is being lost currently from the valley by uncontrolled evapotranspiration from wet and phreatophyte-infested areas. Under the larger recovery program, the accrued debit of Colorado could be offset in a year or two, or additional economic development based on use of ground water would be possible.

Table 14.--Estimated use of ground water in 1970 in the northern Rio Grande region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial generation	Thermo-electric power	Total	
Rio Grande - Colorado	4	2	669	4	0	679	360
Rio Grande - New Mexico	89	11	296	85	10	491	260
Pecos Valley	21	8	445	8	.7	483	256
Closed basins	5	2	182	9	0	198	105
Total	119	23	1,592	106	11	1,851	981

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: U.S. Geological Survey Circular 676 (1972).

In addition to the savings of water through reduction of overirrigation and recovery operations in the San Luis Valley, consideration could be given to withdrawal from ground-water storage. The ground-water reservoir contains 2 billion acre-feet of water in storage, so withdrawal of 2,000,000 acre-feet a year would cause only a 10 percent decrease in storage in 100 years.

The locations and rates of ground-water withdrawal could be regulated so the Alamosa National Wildlife Refuge and the Great Sand Dunes National Monument would not be adversely affected. However, preservation of the wildlife refuge would reduce the amount of water that could be recovered by the amount now consumed on the refuge.

A quantitative hydrologic study of the subregion is in progress, including construction of an analog model, and preliminary analyses have been made of the responses of the hydrologic system to specified input and output of water. The study could be expanded to analyze the response to much wider ranges of input and output in relation to time and space. Special consideration needs to be given to potential ground-water development under constraints of maintaining selected features of high environmental value.

Rio Grande-New Mexico Subregion

The Rio Grande-New Mexico subregion includes all the drainage of the Rio Grande in New Mexico and some basins with internal drainage west of the Rio Grande (fig. 29). The subregion is characterized by a long trough or valley bounded on each side by mountains or plateaus. Elevations range from 3800 feet above sea level at the lower end of the Rio Grande valley to more than 10,000 feet on several peaks in the northern part.

Average annual precipitation ranges from less than 8 inches in the lower part of the valley to more than 24 inches on some of the northern mountains. Much of the moisture falls as snow on the mountains during winter, but maximum precipitation is from rainstorms in August.

The principal stream is the Rio Grande. The yield of surface water is 1.38 million acre-feet per year. An additional 500,000 acre-feet per year flows into the subregion from Colorado (table 13). Maximum runoff in the upper watersheds is in May or June, and streams at lower elevations have maximum runoff in August. Minimum runoff for all the watersheds is in winter, generally in January.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 4.11 million acre-feet (table 13). Evaporation from the reservoirs averages 262,000 acre-feet per year.

Where the Rio Grande enters the subregion, the concentration of dissolved solids averages about 220 mg/l. The dissolved-solids concentration of tributaries that enter the Rio Grande in northern New Mexico generally is less than 500 mg/l, and the concentration in the Rio Grande in central New Mexico also is less than 500 mg/l. Return flow and inflow of saline water from tributaries cause a deterioration in water quality of the Rio Grande farther downstream. Where the Rio Grande leaves the subregion (at the New Mexico-Texas line), the average concentration of dissolved solids averages a little more than 1,000 mg/l.

The amount of surface water withdrawn for consumptive uses averages about 395,000 acre-feet per year, and about 270,000 acre-feet per year is actually consumed. The largest use is for irrigation (392,000 acre-feet per year); the second largest use is for rural supplies (2,000 acre-feet per year).

The principal aquifers are unconsolidated sediments. Locally, consolidated sedimentary rocks (limestone) comprise the principal aquifer. These aquifers generally yield more than 500 gpm of water to individual wells, and yields of 1,000 to 2,000 gpm per well are common.

The depth to water in the principal aquifers ranges from land surface in the lower parts of the valleys to 500 feet or more beneath the higher areas along the margins of the valley.

The concentration of dissolved solids in ground water in the principal aquifers varies widely. The concentration generally is less than 1,000 mg/l, and in many areas is less than 500 mg/l. In other areas the concentration may be more than 2,000 mg/l. Locally in the lower part of the Rio Grande valley, the shallow ground water is saline, due to recirculation of water from the ground to irrigated fields and back into the ground, but deeper water is fresh.

The quantity of freshwater stored in the principal aquifers is 2.25 billion acre-feet, which is about 560 times the storage capacity of all the surface reservoirs (table 13). The quantity of ground water stored in the upper 100 feet of saturated material is 64 million acre-feet.

The amount of ground water withdrawn in 1970 for consumptive uses was 491,000 acre-feet (table 14). The largest use was for irrigation (296,000 acre-feet); the second largest use was for public supplies (89,000 acre-feet), with self-supplied industries a close third (85,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) possible control of phreatophytes to increase the usable water supply; (2) a need to reuse waste water to increase the effective water supply; (3) a need for flood and sediment control on Rio Grande tributaries; (4) localized needs for additional flat-water recreation opportunities; (5) uncontrolled development and use of surface waters and adjacent lands; (6) a possible need for enlargement of the San Juan-Chama project of interbasin transfers; (7) losses of habitat for waterfowl and other wildlife along the Rio Grande; (8) a need for additional water for irrigation and public supplies in the northwestern part of the subregion; (9) competition for water in trout streams; (10) a need to inventory the water resources of Indian reservations, determine the water requirements for the reservations, and develop plans to meet the requirements; (11) high rates of erosion and sedimentation on some Indian reservations; (12) salt loading of streams; (13) a need for more water for irrigation and public supplies in the southwestern part of the subregion; (14) a need for flood control and a need for more water of better quality along the Rio Grande near the New Mexico-Texas line; and (15) a need to pursue development of geothermal energy.

An approach to improving the water-supply situation could be an expansion of conjunctive use of ground water and surface water, which is already being practiced to some extent. Because of the physical connection between the river and the ground-water reservoir, it would not be possible to withdraw large quantities of ground water in some reaches without causing a reduction in streamflow. On the other hand, a large part of the 400,000 acre-feet of water now being lost annually to noneconomic evapotranspiration probably could be recovered for other uses by lowering ground-water levels to about 20 feet below land surface in the wetlands and phreatophyte areas.

Conjunctive use of ground water and surface water has been practiced by individuals in the Elephant Butte irrigation district for many years. Irrigation water from Elephant Butte Reservoir is used when the supply is adequate, but when surface water is in short supply, more than 90 percent of the land receives supplemental ground water from privately owned wells. Part of the water applied to irrigated fields returns to the ground water reservoir, carrying soluble soil salts and fertilizers down into the reservoir. Consequently, the chemical quality of shallow ground water has deteriorated extensively, some now containing as much as 6,000 mg/l of dissolved solids. A systematic approach to total water management, including mixing of the shallow ground water with deeper water of better quality or with surface water possibly would improve the general quality of irrigation and municipal water.

Lowering the ground-water level below the bed of the river would cause losses from the river but once the ground-water level is below the river, additional lowering would not cause a further increase in loss of water from the river. However, ground water that normally would discharge into the river would be intercepted before it reaches the river. Water losses from the river could be controlled in areas where the water table is lowered by diverting the amount of streamflow needed to satisfy downstream rights into an artificial, lined channel. Excess flow could follow the natural channel to recharge the ground-water reservoir.

The increasing demand for water could be met readily by drawing on the large volume of water stored in the underground reservoirs. More than 65,000,000 acre-feet of ground water could be withdrawn by uniformly lowering the water level 100 feet in the valley fill. This approach could more than double the water supply for the next 90 years, even if all the water withdrawn is consumed, which rarely is true. An additional 400,000 acre-feet per year would be recovered in the process, due to reduction of evapotranspiration in wetlands and phreatophyte areas.

Large reserves of coal and natural gas have been mapped in and adjacent to the subregion. Utilization of these resources for electrical power generation to help meet the rapidly growing demand for electrical energy in the southwest could be enhanced by drawing on salvaged water or on the large reserves of ground water in storage.

Some, and possibly all, the wetlands and phreatophyte areas are considered by many to be ecologically desirable. Therefore, it probably would not be reasonable to lower the water level in the ground-water reservoir uniformly, as described above. However, a program of ground-water withdrawal could be designed to lower the water levels more than 100 feet in some areas and less, or none, in selected wet and phreatophyte areas. This approach would not permit as much recovery of water normally lost to noneconomic evapotranspiration. Some areas would be favorable for maintaining favorable wildlife habitat by surface irrigation, using much less water than is now lost by evapotranspiration.

A program could be designed also to utilize the ground-water reservoir to replace part of the surface storage. Water levels could be lowered by pumping ground water into lined canals or pipes for delivery to points of use and using excess surface water for recharge to the underground reservoirs, either by infiltration directly from the streambed or indirectly from spreading areas or recharge ponds in areas favorable for infiltration. This approach has the advantage of salvaging water normally lost to evaporation from surface reservoirs in the subregion (262,000 acre-feet per year), but it increases the available supply only in the amount of this salvage. On the other hand, surface reservoirs have recreational values which may justify large evaporation losses. However, many recreationists prefer a relatively small reservoir of constant size to a large reservoir of widely varying size, and in some instances surface reservoirs could be regulated for nearly constant size by utilizing underground storage for part of the water.

Sewage effluent from municipalities and individual homes in the Rio Grande valley and its principal tributaries contributes to the salt load in streams and underground reservoirs. The principal chemical constituents added to the water are phosphates and nitrates. Methods of removing these constituents are being studied by several organizations at the Federal, State, and local level. One method that is being investigated elsewhere is the spraying of treated effluent on irrigated fields, where much of the phosphates and nitrates are adsorbed in the soil and used by the crops. An excess of water is applied to the land so that a large part is returned to the ground-water reservoir, after the phosphates and nitrates have been adsorbed. This process should work very well on the types of soils in much of the subregion.

The water-supply problem in the southern part of the subregion primarily involves poor quality of the shallow ground water. This problem probably can be solved by drilling deeper wells to get below the zone influenced by return of poor quality water from irrigated fields.

Because the chemical quality of ground water is highly variable, consideration should be given to mixing the water of best quality with water of inferior quality to stretch the supply of usable water.

An interagency study, involving both State and Federal agencies, of part of the subregion is currently (1973) in process. This study, termed the "Rio Grande Regional Environmental Project," is considering a full range of potential resource development plans, including the water resources. Various alternatives in water management will be a part of this study.

Underground space can be used for more than providing a normal water supply, if properly managed. In many parts of the subregion, thick accumulations of unconsolidated sediments lie above the water table, and the average porosity of this unsaturated material is equivalent to, or higher than, that of the saturated material. By constructing spreading ponds, excess surface flow during rainstorms could be retained on the surface in favorable areas for artificial recharge of water into the unsaturated fill. Thus, the volume of water in storage could be increased in some localities. Also, air could be pumped from thick unsaturated materials for air conditioning buildings, as the air at a given depth below land surface has an almost constant temperature throughout the year.

As excess surface water is diverted to recharge facilities, the flow of streams is regulated to some extent without large surface storage facilities. The water recharged into the ground during periods of excess surface flow will eventually find its way to a nearby stream as extra ground-water discharge.

Introduction of excess surface water of good chemical quality into aquifers containing water of inferior quality can improve the general quality of the ground water.

Release of cooling water from thermal electric plants and some types of industrial plants has caused severe problems of thermal pollution of nearby streams in many areas of the country. The ground-water reservoirs in the unconsolidated sediments of the Rio Grande valley could be used as receptacles for thermal waters from these types of plants. If the thermal water was injected into the valley fill at considerable distances from discharge points, either natural discharge points or wells, the heat would be dissipated to the rocks and the atmosphere before it could reach the surface again.

Development of geothermal energy is another special utilization of underground space. In favorable geothermal areas, natural steam can be withdrawn through wells and used to drive turbines for generation of electricity. Experiments to evaluate the injection of cool water into dry geothermal areas for conversion of the water to steam and its recovery for driving turbines are underway, but the outcome is open to speculation. In some parts of the world, geothermal waters are used directly for space heating of homes, offices, and greenhouses.

Several geothermal areas have been identified along the margins of the Rio Grande valley, but none have been adequately explored to evaluate their potential for energy development. The largest and best known geothermal area is west of the Rio Grande in the northern part of the subregion. Hydrologic studies of that area were begun recently (1972).

Experiments indicate that in favorable areas, both heating and cooling of buildings can be accomplished by direct use of ground water from different depths. Shallow ground water, which commonly is cool, can be obtained in summer for cooling buildings and can be reinjected at greater depths for conservation of the water. Warm water from greater depths can be obtained for heating buildings in winter and can be reinjected at shallow depths to maintain the balance between withdrawal and injection. The thick, permeable unconsolidated sediments in the Rio Grande Valley should be favorable for this application.

Quantitative hydrologic studies need to be made of the hydrologic system in the Rio Grande valley through the entire length of the subregion and in parts of tributary valleys. Special emphasis needs to be given to: (1) evaluation of the water resources on Indian reservations; (2) potential salvage of water by control of phreatophytes through control of ground-water levels; (3) reuse of waste water through ground-water recharge; and (4) possible improvement in the chemical quality of saline water through special measures of dilution by mixing, and possibly desalting some of the more saline water.

Exploring of the geothermal areas is needed to evaluate the potential for development of geothermal energy. The studies would include mapping and analysis of the hydrologic system and the thermal anomalies. Drilling and special testing will be needed as part of the studies. Some preliminary studies have already begun in one part of the subregion.

Pecos Valley Subregion

The Pecos Valley subregion includes all the drainage of the Pecos River in New Mexico. The subregion is characterized by high mountains, plateaus, mesas, plains, and valleys. It is bounded by mountains on the north and west and by plains on the east and south. Elevations range from about 3400 feet above sea level along the Pecos River at the southern boundary of the subregion to more than 10,000 feet on some of the mountains.

Average annual precipitation ranges from a little less than 12 inches in the lower part of the Pecos Valley to more than 24 inches on the higher mountains. Much of the moisture falls as snow on the mountains during winter, but maximum monthly precipitation is in August or September, depending on location.

The principal stream is the Pecos River. The yield of surface water is 592,000 acre-feet per year. An additional 9,000 acre-feet per year flows into the subregion from Texas (table 13). Maximum runoff from the higher watersheds is in May or June, and streams at lower elevations have maximum runoff in September. Minimum runoff is in February.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 312,000 acre-feet (table 13). Evaporation from the reservoirs averages 41,000 acre-feet per year.

The maximum concentration of dissolved solids in surface water from the upper watersheds of the north generally is less than 400 mg/l. The quality of water in the Pecos River deteriorates downstream, due to inflow of saline water and, to a lesser extent, return flow of irrigation water. During periods of low flow, the concentration of dissolved solids in the Pecos River approaches 20,000 mg/l, where the river leaves the subregion.

The amount of surface water withdrawn for consumptive uses averages about 201,000 acre-feet per year, and about 98,000 acre-feet per year is actually consumed. The largest use is for irrigation (170,000 acre-feet per year); the second largest use is for self-supplied industries (30,800 acre-feet per year).

The prinicipal aquifers are unconsolidated sediments along the major streams and consolidated sedimentary rocks (mostly limestone) between the valleys. Locally, consolidated sedimentary rock aquifers lie beneath unconsolidated sediment aquifers. Both types of aquifers yield a few hundred to a few thousand gallons per minute of water to individual wells.

The depth to water in the principal aquifers ranges from land surface in some of the lower valley areas to as much as 500 feet below land surface along the margins of the valley. Many wells in the Pecos Valley flowed before extensive pumping in the area.

The concentration of dissolved solids in ground water varies widely. The concentration in the most productive aquifers generally is less than 2,000 mg/l but it may exceed 3,000 mg/l in some localities. In some areas, water in secondary aquifers is saturated with sodium chloride. The main source of dissolved solids in the ground water is highly soluble minerals in the rocks.

The quantity of fresh ground water in storage is 24 million acre-feet, which is 76 times the storage capacity of all the surface reservoirs (table 13).

The amount of ground water withdrawn in 1970 for consumptive uses was 483,000 acre-feet (table 14). The largest use was for irrigation (445,000 acre-feet); the second largest use was for public supplies (21,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) declining ground-water levels in local areas caused by extensive pumping; (2) a need for additional flood control; (3) a need for additional water of better chemical quality for public supplies, irrigation, and industries in the Roswell basin; (4) localized needs for additional flat-water recreation opportunities; (5) possible extension of the Malaga Bend project of preventing flow of brine into the Pecos River through springs; (6) salt loading of the Pecos River through solution of minerals underground; (7) loss of wild life habitat due to removal of phreatophytes; (8) competition for water in trout streams; (9) a need to inventory the water resources, determine the water requirements, and devise plans for meeting the requirements on Indian lands; and (10) extensive erosion and sedimentation on the Mescalero Reservation.

The effective supply of water could be increased and the chemical quality of the water improved by reduction of evapotranspiration from wetlands and phreatophyte areas and by reduction of evaporation from surface storage reservoirs. Salvage of 50 percent of the water now lost in these processes would increase the effective supply by 140,000 acre-feet per year.

The loss of water to evapotranspiration possibly could be reduced by lowering the water table in areas of heavy losses by pumping ground water. However, the salinity of the water in some of the phreatophyte areas is too high for direct use. Desalination might be required for part of the water before it could be used beneficially. On the other hand, withdrawal of saline water in some areas and subsequent desalination would reduce the encroachment of saline water into freshwater zones in areas of intensive pumping.

Some wetlands possibly need to be preserved, especially in established wildlife refuges and parks. A thin stand of saltcedars and cottonwoods could be preserved in selected areas at small loss of water by evapotranspiration by lowering the water table slowly to an optimum level. Control of ground-water levels could prevent the spread and revegetation of saltcedars.

Water recovered by control of wetlands and phreatophytes could be used to meet the increasing demand for public water supplies, to supplement short supplies of irrigation water, or to irrigate new lands. Reduction of evaporation losses from surface storage reservoirs also could be used for these purposes.

The volume of water stored in surface reservoirs, and thus the quantity of water lost by evaporation, could be reduced by controlled recharge to and withdrawal from the ground-water reservoirs. The limestone aquifer in the Roswell basin has a large storage capacity and a high capacity for receiving recharge water, as well as a high capacity for withdrawal of the water as it is needed. This approach to water storage would necessarily have to guarantee delivery of water to satisfy prior rights to diversion of surface water.

Overdraft, or mining, of ground water has resulted in significant decreases in ground water in storage and in increased pumping lifts. This overdraft could be alleviated with sufficient salvage of water now lost by evapotranspiration, by artificial recharge to the ground-water reservoir, or by reduction of irrigation. Salvaged water, as described above, could replace some of the ground water being pumped and reduce the overdraft. Artificial recharge could alleviate the overdraft, but the supply of water that might be available for this purpose is limited. Eventually, it may become necessary to reduce the irrigated acreage, which would have a severe adverse impact on the economy of the area.

Local floods have caused serious problems in parts of the subregion. Under favorable circumstances, the floodwaters could possible be diverted to recharge areas, before they reach populated areas and irrigated farms, and provide better management of the water than to permit it to flow into surface reservoirs. However, the floodwaters of the region have been appropriated, and these rights would have to be protected. The floodwaters generally carry heavy loads of sediment, which reduce the storage capacity of the surface reservoirs. The capacity of underground reservoirs would not be reduced significantly by deposition of sediments, as the sediments would be retained on the land surface.

The high salinity of much of the water is one of the most serious water problems. It is difficult to manage the freshwater so it does not become mixed with the abundant saline water, which in effect reduces the supply of freshwater. The quality of the water could be improved generally by pumping and desalting in areas of saline-water discharge or of encroachment into freshwater zones of underground reservoirs, without reducing the total water supply significantly.

An experimental desalting plant has been operated successfully in the Pecos River valley in the southern part of the subregion to obtain data on the feasibility of desalting water having chemical character prevalent in the subregion. Another possible approach is pumping the more saline water to evaporation ponds. At one place, brine that normally discharges into the Pecos River has been intercepted by pumping from a well and discharged into a natural depression. The effect of this experiment is still being evaluated.

Elimination of evaporation from wetlands and transpiration by phreatophytes would improve the quality of water. The salts are concentrated by these processes, and the salts eventually return to the principal water systems, contaminating more of the freshwater supply.

Management of the scarce water supplies of the subregion possibly could be improved by treating all the sources of supply and storage facilities as a single system, managed for the maximum benefit of all users. However, this approach would require considerable reorganization of the complex managerial structures for water that are now in operation.

Quantitive hydrologic studies need to be made in the areas of extensive water-resources development. Special emphasis needs to be given to: (1) use of storm runoff or other surface waters for artificial ground-water recharge; (2) salvage of water from excessive losses by phreatophyte use, while maintaining reasonable wildlife habitat; and (3) improvement in the chemical quality of water.

Closed Basins Subregion

The closed basins subregion includes a group of basins having internal drainage, lying between the drainage basins of the Rio Grande and the Pecos River and north of the New Mexico-Texas line. The subregion is characterized by discontinuous mountain ranges and broad intermontane valleys. Elevations range from about 3,700 feet above sea level along the southern boundary to more than 10,000 feet on some of the mountains.

Average annual precipitation ranges from a little less than 10 inches in the lower southern part to more than 24 inches on the highest mountains. Much of the moisture falls as snow during winter, but maximum monthly precipitation is rain in July, generally associated with brief thunderstorms.

Streamflow is limited to a few small perennial streams in the mountains and intermittent flow in normally dry washes in the valleys. The latter streams flow only in responses to rainstorms of high intensity.

The yield of surface water has not been adequately measured, but estimates indicate a total runoff of about 48,000 acre-feet per year (table 13). All the surface flow infiltrates into the ground or collects in playas and evaporates.

Surface reservoirs for regulation of streamflow have not been constructed (table 13).

Chemical quality of water has not been measured systematically.

The amount of surface water withdrawn for consumptive uses is about 15,000 acre-feet per year, and about 7,000 acre-feet per year is actually consumed.

The principal aquifers are unconsolidated sediments, except for a few small areas where consolidated sedimentary rocks (limestone) constitute the principal aquifers. Yields of 800 to 1,000 gpm of water to individual wells are common, and locally, yields as high as 3,600 gpm have been obtained.

The depth to ground water in the principal aquifers ranges from land surface in some of the playas to as much as 500 feet along the margins of some valleys.

The concentration of dissolved solids in ground water varies widely. The concentration is less than 500 mg/l in favorable areas around the margins of the valleys but commonly is more than 3,000 mg/l in the central parts. The shallow water in some of the playas is a saturated brine.

The quantity of fresh water (less than 1,000 mg/l dissolved solids) stored in the principal aquifers is about 11.5 million acre-feet. An additional 225 million acre-feet of slightly saline water (1,000 to 3,000 mg/l dissolved solids) is stored in the principal aquifers (table 13).

The amount of ground water withdrawn in 1970 for consumptive uses was 198,000 acre-feet, of which 105,000 acre-feet was actually consumed (table 14). The largest use was for irrigation (182,000 acre-feet); the second largest use was for self-supplied industries (9,000 acre-feet).

The Westwide study group did not identify any specific water-resources problems in the closed basins subregion. Perhaps the most critical problems are limited ground-water recharge and limited supplies of fresh ground water in storage (table 13).

The large supply of saline water offers an opportunity for economic development that could utilize saline water. One possibility might be utilization of the water for cooling thermal powerplants. The unconsumed water from the cooling facilities could be reinjected into the underground reservoirs at adequate distances from the withdrawal points to permit heat dissipation before the water returns to the production wells, thus minimizing the consumption of water. The amount of freshwater required for the operation could be provided by desalting. Large supplies of freshwater for other uses also could be obtained by desalting the saline water.

Ground water has been mined in a large area of the Estancia basin. The water table has been lowered as much as 50 feet in areas of maximum pumpage. The overdraft could be alleviated to some extent by inducing recharge to the ground-water reservoir during the infrequent periods of surface runoff and by dispersing some of the pumpage to areas of natural discharge. The quantity of water being lost by evaporation from the playas is more than the quantity of water being consumed by beneficial uses, and most of the water lost is from natural ground-water discharge.

Ground water also has been mined in parts of Salt basin. Water levels have declined as much as 20 feet in the New Mexico part. Additional artificial recharge and dispersal of pumping to discharge areas in this basin could possibly reduce the overdraft of ground water. Some natural ground-water discharge has already been intercepted by lowering the water levels while pumping.

Quantitative hydrologic studies need to be made in areas where ground-water development is extensive. Detailed studies of the areas containing only saline water are not needed, until such time as serious consideration is given to development of the saline-water resources for direct use or for desalting. Some studies of potentials for artificial recharge to increase the amount of fresh ground water in storage would be useful.

Western Arkansas Region

Arkansas Valley Subregion

The Arkansas valley subregion includes all the drainage of the Arkansas River in Colorado and a very small area in New Mexico (fig. 30). The subregion is characterized by high mountains and narrow valleys and canyons in the western quarter and level to irregular plains in the eastern three-quarters. Elevations range from about 3300 feet above sea level where the Arkansas River leaves the subregion to about

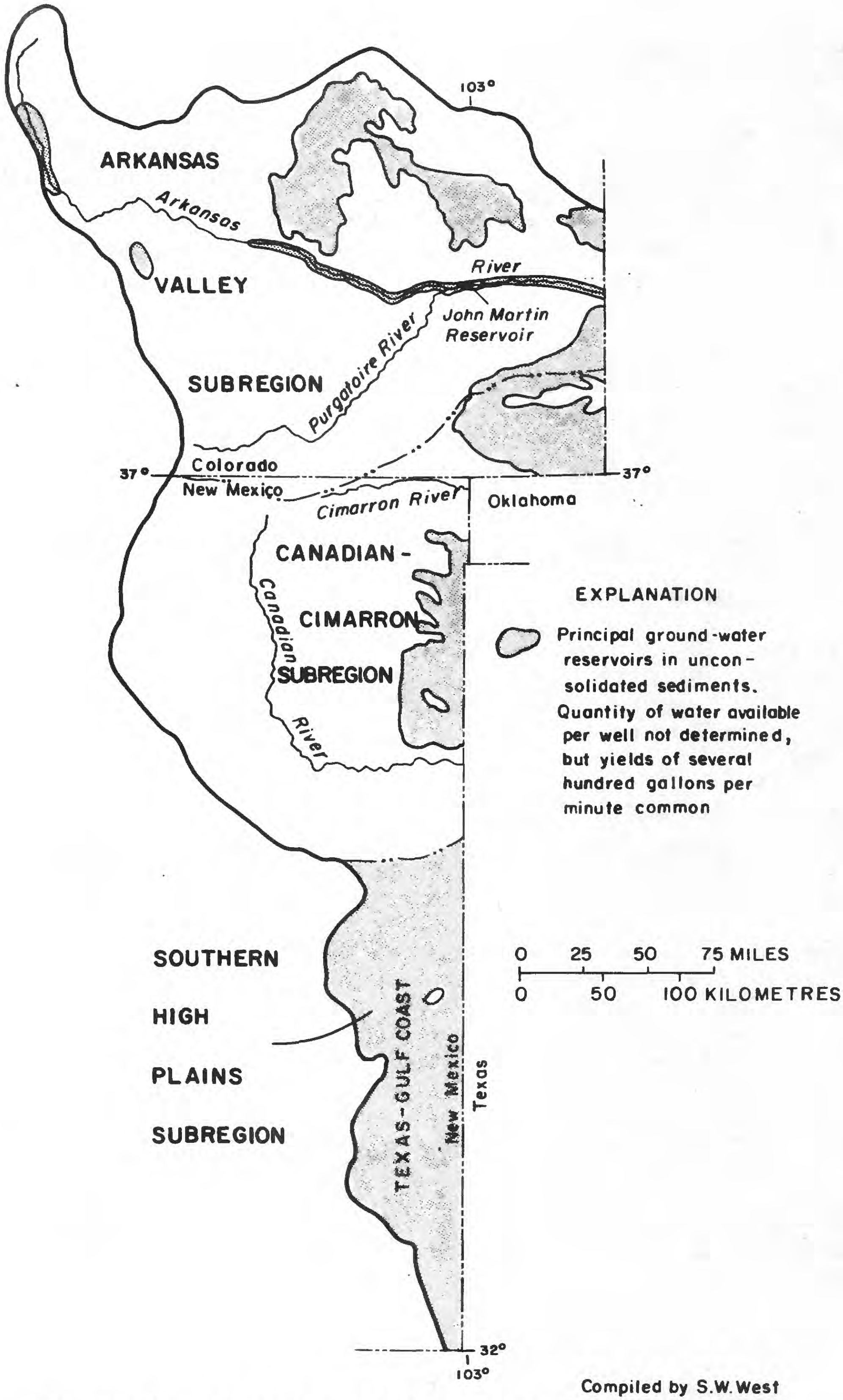


Figure 30. - General availability of ground water in the western parts of the Arkansas River and Texas-Gulf Coast regions.

14,000 feet in the mountains along the northwest boundary. The Arkansas River is the principal stream.

Average annual precipitation ranges from about 14 inches along the Arkansas River near the east boundary to more than 30 inches in the high mountains of the headwaters area. Much of the precipitation falls as snow on the high mountains, where winter and summer precipitation is about equally divided. Rain during spring and summer dominates the precipitation on the plains.

The yield of surface water averages about 871,000 acre-feet per year; an additional 98,000 acre-feet per year is imported from the upper Colorado region (table 15). Most of the streamflow in the mountains is derived from snowmelt, and maximum runoff is in June; minimum runoff is in February. On the plains, maximum runoff is in June or July, depending on location; minimum runoff varies widely according to location and characteristics of the watershed.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 801,000 acre-feet (table 15). Evaporation from the reservoirs averages 58,000 acre-feet per year.

The concentration of dissolved solids in the headwaters streams generally is less than 100 mg/l. The concentration increases downstream, generally ranging from less than 200 to more than 500 mg/l in the upper part of the Arkansas River and from about 1,000 to about 3,800 mg/l in the lower part.

The amount of surface water withdrawn for consumptive uses averages about 1.24 million acre-feet per year, and 620,000 acre-feet per year is actually consumed. The largest use is for irrigation; the second largest use is for self-supplied industries.

The principal aquifers are unconsolidated sediments in the major river valleys, especially in the Arkansas River valley. These aquifers yield as much as 3,150 gpm of water to wells; the average yield per well is 650 gpm. Consolidated sedimentary rocks (sandstone) yield as much as 2,500 gpm of water to wells in some areas.

The depth to ground water in the unconsolidated sediments generally is less than 40 feet below land surface, and depths less than 20 feet are common.

The concentration of dissolved solids in ground water ranges from about 600 to about 8,150 mg/l, but the concentration in more than half of the water samples ranges between 1,000 and 3,000 mg/l. The salinity of the

Table 15.--Generalized water budget for the western Arkansas Region 1/

(1,000 acre-feet)

Subregion	Income		Outgo				Storage capacity	
	Surface-water inflow (ac-ft per yr)	Surface-water yield (ac-ft per yr)	Surface-water outflow (ac-ft per yr)	Consumption			Surface water (ac-ft)	Ground water (ac-ft) 3/
				Man's activities (ac-ft per yr) 2/	Wet land and phreatophytes (ac-ft per yr)	Reservoir evaporation		
Arkansas Valley	98	871	178	762	29	58	801	22,000 3/
Canadian - Cimarron	0	583	318	150	20	85	541	72,700
Totals (rounded)		1,450		912	49	143	1,340	94,700

1/ Data from published and unpublished reports and records of the New Mexico State Engineer Office and the U.S. Geological Survey.

2/ Includes consumption of both surface water and ground water.

3/ Storage in valley alluvium only.

water is due to diversion of slightly saline water for irrigation, part of which infiltrates into the ground with an added load of soil salts and fertilizer, and recirculation of ground water that is repeatedly pumped onto irrigated fields and part returned to the ground-water reservoir.

The quantity of ground water stored in the principal aquifer is about 22 million acre-feet, which is 27 times the storage capacity of all the surface reservoirs (table 15).

The amount of ground water withdrawn in 1970 for consumptive uses within the subregion was 251,000 acre-feet (table 16), of which 143,000 acre-feet was actually consumed. The largest was for irrigation (229,000 acre-feet); the second largest use was for self-supplied industries (12,000 acre-feet).

Water-resources problems in the Arkansas valley subregion that were identified by the Westwide study group include: (1) a need for more water of better quality for several cities and towns; (2) a need for more water for industries; (3) a conflict of preserving Bent's Old Fort or stabilizing the banks of the Arkansas River; (4) localized needs for additional flat-water recreation opportunities; (5) a possible need to purchase existing water rights to provide for permanent pools in reservoirs; (6) the possible desirability of designating wilderness areas in the mountains; (7) a need for more flood control; (8) mine drainage water of poor chemical quality; (9) salt loading of the Arkansas River; (10) a need for additional peak power and its relation to water supply; (11) water requirements and water rights for Federal lands; (12) a need for artificial recharge of ground water; (13) loss of agricultural land in the Arkansas valley; (14) severe erosion and sedimentation in some areas; (15) a need to modify the Arkansas River compact between Colorado and Kansas; (16) a conflict between protecting the environment and further economic development; and (17) use of flood plains for recreation to reduce potential flood damages.

Water supplies of better chemical quality for cities and towns in the Arkansas valley could be obtained by withdrawal of either surface water or ground water in the upper valley and transporting the water to places of use in transmission facilities isolated from the general hydrologic system. This procedure would not add to the water supply, but it would provide water of good quality in exchange for water of poor quality. The effective water supply can be increased only by better water management or by augmentation, that is, by importation or weather modification.

In some areas, flood problems could be eased by diverting floodflows to artificial recharge facilities, and the water would be stored for later

Table 16.--Estimated use of ground water in 1970 in the Western Arkansas Region

(1,000 acre-feet per year)

Subregion	Ground water withdrawn						Ground water consumed 1/
	Public supplies	Rural	Irrigation	Self-supplied industrial	Thermo-electric power generation	Total	
Arkansas Valley	10	9	220	12	0	251	143
Canadian-Cimarron	3	4	75	.6	.1	83	47
Total	13	13	295	13	.1	334	190

1/ Based on the ratio of water consumed to water withdrawn from all sources for the region.

Source: U.S. Geological Survey Circular 676 (1972).

use as needed. Also, nonflood surface flow in excess of immediate needs could be stored underground for later recovery and use.

Conjunctive use of ground water and surface water has been practiced for many years in the Arkansas valley. However, this approach could be greatly improved through a unified water-management program. At the present time, ground-water recharge is incidental to surface-water irrigation, rather than planned and controlled recharge, and ground-water withdrawals reduce surface flows, without provision for satisfying downstream rights to divert surface water.

Quantitative hydrologic studies are in progress in the lower part of the valley, including construction of an analog model and preliminary analyses of the responses of the hydrologic system to different stresses of input and output of water. The model is still available for analyses that may be needed for planning a total water-management program.

Preliminary studies of the upper part of the basin indicate as much ground water may be stored there as in the lower part of the basin. Quantitative hydrologic studies of the upper part are needed, so the entire basin can be integrated into a single hydrologic system for planning total water management.

Special emphasis also needs to be given to possibilities of artificial recharge with floodflows and salvage of water now consumed by phreatophytes.

Canadian-Cimarron Subregion

The Canadian-Cimmaron subregion includes all the drainage of these rivers in New Mexico (fig. 30). The subregion is characterized by high mountains and narrow valleys and canyons in the western part and level to irregular plains in the eastern part. Elevations range from about 3700 feet along the Canadian River where it leaves the subregion to more than 10,000 feet on some of the mountains along the western boundary. The principal stream is the Canadian River.

Average annual precipitation ranges from about 15 inches on a large part of the plains to more than 24 inches on the higher mountains. Much of the precipitation in the mountains falls as snow in winter. Most of the precipitation on the plains is rain with the monthly maximum anytime from May to August, depending on location.

The yield of surface water averages 583,000 acre-feet per year (table 15). Much of the runoff from the mountains is derived from snowmelt, and maximum runoff is in May; the minimum is in December. The maximum and minimum runoff from the plains varies by location and is affected directly by rates of rainfall.

Surface reservoirs for regulation of streamflow have a combined storage capacity of 541,000 acre-feet (table 15). Evaporation from the reservoirs averages 85,000 acre-feet per year.

The concentration of dissolved solids in headwaters streams generally is less than 200 mg/l. The concentration increases downstream, and the Canadian River contains as much as 7,000 mg/l dissolved solids during low flow, near the New Mexico-Texas line. The increase in dissolved solids downstream is due primarily to solution of abundant soluable minerals in the rocks across and through which the water flows. Some increase is due to return flow of irrigation water.

The amount of surface water withdrawn for consumptive uses averages about 234,000 acre-feet per year, and 103,000 acre-feet per year is actually consumed. The largest use is for irrigation (223,000 acre-feet); the second largest use is for rural supplies (9,100 acre-feet per year).

The principal aquifers in the Canadian-Cimarron subregion are unconsolidated sediments in stream valleys and on the level plains. Secondary aquifers are consolidated sedimentary rocks (sandstone and limestone). The distribution of aquifers in unconsolidated sediments is shown in figure 30. The yield of the principal aquifers is highly variable, depending on the character and thickness of the material. Yields of water to individual wells commonly are a few to several hundred gallons per minute. Sandstone aquifers generally yield less than 100 gpm of water to wells. Locally, volcanic rocks yield a few hundred to a few thousand gpm of water to wells, but the lateral extent of these aquifers is small.

The depth to ground water in the principal aquifers generally is less than 200 feet below land surface but may be as much as 500 feet in some areas.

The concentration of dissolved solids in ground water generally is less than 1,000 mg/l, but in some areas it may approach 1,500 mg/l.

The quantity of ground water stored in the principal aquifers is 72.7 million acre-feet (table 15), which is 134 times the storage capacity of all the survace reservoirs in the subregion.

The amount of ground water withdrawn in 1970 was 83,000 acre-feet, of which 47,000 acre-feet was actually consumed (table 16). The largest use was for irrigation (75,000 acre-feet); the second largest use was for rural supplies (4,000 acre-feet).

Water-resources problems that were identified by the Westwide study group include: (1) declining ground-water levels caused by heavy pumping in local areas; (2) a need for more water of better chemical quality for most towns; (3) a salinity problem in reservoirs; (4) economically depressed areas; (5) severe erosion and sedimentation; (6) a need for studies to determine instream flow requirements for fish and wildlife and outdoor recreation; (7) localized needs for additional flat-water recreation opportunities; and (8) uncontrolled development and use of surface waters and adjacent lands.

The water supply in the areas of declining ground-water levels could be increased by importation or weather modification. The cost of importation from most available sources probably would be prohibitive under the present economy. Weather modification, in conjunction with artificial recharge, also would be costly but possibly feasible under favorable conditions. Some artificial recharge to the principal aquifer possibly could be accomplished by diversion of excess flow from the major streams.

The ground water has been overdeveloped under a State philosophy of permitting development to the extent of allowing a reasonable return on the investment over a finite period of time. The productive life of an aquifer can be maximized by use of the best technology in water conservation.

Preliminary studies indicate that adequate supplies of ground water for new developments may be available in some local areas, where there has been little exploration. However, the potential of these areas has not been evaluated.

Quantitative hydrologic studies need to be made in the area containing the principal aquifer in the east-central part of the subregion (fig. 30). These studies would include an evaluation of the possibilities for artificial recharge from local accumulations of surface water during rainy periods and by diversion from major streams. The studies need to be extended to an evaluation of the potential for weather modification to increase precipitation, in order to augment the water supply.

Quantitative studies, possibly including special drilling and hydraulic testing, need to be made in the areas that appear to have a potential for new ground-water developments but have not been adequately explored.

Southern High Plains Subregion

The Southern High Plains subregion includes that part of the Texas Gulf region in eastern New Mexico (fig. 30). It is described along with the western Arkansas region because it is adjacent and has many characteristicts in common with that region. The subregion is characterized by level to slightly irregular plains. There are no perennial streams, and much of the drainage is internal to innumerable small depressions, where the water infiltrates slowly into the ground or evaporates.

Average annual precipitation on the subregion is about 16 inches. Maximum monthly precipitation varies from one area to another but is in the period July to September. Minimum monthly precipitation is in February.

The yield of surface water has not been determined, because of local flow into the many small depressions.

The only use of surface water is a small amount of pumping from the depressions onto nearby fields, when water is available in the depressions.

The principal aquifers in the Southern High Plains subregion consists of unconsolidated sediments, as shown in figure 30. Secondary aquifers are in consolidated sedimentary rocks (mainly sandstone), generally underlying the unconsolidated sediments. The principal aquifers yield as much as 1,700 gpm of water to individual wells, and yields of 1,000 gpm are common. Yields of more than 100 gpm are obtained throughout most of the subregion. The secondary aquifers yield as much as 1,000 gpm to wells only in small local areas.

The depth to ground water in the principal aquifers generally is less than 200 feet but is 200 to 500 feet in some areas.

The concentration of dissolved solids in ground water from the principal aquifers generally is less than 600 mg/l but may be as much as 1,500 mg/l locally. The water in the secondary aquifers is more saline than that in the primary aquifers.

The quantity of fresh ground water in storage is 30 million acre-feet. An additional 55 million acre-feet of slightly saline water is in storage.

The amount of ground water withdrawn in 1970 for consumptive uses was 533,000 acre-feet, of which 274,000 acre-feet was actually consumed. The largest use was for irrigation (487,000 acre-feet); the second largest use was for self-supplied industries (26,800 acre-feet).

Ground-water problems and studies needed in the Southern High Plains subregion are similar to those in the Canadian-Cimarron subregion, except that perennial streams do not exist in the Southern High Plains. The reader is referred to the description of possible alternatives and studies needed, described for the Canadian-Cimarron subregion.

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