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Hydrologic Engineering Center

Importance of Surface-Ground Water Interaction to Corps Total Water Management: Regional and National Examples

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Hydrologic Engineering Center
U.S. Army Corps of Engineers
609 Second Street
Davis, CA 95616
(916) 756-1104

IMPORTANCE OF SURFACE-GROUND WATER
INTERACTION TO CORPS TOTAL WATER MANAGEMENT:
REGIONAL AND NATIONAL EXAMPLES

CONTENTS

PREFACE

The Hydrologic Engineering Center was asked through the Corps of Engineers' research and development program to examine the interaction of surface and ground water and its role in Corps of Engineers' planning and management. While surface water and ground water have each been investigated extensively over many years, their interaction, particularly along rivers, has been studied much less. How this interaction affects the planning and management of our nation's water resources is even less understood. So the topic is appropriate for research.

This document reports on an initial effort of the study. Its purpose is to present examples of watersheds and river basins where the Corps of Engineers has facilities whose operation is influenced by the surface-ground water exchange of the region. It is a conceptual presentation. Examples are selected which illustrate differences in region, hydrology and geohydrology. The point illustrated by each example is that the water resource being managed has as its source both surface and ground water and management of the total resource necessitates an understanding of the exchange between the two sources. References are cited that provide additional technical information, however, as might be expected, they often do not address surface-ground water interaction directly or in detail.

The graphics for this report were prepared by Roger Kohne and Bill Johnson served as project engineer in the Planning Analysis Division, Hydrologic Engineering Center. During the study Mike Burnham was Chief, Planning Analysis Division and Darryl Davis, Director, Hydrologic Engineering Center.

FINDINGS OF THIS STUDY

Surface and ground water are commonly identified as separate resources. They are, however, both part of the same resource with the same origin, the same hydrologic cycle, and the same ult'mate destination. Together they meet the vast fresh water needs of our nation. The Corps of Engineers, through its water control responsibilities, is directly involved in storing, diverting, releasing, spreading, and otherwise managing both surface and ground water. Because surface and ground water are physically interconnected, the management of one affects the availability of the other.

It is the purpose of this report to describe specific regional and national examples where surface and ground water are integral to the Corps' water control responsibilities. Through these examples an effort is made to show how ground water and its interaction with surface water are important to improve the Corps' planning and management.Each example includes a brief summary, illustrative figures, and technical references. The references provide technical depth not present in the summary or figures. The regions covered by the selected examples are shown in Figure 1. They provide a broad geographical distribution throughout the country and illustrate surface-ground water exchange near rivers. Two national examples are cited: wetlands where discharge and recharge occur between surface and ground water, and Army installations where environmental restoration is focused on preventing surface contaminants from polluting underlying ground-water supplies at local disposal sites.

One observation that comes through clearly in each example is the necessary and integral role ground water plays in total water management. The examples illustrate that ground water is a major supply source in the Snake River plain; affects multiple uses in the Delaware River basin; and is recharged by reservoir releases in the Los Angeles basin. Ground water is also a source of discharge and recharge in wetlands hydrology; interacts seasonally with irrigation and drainage canals such as are common in Southeast Florida; and is a source of salt pollution in surface streams throughout the Southwest. The Army's restoration program illustrates the potential for ground-water contamination from surface waste disposal sites.

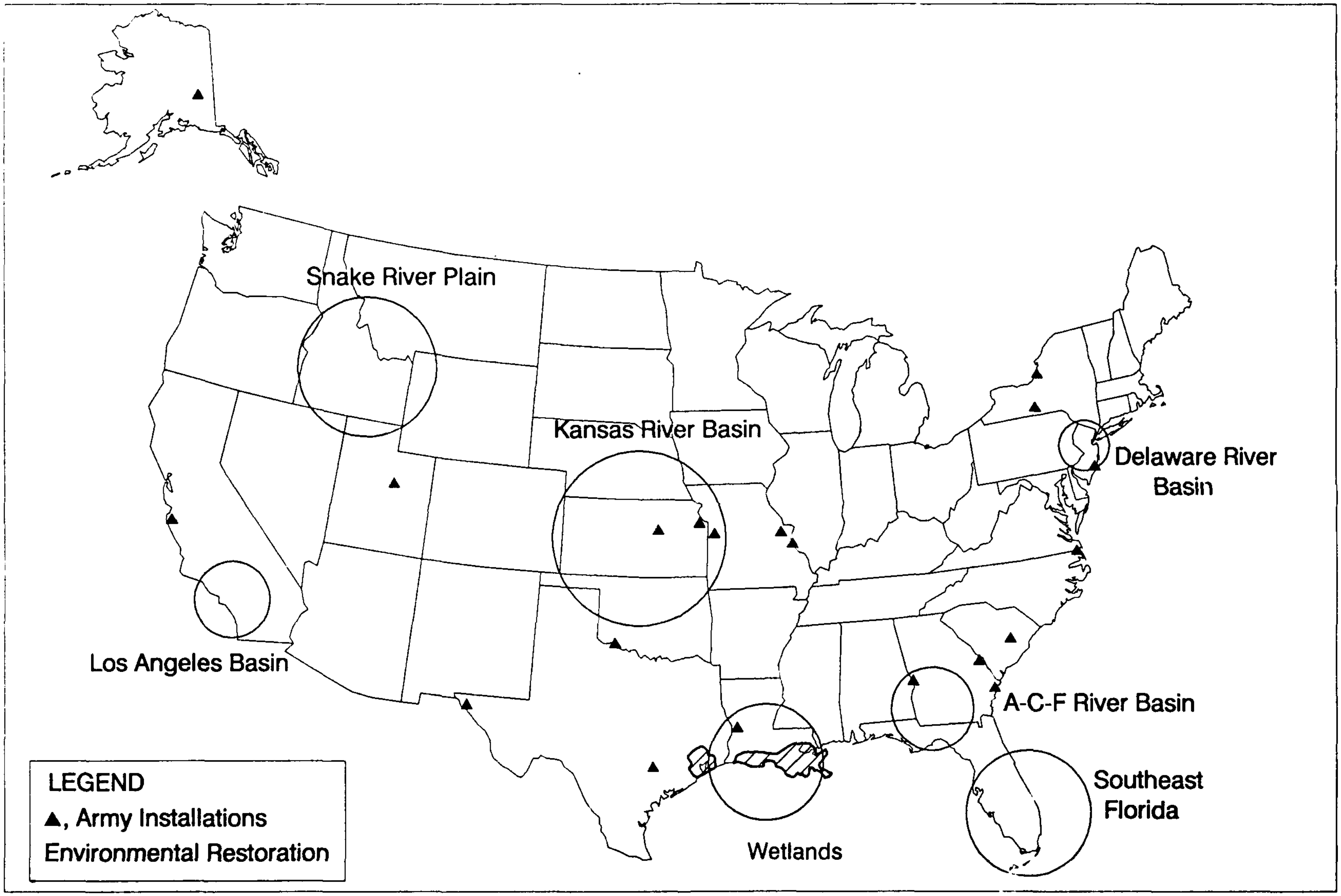


Figure 1: Location Map, Examples of Surface-Ground Water Interaction

The integral nature of surface and ground water provides an opportunity for the Corps to incorporate ground water into its planning and management in a direct, explicit way. Some specific examples of what can be done include,

. an analysis of available technical information about the hydrogeology of ground-water aquifers underlying rivers and reservoirs managed by the Corps,

. the development of information, using available data, on the rate and seasonal variability of the exchange between surface and ground water along rivers effected by Corps' operations,

. the compilation of available data on the location and withdrawal rate of pumping wells in the vicinity of rivers and reservoirs managed by the Corps,

. an analysis of the role of ground water during Corps' drought operations and its contribution to low streamflow,

. an assessment, in water-scarce regions, of the opportunities for surface-ground water (conjunctive use) management by the Corps.

Most technical information about the hydrogeology of our nation's aquifers resides with the U.S. Geological Survey through its long history of studying aquifers and through recent efforts to describe their regional nature in its Regional Aquifer System Analysis (RASA) program and Ground-Water Atlas of the United States. The RASA program and its technical reports present data and analyses that have direct application to Corps' planning and management. There are over 500 such documents on aquifers nationwide. This study cites some of these documents as references. They provide comprehensive and detailed ground-water information which is applicable to many aspects of the Corps' mission.

LOS ANGELES BASIN: GROUND-WATER RECHARGE

The use of flood waters stored at Corps reservoirs for recharge into a ground-water aquifer is illustrated at Whittier Narrows Dam in the Los Angeles Basin (Figure 2). Streamflow from the Rio Hondo and San Gabriel Rivers enter the reservoir, is stored and later released to spreading grounds downstream for ground-water recharge (Figure 3). Beyond the spreading grounds both rivers empty into the ocean. This manner of operation enhances local water supply programs within a framework of preserving the flood protection capability.

The Rio Hondo River is concrete lined from the dam to the ocean. The spreading grounds are operated as off-channel basins on both sides of the river (Figure 3). Water released to the river is diverted to the spreading grounds through Los Angeles County, Department of Public Works control gates. Total storage capacity in the basins is approximately 4300 acre-feet.

The San Gabriel River is unlined from the dam to the ocean. Water released to the river channel is stored behind air inflatable rubber dams which allow both for diversion of the water to the off-channel spreading grounds and recharge directly to the river (Figure 3). Approximately 1250 acre-feet of storage is available in the spreading grounds and river.

Recharge operations occur throughout the year provided water is available in the reservoir. During the 1988 water year, 11,500 acre-feet of water was recharged to the aquifer through the storage and release operation of the Corps.

References

U.S. Army Corps of Engineers, 1989, *Annual Report on Water Control Management, Water Year 1988*, Los Angeles District.

U.S. Army Corps of Engineers, No date, *Water Control Handbook, Reservoir Regulation Unit*, Los Angeles District.

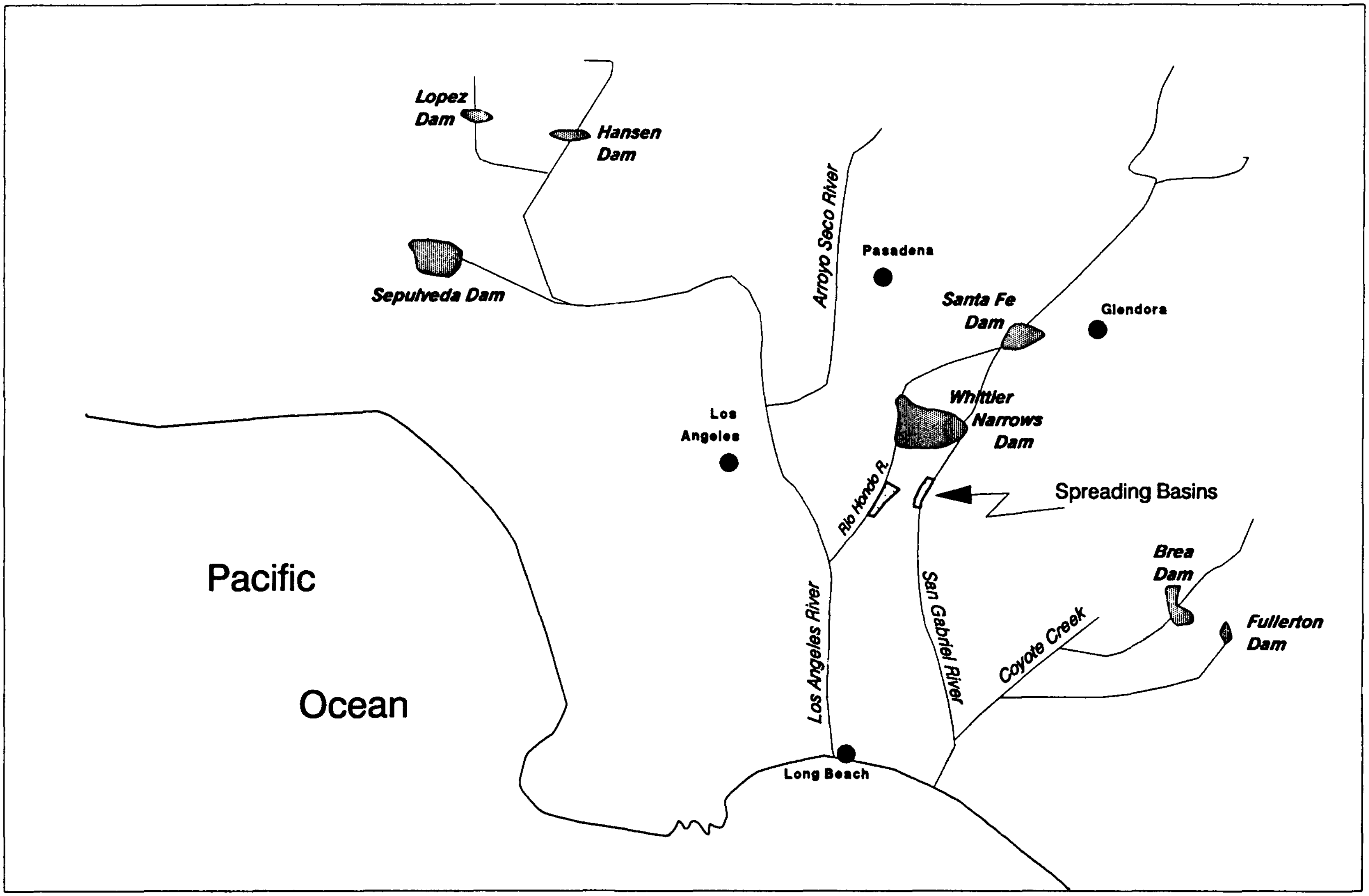


Figure 2: Los Angeles Basin and Whittier Narrows Dam recharge area

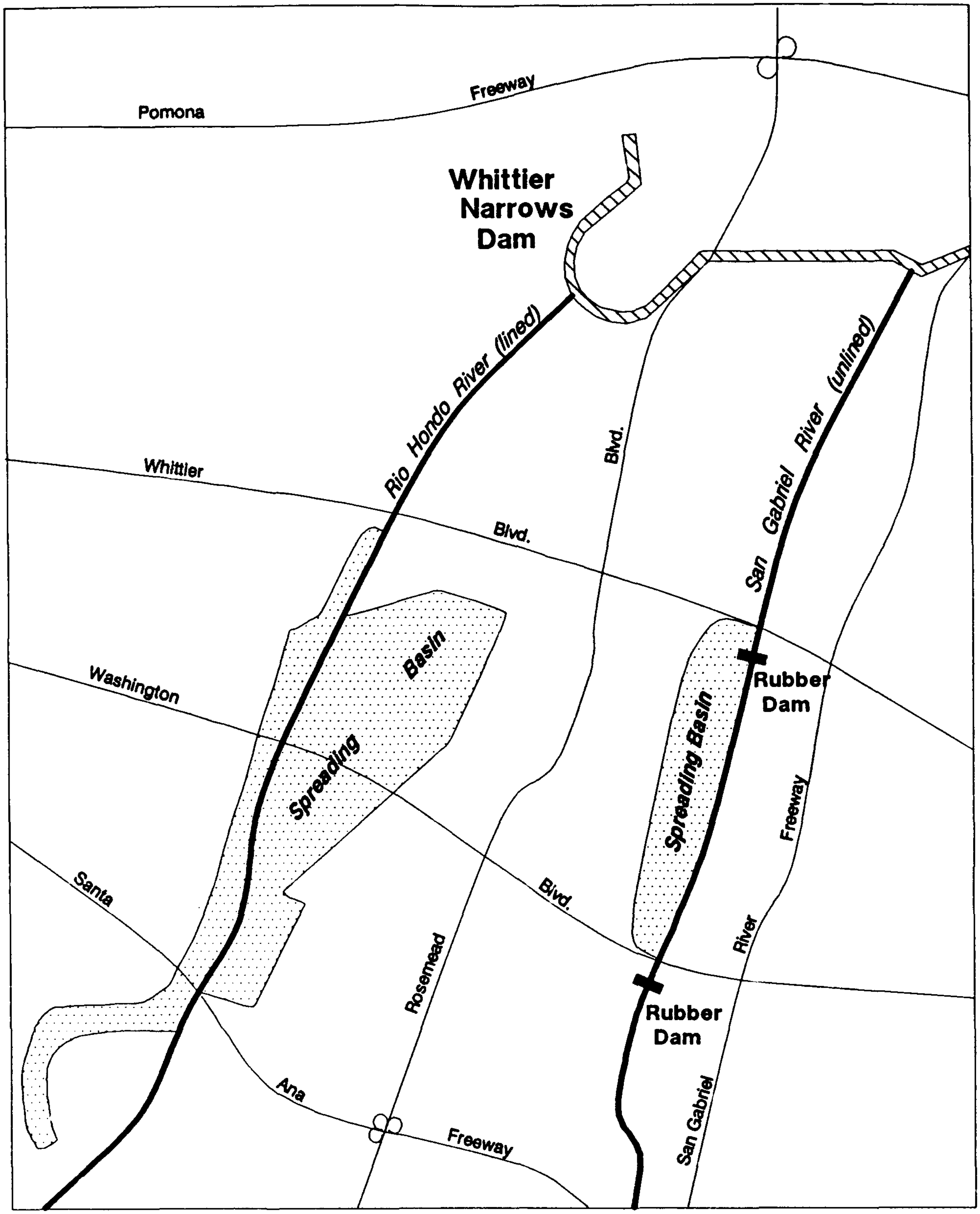


Figure 3: Whittier Narrows Dam and downstream recharge basins

SNAKE RIVER PLAIN: GROUND-WATER SUPPLY TO DOWNSTREAM RESERVOIRS

The Snake River Plain is an example of the significant role played by ground water as a source of supply to surface water and Corps' reservoirs downstream. The plain extends across southern Idaho into eastern Oregon covering an area of about 15,600 mi^2 and ranging in width from 30 to 75 mi (Figures 4 and 5). The Corps of Engineers operates five multiple-purpose reservoirs on the lower and middle Snake River, downstream from the plain. There is one Corps reservoir, Lucky Peak, on the Boise River, which is tributary to the Snake River at the lower end of the plain (Figure 5). Other reservoirs which regulate flow to or in the plain are operated by the U. S. Bureau of Reclamation and non-federal interests. Water is regulated for flood control, hydroelectric power, fish and wildlife, recreation, and irrigation. Upstream from Weiser (Figure 5) there is approximately 9.5 million acre-ft of usable storage capacity. Downstream, water from the Snake is used for similar purposes and also navigation. During flood conditions the aquifer serves as a storage reservoir for runoff.

The plain to the east of the community of King Hill is underlain primarily by volcanic rocks, mostly basalt, and the aquifers discharge large volumes of water to the Snake River. The western plain is underlain by sedimentary rocks and the aquifers in these rocks generally store and release smaller volumes of water. The underlying aquifers in the plain are hydraulically connected to the surface through infiltration of precipitation and irrigation. Discharge from the aquifer is through springs and seeps.

In water year 1980, the net ground-water discharge to the Snake River equaled 58 percent of the flow in the Snake River at Weiser. Springs flowing from the north side of the Snake River canyon in the reach from Milner to King Hill constitute a major part of this ground-water discharge. Average annual ground-water discharge from the north side in water year 1980 was approximately 6000 cfs (4.3 million acre-ft per year).

Irrigation is widely practiced in the Snake River Plain and has greatly affected the natural flow regime of the Snake River. Originally surface irrigation increased ground-water levels and discharge to the river. Since 1955 increased ground-water withdrawals by pumping have decreased ground-water discharge in some reaches.

The significant discharge of ground water to the Snake River illustrates the importance of ground water as a supply source for meeting surface water needs. The two are closely related and together form the basis for the planning and management of water resources in the region.

References

Kjelstrom, L. C. 1986. "Flow Characteristics of the Snake River and Water Budget for the Snake River Plain, Idaho and Eastern Oregon," *Hydrologic Investigations Atlas, HA-680*, U. S. Geological Survey, Reston, VA.

Kjelstrom, L. C. 1988. "Estimates of Gains and Losses for Reservoirs on the Snake River from Blackfoot to Milner, Idaho, for Selected Periods, 1912 to 1983," *Water Resources Investigations Report 87-4063*, U. S. Geological Survey, Boise Idaho.

U. S. Army Corps of Engineers. 1986. *Columbia River Water Management Report for Water Year 1986*, Columbia River Water Management Group.

Kjelstrom, L. C. (draft) "Ground-water/surface-water Relations and Ground-water Budgets for the Snake River Plain, Idaho and Eastern Oregon," *Professional Paper 1408-C*, U. S. Geological Survey, Washington D.C.

Lindholm, G. F. et al 1987. "Configuration of the Water Table and Depth to Water, Spring 1980, Water-Level Fluctuations, and Water Movement in the Snake River Plain Regional Aquifer System, Idaho and Eastern Oregon," *Hydrologic Atlas HA-703*, U. S. Geological Survey, Reston, VA.

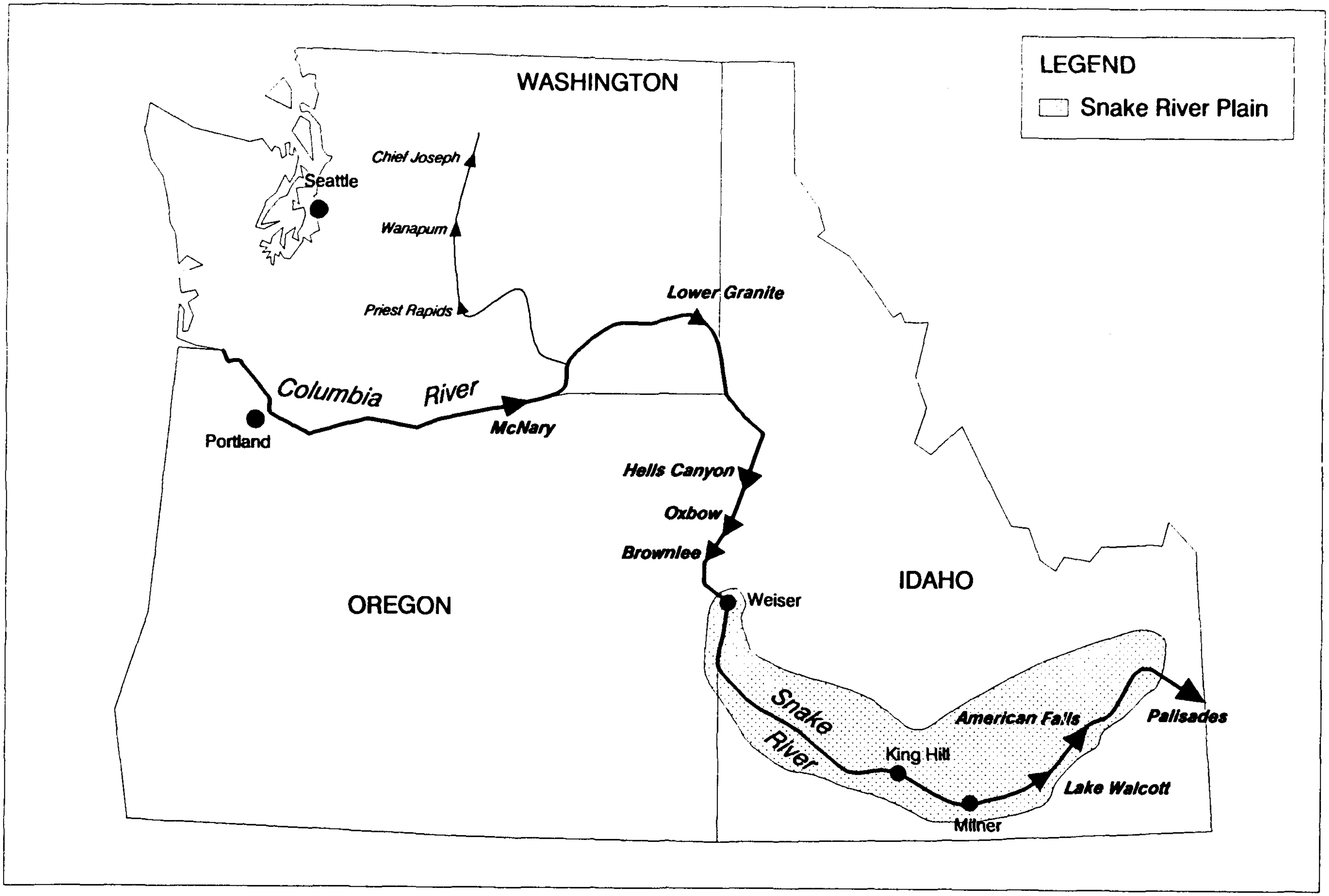


Figure 4: Lower Snake River Plain

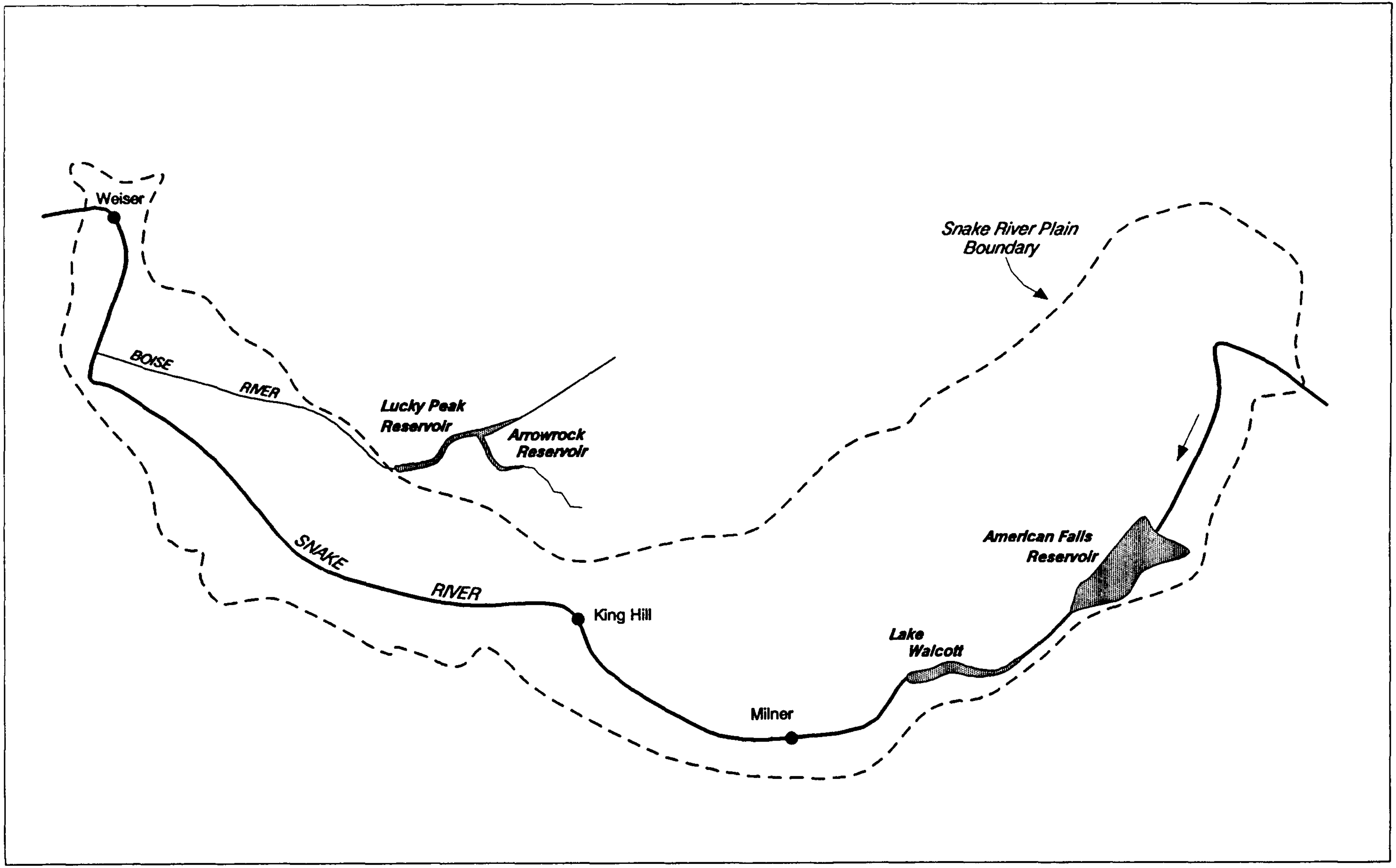


Figure 5: Snake River Plain

SOUTHWESTERN RIVER BASINS: MINERAL INTRUSION FROM GROUND WATER

Natural mineral intrusion into surface streams is a pollution problem in a large region of the Southwest (Figure 6). The dissolution of salt from natural geologic formations enters streams through pressure and percolation of water from ground water, springs, and seeps. The principal contaminants are sodium chloride (table salt) and calcium sulfate (gypsum). Salts reduce the quality of the surface water and during low streamflow conditions may cause the quality to exceed recommended drinking-water quality standards for chloride. In some locations streamflow is not suitable for municipal, industrial, or agricultural purposes and affect the population centers and agricultural production served by surface streams. If this salinity problem were reduced, greater use could be made of surface flow.

Corps' offices in the region are often involved in cooperative investigations with state and federal agencies to identify alternative ways to control mineral contamination. Dilution and interception are two common ways used to contain, control, and dispose of salts. In Kansas, for example, dilution releases could be made from Corps' reservoirs Milford, Tuttle Creek and Perry Lakes when necessary to dilute mineralized waters entering surface streams (Figure 7). Interception wells reduce the flow of saline water to streams and dispose of it through deep well injection or evaporation ponds.

References

Kansas Water Office. 1985. *Kansas Water Plan, Quality Section, Sub-Section: Mineral Intrusion*, Topeka, Kansas.

U. S. Army Corps of Engineers. 1988. *Kansas and Osage River, Kansas, Appendix C: Mineral Intrusion Control*, Kansas City District, Kansas City, MO.

Rought, Barry G. 1984. "The Southwestern Salinity Situation: the Rockies to the Mississippi River," in French, Richard H. (editor) *Salinity in Watercourses and Reservoirs, Proceedings of the 1983 International Symposium on State-of-the-Art Control of Salinity, July 13-15, 1983*, Salt Lake City, Utah.

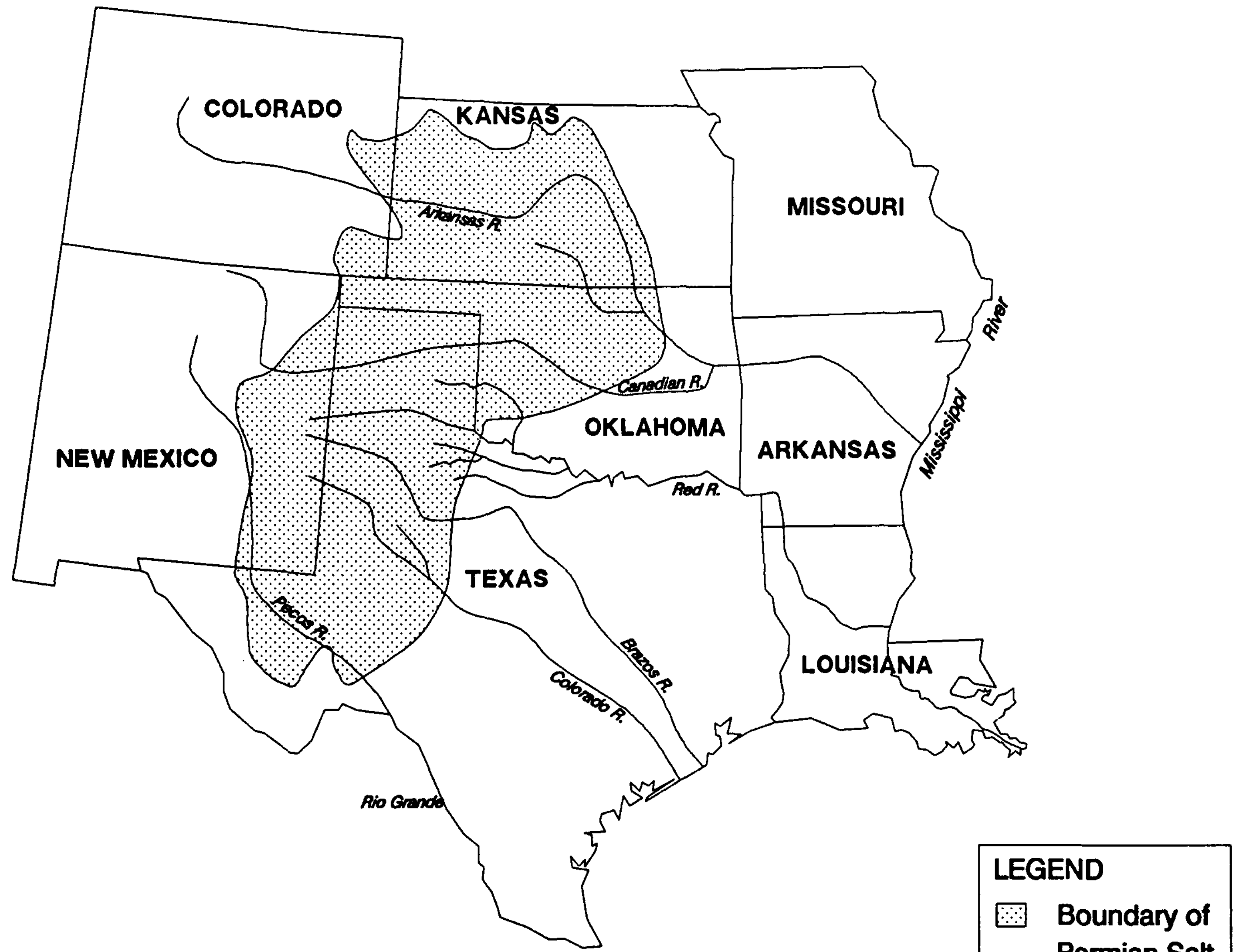


Figure 6: Salt Area, Southwestern United States

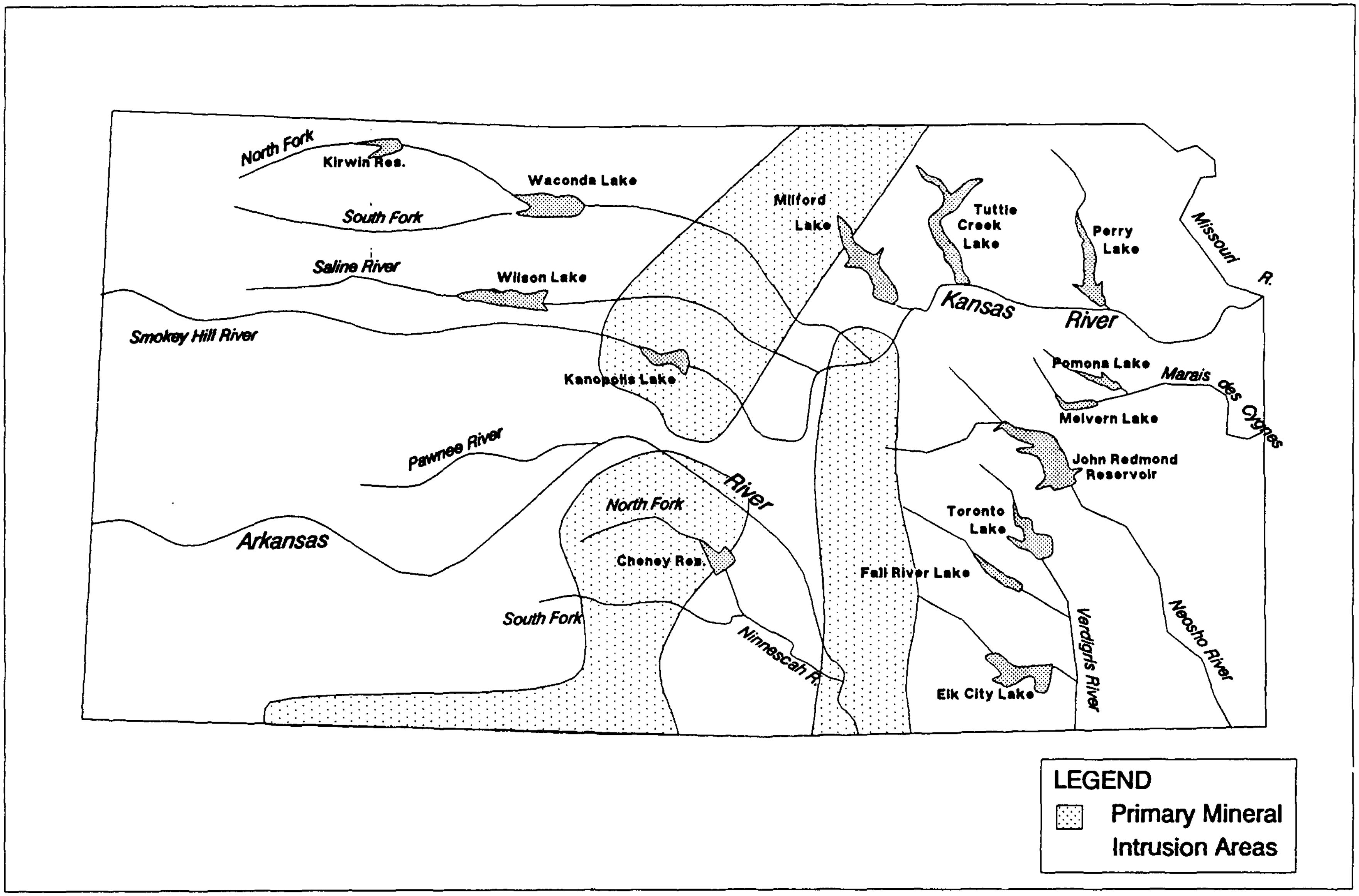


Figure 7: Primary mineral intrusion areas in Kansas
(Adapted from Kansas Water Office, 1985)

APALACHICOLA-CHATTAHOOCHEE-FLINT RIVER BASIN: GROUND WATER IN MULTIPLE-PROJECT OPERATIONS

The Apalachicola-Chattahoochee-Flint River basin, Georgia, is shown in Figure 8. Ground water is a significant source of supply to the Flint River below Albany, Georgia. Ground-water discharging to the Flint River then flows downstream into Lake Seminole, a Corps of Engineers run-of-river project, where it is joined by inflow from the Chattahoochee River. Together these two surface water sources are used at Jim Woodruff Dam to generate hydroelectric power and meet short duration navigation needs downstream. Reduced surface flows in the Flint River affect both operations at Jim Woodruff Dam and releases from Buford Dam upstream on the Chattahoochee River.

The Flint River is an example of a surface supply that is predominantly ground water. Ground water flows both to the Flint River and to tributary streams throughout the Flint River watershed. The rate of discharge varies depending upon the hydraulic conductivity of the aquifer, the hydraulic gradient between the aquifer and the stream stage, and the streambed conductance in areas of diffuse discharge. The hydraulic conductivity varies throughout the watershed as does the hydraulic gradient. The hydraulic gradient, however, also varies seasonally, during drought, and with well pumping.

When the potentiometric surface of the aquifer is high, usually during winter and early spring, the aquifer discharges maximum quantities of water into the Flint River and its tributaries. This is a period of heavy rainfall, low evapotranspiration and low irrigation pumping. When the potentiometric surface has been lowered by heavy pumping, high evapotranspiration and low rainfall, usually during late spring and early summer, discharge to the streams is reduced.

Discharge is also reduced during drought. Because the aquifer is recharged primarily by precipitation the absence of precipitation causes a lowering of the potentiometric surface and discharge rate. Recharge is normally during the period December through March when rainfall is heavy and of long duration.

Irrigation pumping also reduces discharge from the aquifer to the river. This is normally during late spring and early summer. Large withdrawals from the aquifer began about 1975 and have increased to 66 million gallons per day in 1983. Yet such withdrawals have not caused a long-term, regional decline of the water level in the aquifer. Studies by the U. S. Geological Survey are currently underway to determine the effects of increased withdrawals in the future.

The Flint River illustrates the interrelationships not only between surface and ground water but also between two projects. Release decisions at both Jim Woodruff Dam and Buford Dam depend upon surface inflow. Surface inflow from the Flint River, however, is supplied principally by ground water which is affected not only by precipitation but by the complex hydrogeologic features of the watershed. Understanding these features helps to improve water planning and management of the multiple-project system.

References

Hayes, Larry R., Morris L. Maslia, and Wanda C. Meeks. 1983. "Hydrology and Model Evaluation of the Principal Artesian Aquifer, Dougherty Plain, Southwest Georgia," *Bulletin 97*, Georgia Geologic Survey, Atlanta, GA.

Hicks, D.W., H.E. Gill, and S.A. Longsworth. 1987. "Hydrogeology, Chemical Quality, and Availability of Ground Water in the Upper Floridan Aquifer, Albany Area, Georgia," *Water-Resources Investigations Report 87-4145*, U. S. Geological Survey, Washington D.C.

Bush, Peter W. and Richard H. Johnston. 1988. "Ground-Water Hydraulics, Regional Flow, and Ground-Water Development of the Floridan Aquifer System in Florida and in Parts of Georgia, South Carolina, and Alabama," *Professional Paper 1403-C*, U. S. Geological Survey, Washington D. C.

Georgia Department of Natural Resources. 1984. *Water Availability & Use, Flint River Basin*, Environmental Protection Division, Atlanta, GA

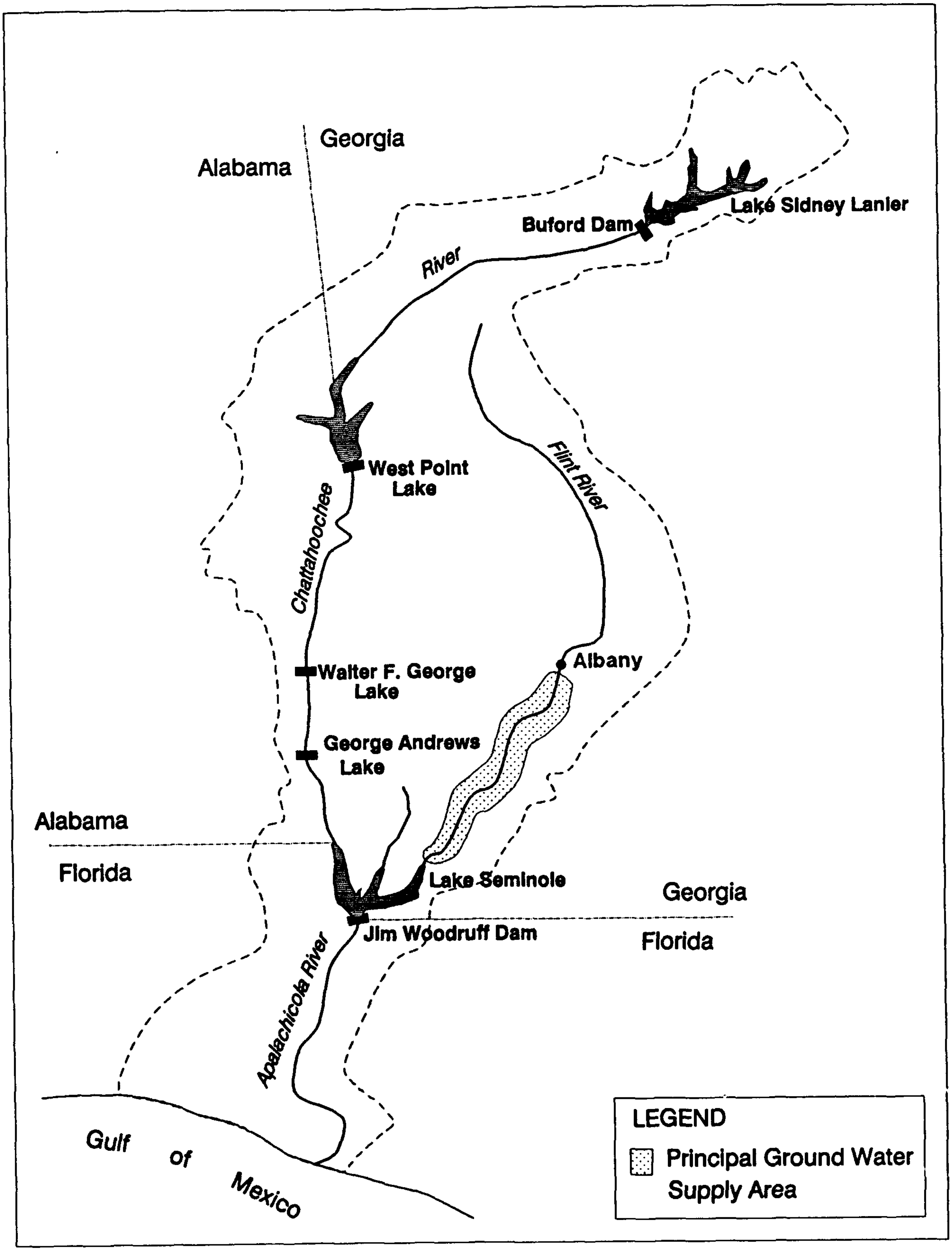


Figure 8: Apalachicola-Chattahoochee-Flint River Basin

SOUTHEAST FLORIDA: CANAL-AQUIFER EXCHANGE

The Southeast Florida canal system covers an area of approximately 3200 sq. mi. south of Lake Okeechobee to the Gulf of Mexico. The main canals and control structures are operated by the Corps of Engineers, the feeder canals by local interests. Significant exchanges of water occur between the canals, which are cut into the ground surface, and the highly transmissive Biscayne water table aquifer. Water flows into the canal when the water level is higher in the adjacent aquifer and from the canal when the water level is higher in the canal. These conditions are illustrated in Figure 9.

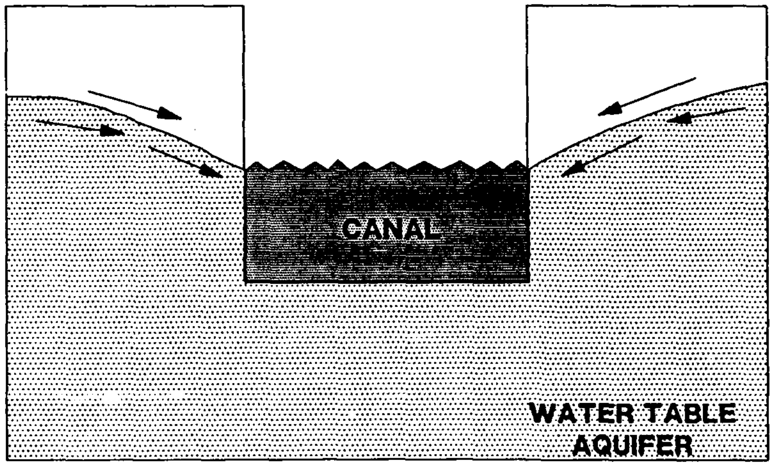
During rain storms the canal system helps to reduce flooding through rapid drainage of excess water from the land and its collection and transport to the ocean. This rapid drainage aids agricultural production significantly, especially during the planting season. Under normal weather, ground water flows to the canals where it is transported to the coastal areas to infiltrate into the aquifer raising the water table and retarding saltwater intrusion. The high transmissivity of the soil, together with the canal collection and transport system, make this recharge possible.

During low-flow conditions maintaining canal levels is difficult because water in the canal seeps into the aquifer lowering the canal stage. With the canal stages lower it is not possible to maintain sufficient head in the coastal areas to prevent saltwater intrusion. The saltwater intrusion affects agriculture through increased soil salinities, affects municipal water supply by contamination, and plant life by the drying of soils. Saltwater intrusion is a problem along the entire coastal zone of the Biscayne aquifer. It moves inland and upward in response to low ground-water levels and seaward and downward in response to high ground-water levels. Figure 10 illustrates the change in saltwater intrusion from 1943 to 1971.

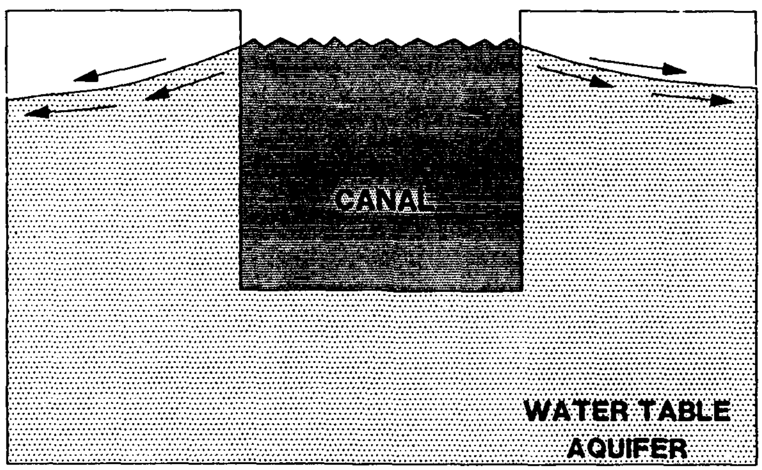
<u>References</u>

Klein, H. and J. E. Hull. 1978. "Biscayne Aquifer, Southeast Florida," *Water-Resources Investigation 78-107*, U. S. Geological Survey, Tallahassee, FL

Allman, David W., Paul G. Jakob, Tom McCann. 1979. "Improvement of the Canal-Aquifer Flow Regime in the C-IN Basin," *Technical Publication #79-2*, South Florida Water Management Distict, West Palm Beach, FL.



Ground-water seepage to the canal



Canal seepage to the aquifer

Figure 9: Canal-Aquifer Interaction

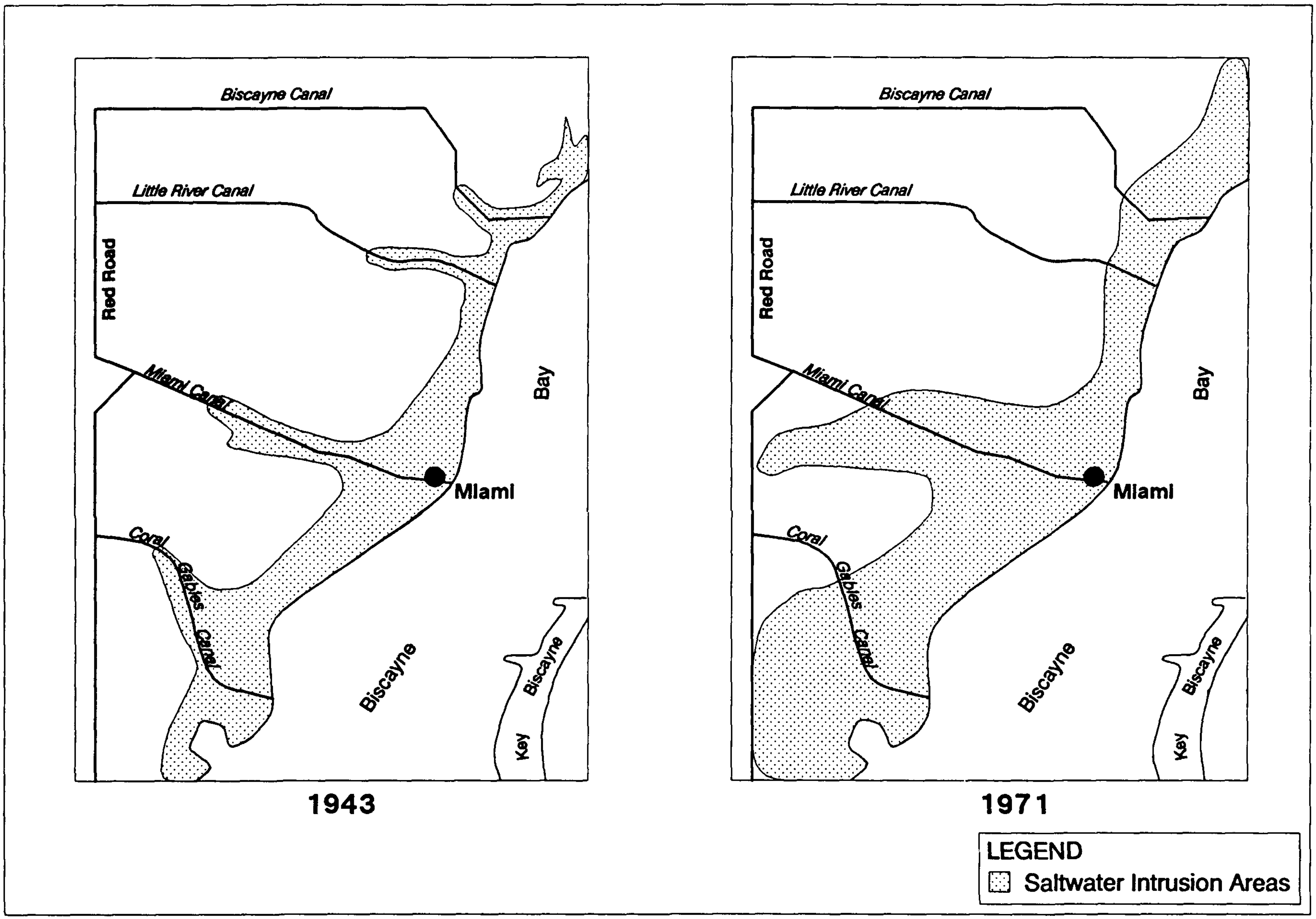


Figure 10: Areas affected by saltwater intrusion, 1943 and 1971

South Florida Water Management District. 1977. *Water Use and Supply Development Plan, Volume IB, Water Management System History and Performance*, West Palm Beach, FL.

DELAWARE RIVER BASIN: GROUND WATER FOR MULTIPLE-PURPOSE USE

The surface and ground-water resources of the Delaware River Basin provide water for a wide variety of purposes along the 339 miles of the Delaware River (Figure 11). These purposes include: municipal and industrial water supply, ground-water recharge and quality, stream and lake recreation, fish and wildlife habitat, wastewater and suspended-sediments dilution, navigation, and prevention of saltwater intrusion. The Corps of Engineers, through management of its reservoirs in the upper basin and navigation dredging in the lower basin, has an important role in meeting these needs. Also of importance is the effect of the river-aquifer interaction along the Delaware from Trenton to Wilmington. Here the Potomac-Raritan-Magothy aquifer system outcrops along approximately 65 miles of the Delaware River as it enters the estuary (Figures 12 and 13). The exchange between the river and aquifer has an important influence on the use of storage in the upper basin and the capacity of the basin to meet its water related needs.

Prior to the Coastal Plain becoming urbanized and development of well fields for domestic and industrial supply, ground water from the Potomac-Raritan-Magothy aquifer system flowed to the Delaware River. As the area became populated and industrialized, pumping increased, the aquifer head declined, and the hydraulic gradient reversed, causing Delaware River water to flow to the aquifer. This reversal is particularly significant in the vicinity of Camden.

The withdrawal of ground water from the Coastal Plain must be replaced by recharge from the Delaware River, precipitation, or other freshwater sources to prevent saltwater intrusion of the Potomac-Raritan-Magothy aquifer. Without replenishment, the saltwater-freshwater interface will move landward contaminating the freshwater aquifer and threatening potable ground-water supplies. The significant quantities of water needed from the Delaware River near the pumping centers place an additional demand on the basin's surface water supplies.

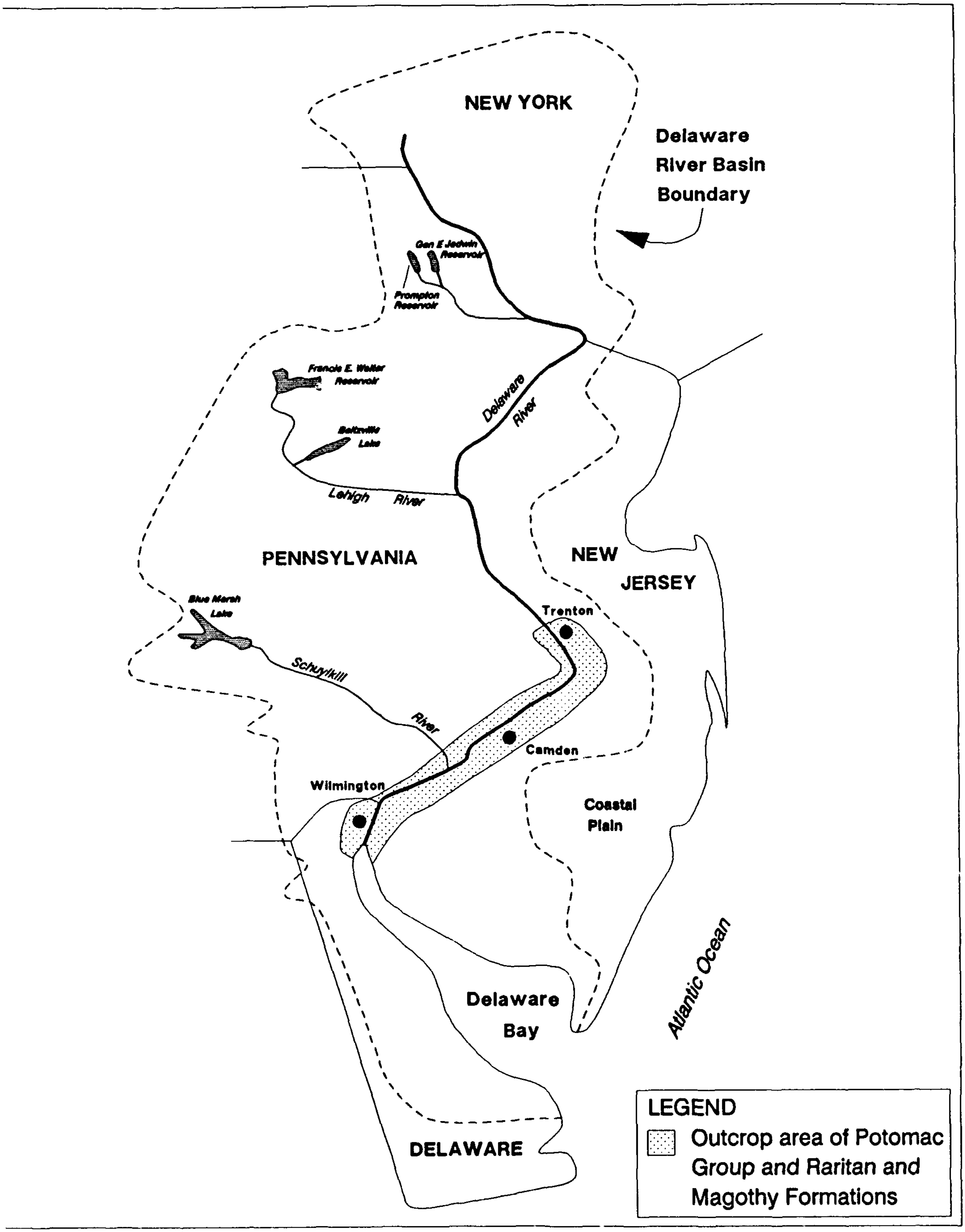


Figure 11: Delaware River Basin

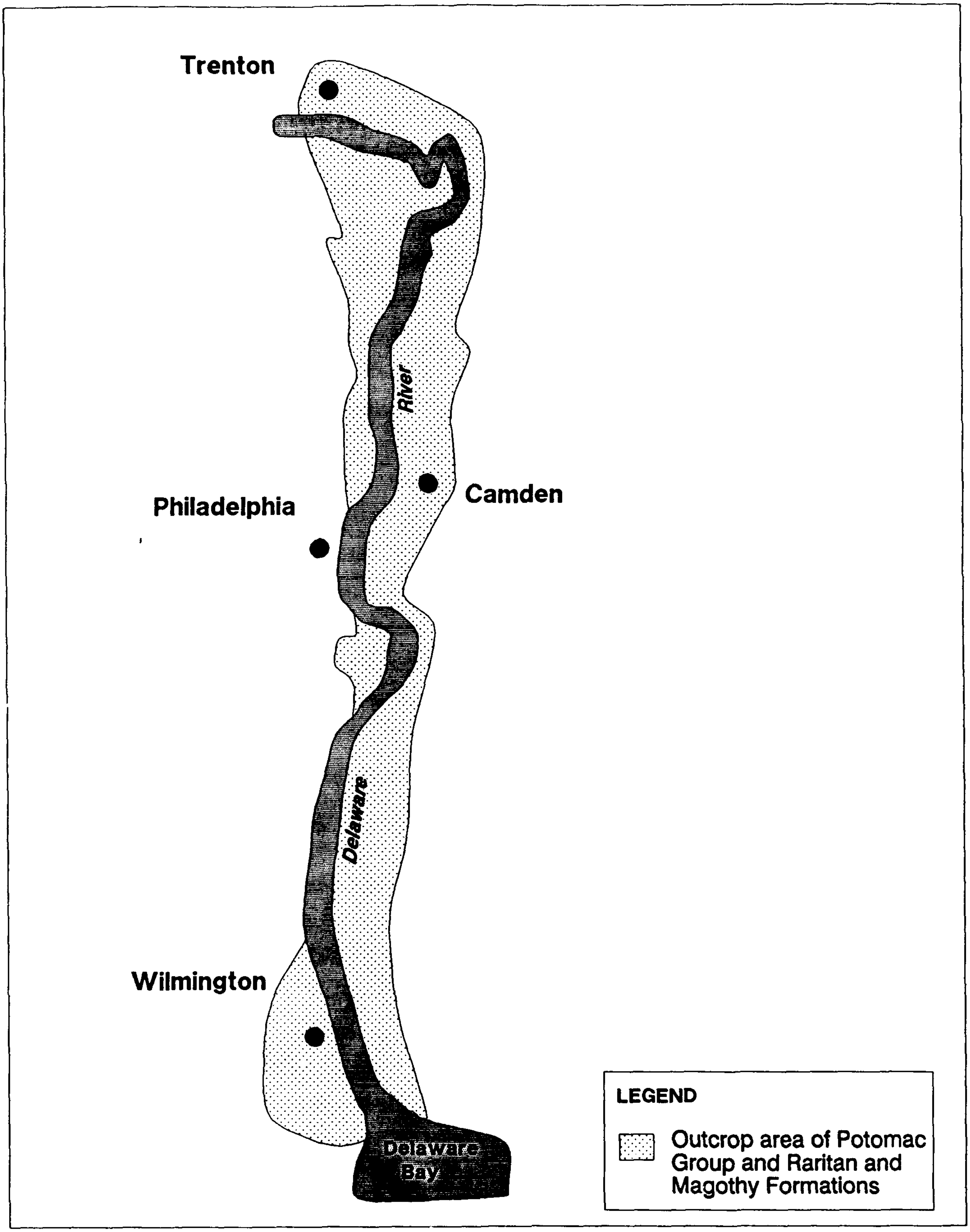


Figure 12: Delaware River and outcrop area of the Potomac-Raritan-Magothy aquifer system

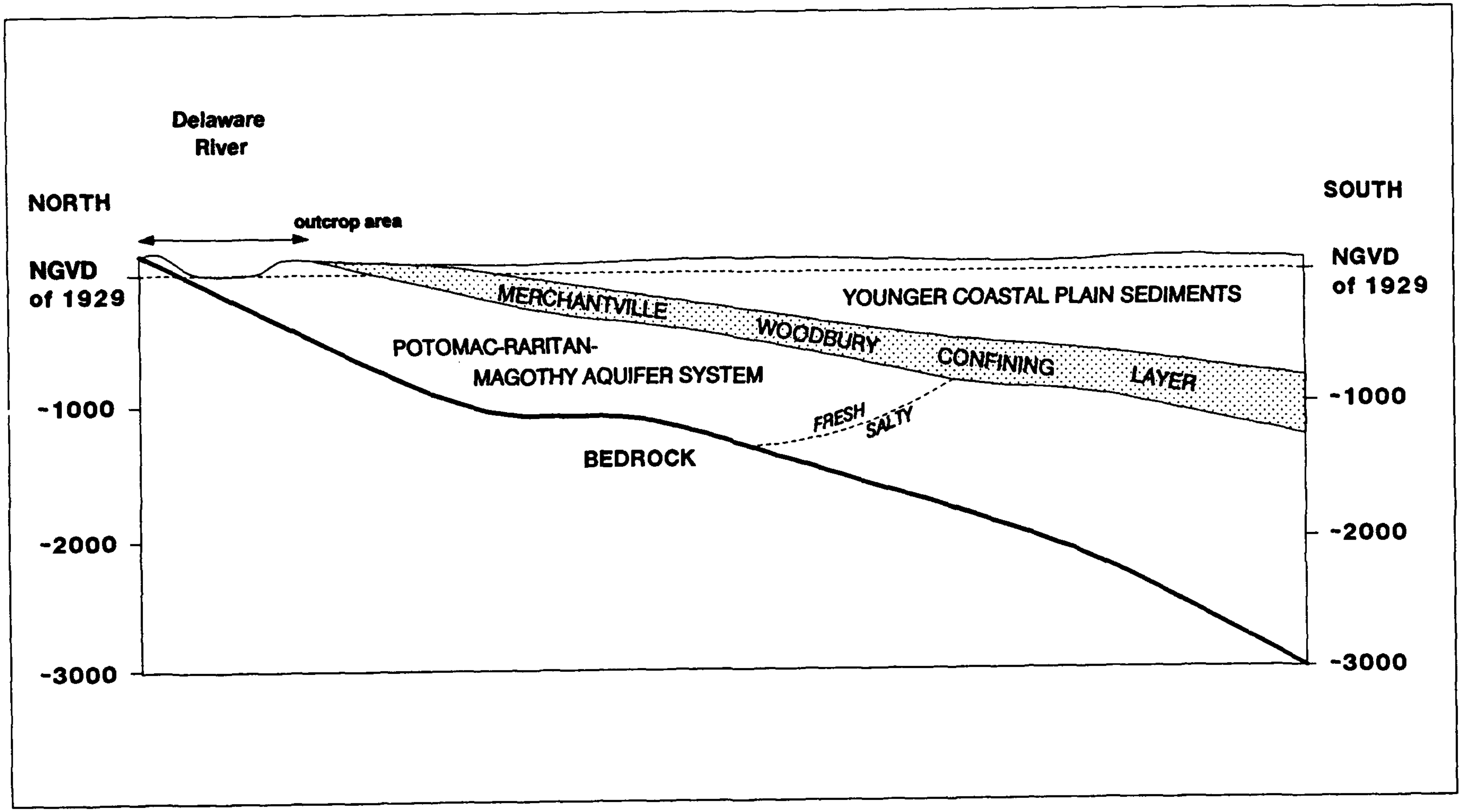


Figure 13: Cross section of Potomac-Raritan-Magothy aquifer system (modified from Harbaugh et al, 1980)

South of Trenton the Delaware River is used by ocean-going vessels and is dredged by the Corps of Engineers to maintain navigability. The hydraulic effects of the dredging are not well understood, however, it is possible that the dredging may increase the hydraulic connection between the river and the underlying aquifer. This could occur when bed sediments of low permeability are removed exposing aquifer sands and increasing the area available for infiltration resulting in an increase in recharge to the aquifer and changes in the chemical and physical quality of water in the aquifer. An increase in aquifer recharge will cause a decrease in surface water supplies.

References

Luzier, J. E. 1980. "Digital-Simulation and Projection of Head Changes in the Potomac-Raritan-Magothy Aquifer System, Coastal Plain, New Jersey," *Water Resources Investigations 80-11*, U. S. Geological Survey, Trenton, NJ

U. S. Army Corps of Engineers. 1985. *Modification of the Francis E. Walter Dam and Reservoir, General Design Memorandum*, Philadelphia District, Philadelphia, PA

Duran, Philip B. 1986. "Distribution of Bottom Sediments and Effects of Proposed Dredging in the Ship Channel of the Delaware River Between Northeast Philadelphia, Pennsylvania and Wilmington, Delaware, 1984", *Hydrologic Investigations Atlas, HA-697*, U. S. Geological Survey, Reston, VA

U. S. Environmental Protection Agency. 1986. "Greenhouse Effect, Sea Level Rise, and Salinity in the Delaware Estuary," *EPA 230-05-86-010*, Washington D.C.

Harbaugh, Arlen W. et al. 1980. "Computer-Model Analysis of the Use of Delaware River Water to Supplement Water from the Potomac-Raritan-Magothy Aquifer System in Southern New Jersey," *Water Resources Investigations 80-31*, U. S. Geological Survey, Trenton, NJ.

WETLANDS: GROUND-WATER RECHARGE AND DISCHARGE

Corps of Engineers' water planning and management activities have the potential to alter the nature of the wetlands, and as a consequence, the interaction between surface and ground water. Construction of projects can eliminate wetlands through drainage, filling, and flooding. Reservoir operations can alter the timing, frequency and duration of water available to wetlands. Project maintenance can affect wetlands through elimination of vegetation, dredging and dredge disposal. The extent of these effects depends upon the type of project, geographic location and hydrologic and hydrogeologic characteristics of the wetlands.

Wetlands occur throughout the United States and include salt marshes along the coasts, swamps and bogs in the northern states, prairie potholes in the Midwest, playa lakes in the western states, and the wet tundra of Alaska (Figure 14). Wetlands usually lie along rivers, lakes and coastal waters where there is periodic flooding, in depressions or on slopes where water is supplied by runoff or ground-water seeps. Wetlands are valuable resources as habitat for fish and wildlife, as a natural purifier of water quality and producer of food to support aquatic life, and as a source of storage for flood and storm protection, ground-water recharge and supply, and recreation and aesthetic values (Figure 15).

The interaction between surface and ground water in wetlands is complex, alternating between being a source of recharge to an aquifer to receiving discharge from an aquifer. The ground-water aquifer may be part of a local, intermediate, or regional flow system and recharge and discharge occurs throughout the landscape in different ways. Some of the factors which influence the nature, magnitude and timing of this interaction are: the relative location of ground water to the wetland; the geology of the aquifer and wetland; the surface hydrology; the transmissive characteristics of the aquifer; and topography of the landscape. For any specific wetland, all of these factors must be examined to determine whether the interaction is one of recharge or discharge.

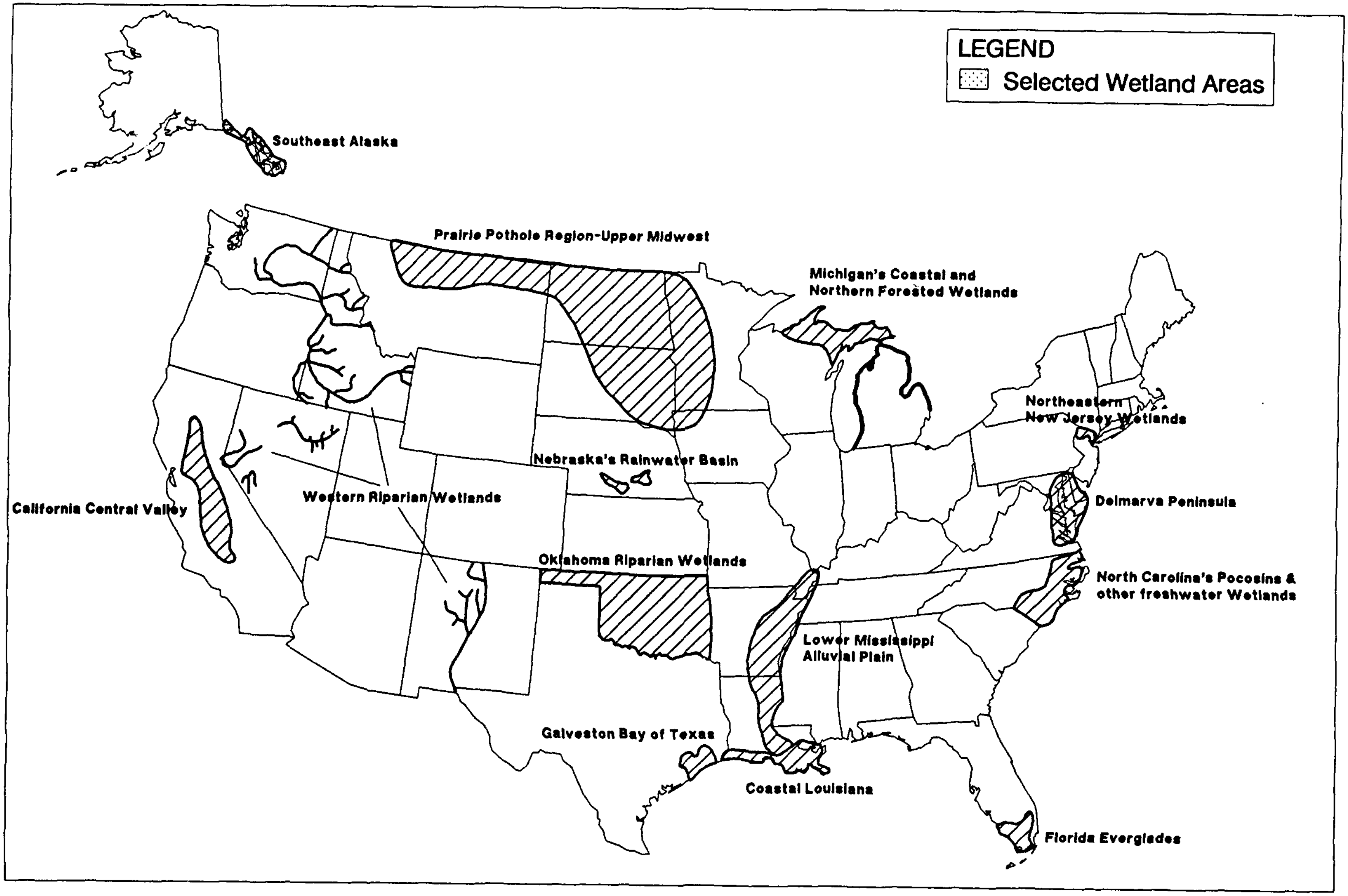


Figure 14: Selected Wetlands of the United States

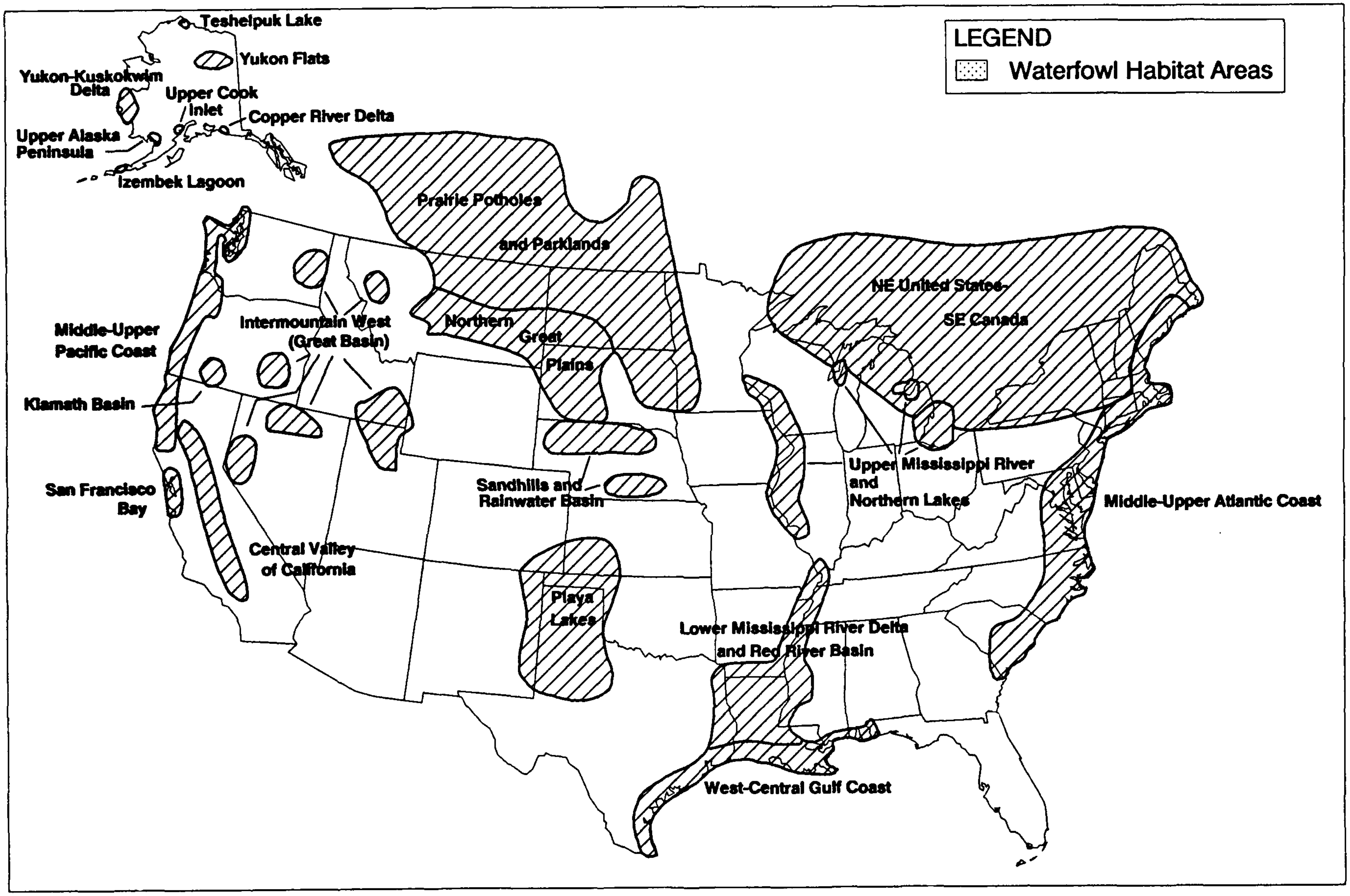


Figure 15: Waterfowl habitat areas of major nation concern

References

Kusler, Jon A. and Gail Brooks (editors). 1987. *Proceedings of the National Wetland Symposium: Wetland Hydrology, September 16-18, 1987, Chicago, Illinois*, Association of State Wetland Managers, Inc., Berne, NY

Tiner, Ralph W. Jr. 1984. *Wetlands of the United States: Current Status and Recent Trends*, U. S. Fish and Wildlife Service, Habitat Resources, Newton Corner, MA

Hook, D. D. et al. 1988. *The Ecology and Management of Wetlands, Volume 1: Ecology of Wetlands, Volume 2: Management, Use and Value of Wetlands*, Timber Press, Portland, OR

Cowardin, Lewis M. et al. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*, U. S. Fish and Wildlife Service, Washington D. C.

U. S. Department of Interior. 1988. *The Impact of Federal Programs on Wetlands, Volume I: The Lower Mississippi Alluvial Plain and the Prairie Pothole Region, Volume II (draft): Other Major Wetland Regions*, A Report to Congress by the Secretary of the Interior, Washington D. C.

ARMY INSTALLATIONS: ENVIRONMENTAL RESTORATION

The Corps of Engineers through its Defense Environmental Restoration Program (DERP) has responsibility for managing the clean-up of hazardous wastes at Department of Defense installations nationwide. Many of these installations are at Army facilities in different regions of the country (Figure 16). Field management of the program is being carried out by the Missouri River Division and Omaha and Kansas City Districts.

Table 1 shows the different sources of potential contamination. Each source can be tied to a variety of contaminants. The waste sites vary in size from one to several thousand acres. Not all sites pose a threat to underlying ground water. Many sites are currently being investigated to determine what, if any, contamination could occur. The program illustrates a significant commitment by the Corps to understanding and preventing the contamination of ground water by surface sources. It provides an example of surface-ground water interaction involving wastes other than water and wastes carried by water.

Table 1

SOURCES OF HAZARDOUS WASTES

Underground pipelines
Sanitary landfills
Open burn areas
Surface container storage
Underground storage tanks
Waste disposal sites
Hazardous waste storage buildings
Fire training pits
Demolition grounds

The movement of contaminants from the surface to underlying ground water is a complex process which depends both upon the nature of the contaminant and the strata through which it moves. The Corps work includes understanding this process and taking remedial action, if necessary. Understanding the interaction

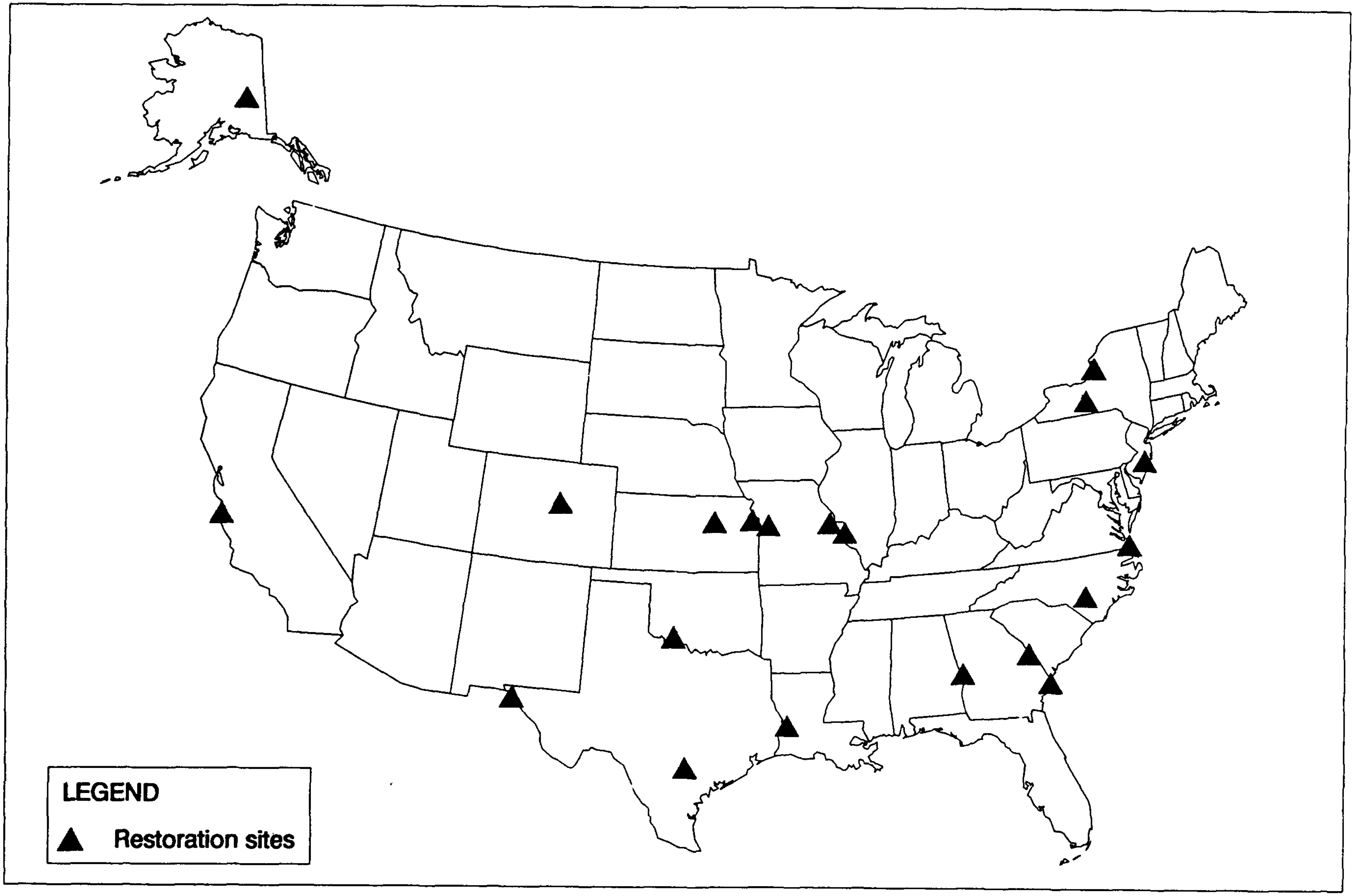


Figure 16: Army Installation Restoration Program Ongoing Projects, 1989

between the contaminant and the subsurface may require siting, drilling and installing monitor wells; sampling ground water; chemical analysis of those samples; ground-water modeling; and a great deal of professional judgment. Following investigation, alternative remedial actions are evaluated.

References

U. S. Army Corps of Engineers. 1988. *Hazardous/Toxic Waste Management Plan*, Directorate of Engineering and Construction, Washington D.C.

U. S. Army Corps of Engineers, 1989, *Kansas City District, Second Quarter, FY 89 DERP Line Item Review Briefing Book, Sacramento, CA March 15-16, 1989*, Sacramento, CA

U. S. Army Corps of Engineers, 1989, *Omaha District, Second Quarter, FY 89, DERP Line Item Review Briefing Book, Sacramento, CA March 16, 1989*, Sacramento, CA

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In this report specific regional and national examples are described where surface and ground water are integral to the Corps of Engineers water control responsibilities. Each example includes a brief description, illustrative figures, and technical references. The references provide technical depth not present in the descriptions or figures. The regions covered by the examples are selected to provide a broad geographical distribution throughout the country. Two national examples are cited: wetlands, where discharge and recharge occur between surface and ground water, and Army installations where environmental restoration is focused on preventing surface contaminants from polluting underlying ground water supplies.

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Michael W. Burnham, Ch., Planning Div., HEC	(916) 756-1104	CEWRC-HEC-P

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