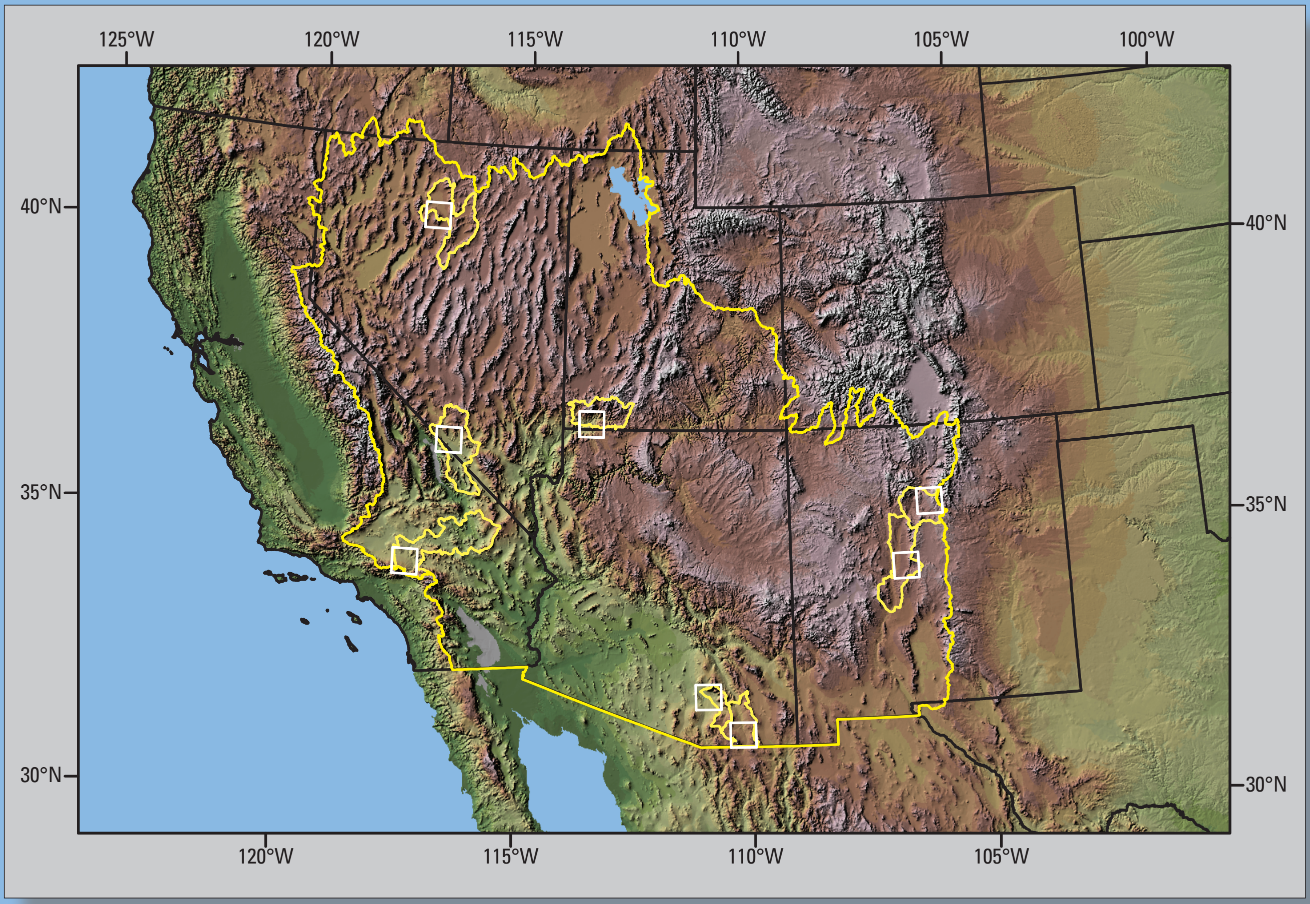
Ground-Water Resources Program
National Research Program

Ground-Water Recharge in the Arid and Semiarid Southwestern United States



Professional Paper 1703

U.S. Department of the Interior
U.S. Geological Survey

Ground-Water Recharge in the Arid and Semiarid Southwestern United States

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Volume comprises chapters A, B, C, D, E, F, G, H, I, J, K, and appendicies 1 and 2

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U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

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FRONT COVER. Digital elevation map of the southwestern United States showing the boundary of the regional-analysis area (large yellow outline) and site-specific study areas (small yellow outlines and white squares). Base map, extracted from the USGS National Atlas product “Shaded Relief of North America,” shows elevations from below sea level (gray) to greater than 3,000 meters (white). The caption of figure 1 in chapter C provides additional details.

Foreword

The population of the arid and semiarid southwestern United States is growing at a rate roughly three times that of the Nation as a whole. With limited rainfall and surface-water resources, the area relies heavily on ground water for beneficial uses. The sustainability of ground-water resources, including the life-supporting springs, wetlands, and streams that are fed by natural ground-water discharge, depends on the often sensitive balance of replenishment and depletion.

Recharge is the input to ground-water systems, yet determining recharge has long remained one of the most difficult challenges in hydrologic science. Ground-water systems are seldom at steady state, particularly in dry regions where precipitation and temperature are highly variable. Water-resources planning in such regions relies not only on identifying the timing, locations, and amounts of recharge but also on understanding the interacting processes that modulate recharge. An improved understanding of recharge dynamics can enhance our ability to assess and potentially mitigate the susceptibility of ground-water resources to natural and anthropogenic climatic and vegetational shifts.

As part of the U.S. Geological Survey mission to provide reliable information for resource management, this volume represents a systematic attempt to improve understanding of ground-water recharge in the arid and semiarid southwestern United States. The studies contained herein represent a major step toward characterizing recharge processes and rates throughout this part of the Nation and toward advancing methods for conducting recharge assessments and related scientific research in similar regions around the world.

Robert M. Hirsch

Associate Director for Water

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Professor Andrew M. Binley’s borehole geophysics study (reported in Appendix 2) was funded by the United Kingdom’s Natural Environment Research Council under grant GR3/11500.

Many employees helped in the execution of studies and with report preparation and review. In accordance with USGS practice, these employees are not acknowledged by name. Nevertheless, their efforts were essential to the field, modeling, and laboratory aspects of this research and resulted in an improved final document. In addition to the efforts of the internal reviewers, Professor Ty P.A. Ferré (University of Arizona), James R. Harrill (USGS-retired), and Professor Kamini Singha (Pennsylvania State University) provided helpful suggestions and comments on individual sections of the document.

Volume Contents

Chapters:

Appendicies:

Conversion Factors and Datums

Multiply	By	To obtain
	Length	
millimeter (mm)	3.93701	hundreth of an inch (1/100 in)
centimeter (cm)	0.393701	inch (in)
meter (m)	39.3701	inch (in)
meter (m)	3.28084	foot (ft)
kilometer (km)	0.621371	mile (mi)
	Area	
square meter (m^2)	10.76391	square foot (ft^2)
hectare (ha)	2.47104	acre (acre)
square kilometer (km^2)	247.104	acre (acre)
square kilometer (km^2)	0.386102	square mile (mi^2)
	Volume	
cubic centimeter (cm^3)	0.0610237	cubic inch (in^3)
liter (L)	0.264172	gallon (gal)
cubic meter (m^3)	264.172	gallon (gal)
cubic hectometer (hm^3)	810.710	acre foot (acre-ft)
million cubic meters (Mm^3)	810.710	acre foot (acre-ft)
	Mass	
milligram (mg)	0.0154327	grain, avoirdupois (gr)
gram (g)	0.0352740	ounce, avoirdupois (oz)
kilogram (kg)	2.20462	pound, avoirdupois (lb)
	Density	
gram per cubic centimeter (g/cm^3)	0.578037	ounce per cubic inch (oz/in^3)
megagram per cubic meter (Mg/m^3)	62.4280	pound per cubic foot (lb/ft^3)
	Rate or flux density	
millimeter per second (mm/s)	0.0393701	inch per second (in/s)
millimeter per year (mm/yr)	0.0393701	inch per year (in/yr)
meter per hour (m/hr)	3.28084	foot per hour (ft/hr)
meter per hour (m/hr)	78.7402	foot per day (ft/day)
meter per day (m/d)	3.28084	foot per day (ft/d)
meter per year (m/yr)	3.28084	foot per year (ft/yr)
liter per second (L/s)	15.8503	gallon per minute (gal/min)
cubic meter per second (m^3/s)	35.3147	cubic foot per second (ft^3/s)
cubic meter per minute (m^3/min)	0.588578	cubic foot per second (ft^3/s)
cubic meter per day (m^3/d)	35.3147	cubic foot per day (ft^3/d)
cubic meter per day (m^3/d)	264.1721	gallon per day (gal/d)
cubic hectometer per year (hm^3/yr)	810.710	acre foot per year (acre-ft/yr)
million cubic meters per year (Mm^3/yr)	810.710	acre foot per year (acre-ft/yr)
	Hydraulic conductivity	
meter per day (m/d)	3.28084	foot per day (ft/d)
	Pressure	
kilopascal (kPa)	0.145038	pound per square inch (psi)
megapascal (MPa)	9.86923	atmosphere (atm)

Conversion Factors and Datums—Continued

Multiply	By	To obtain
	Heat	
joule (J)	0.23885	calorie, international (cal)
	Volumetric heat capacity	
joule per cubic meter per degree Celsius (J/m^{3}ºC)	0.0037575	calorie per cubic foot per degree Fahrenheit (cal/ft^{3}ºF)
	Thermal conductivity	
watt per meter per degree Celsius (W/m ºC)	0.040445	calorie per second per foot per degree Fahrenheit (cal/s ft^{3}ºF)
	Radioactivity	
becquerel per liter (Bq/L)	27.027	picocurie per liter (pCi/L)

Except as noted, horizontal coordinates refer to the North American Datum of 1927 (NAD 27).

Vertical coordinates refer to the North American Vertical Datum of 1988 (NAVD 88).

"Altitude" in this report refers to the vertical distance above the vertical datum.

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Concentration units for chemical constituents in water are milligrams of solute per liter of solution (mg/L), or micrograms of solute per liter of solution (µg/L).

Specific-conductance units are microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

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