GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, THE SOUTHERN SEVIER DESERT AND PAHVANT VALLEY, MILLARD COUNTY, UTAH

by

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Utah Geological Survey

and

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Utah Department of Agriculture and Food

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UTAH GEOLOGICAL SURVEY

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TABLE OF CONTENTS

FIGURES

TABLES

PLATES

GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, THE SOUTHERN SEVIER DESERT AND PAHVANT VALLEY, MILLARD COUNTY, UTAH

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ABSTRACT

The U.S. Environmental Protection Agency is recommending that states develop Pesticide Management Plans for four agricultural chemicals — alachlor, atrazine, metolachlor, and simazine — herbicides used in Utah in the production of corn and sorghum. This report and accompanying maps are intended to be used as part of these Pesticide Management Plans to provide local, state, and federal government agencies and agricultural pesticide users with a base of information concerning sensitivity and vulnerability of ground water to agricultural pesticides in the southern Sevier Desert and Pahvant Valley, Millard County, Utah. We used existing data to produce pesticide sensitivity and vulnerability maps by applying an attribute ranking system specifically tailored to the Western United States using Geographic Information System analysis methods.

Ground-water sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by any pesticides applied to or spilled on the land surface. Hydrogeologic setting (vertical ground-water gradient and presence or absence of confining layers), soil hydraulic conductivity, retardation of pesticides, attenuation of pesticides, and depth to ground water are the factors primarily determining ground-water sensitivity to pesticides in the southern Sevier Desert and Pahvant Valley. Areas of high sensitivity are generally located along the margins of the southern Sevier Desert basin and Pahvant Valley, and in the central, southwest, and northwest parts of the study area; in these areas, ground water is either shallow with no overlying confining layers, or insufficient data are available to determine depth to shallow ground water.

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by the activities of humans. Ground-water sensitivity to pesticides, the presence of applied water (irrigation), and crop type are the three factors generally determining ground-water vulnerability to pesticides in the southern Sevier Desert and Pahvant Valley. Areas of high vulnerability are primarily located in primary recharge areas along valley margins where corn or sorghum crops are grown, or where the depth to shallow ground water is unknown. Of particular concern are areas where influent (losing) streams originating in mountainous areas cross the valley margin; streams in these areas are the most important source of recharge to the basin-fill aquifer, and efforts to preserve water quality in streams at these points would help to preserve ground-water quality in the entire basin.

Because of relatively high retardation (long travel times of pesticides in the vadose zone) and attenuation (short half-lives) of pesticides in the soil environment, pesticides applied to fields in the southern Sevier Desert basin and Pahvant Valley likely do not represent a serious threat to ground-water quality. To verify this conclusion, ground-water sampling by the Utah Department of Agriculture and Food should be concentrated in areas of moderate and high sensitivity or vulnerability, typically along valley margins. Sampling in the central areas of the the southern Sevier Desert basin and Pahvant Valley characterized by low sensitivity and vulnerability should continue, but at a lower density than in areas of higher sensitivity and vulnerability.

INTRODUCTION

Background

The U.S. Environmental Protection Agency (EPA) is recommending that states develop Pesticide Management Plans (PMPs) for four agricultural chemicals that in some areas impact ground-water quality. These chemicals — herbicides used in production of corn and sorghum — are alachlor, atrazine, metolachlor, and simazine. All four chemicals are applied to crops in Utah. In some areas of the United States where these crops are grown extensively, these pesticides have been detected as contaminants in ground water. Such contamination poses a threat to public health, wildlife, and the environment. In many rural and agricultural areas throughout the United States — and particularly in the state of Utah — ground water is the primary source of drinking and irrigation water.

This report and accompanying maps provide federal, state, and local government agencies and agricultural pesticide users with a base of information concerning vulnerability of ground water to agricultural pesticides in the southern Sevier Desert basin and Pahvant Valley, Millard County, Utah (figure 1). This study, conducted jointly by the Plant Industry Division of the Utah Department of Agriculture and Food (UDAF) and the Utah Geological Survey (UGS), provides needed information on ground-water sensitivity and vulnerability to pesticides in the unconsolidated basin-fill aquifers of the southern Sevier Desert basin and Pahvant Valley. Geographic variation in sensitivity and vulnerability, together with hydrologic and soil conditions that cause these variations, are described herein; plates 1 and 2 show the sensitivity and vulnerability, respectively, of the unconsolidated basin-fill aquifers in the southern Sevier Desert and Pahvant Valley to agricultural pesticides.

Sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by pesticides applied or spilled on the land surface, whereas vulnerability to pesticides is determined by assessing human-induced factors and their response to natural factors. For this study, sensitivity incorporates hydrogeologic setting, including vertical ground-water gradient, depth to ground water, and presence or absence of confining layers, along with the soils' hydraulic conductivity, bulk density, organic content, and field capacity. Sensitivity also includes the influence of pesticide properties such as the capacity of molecules to adsorb to organic carbon in soil and the half-life of a pesticide under typical soil conditions. Vulnerability includes human-controlled factors such as whether

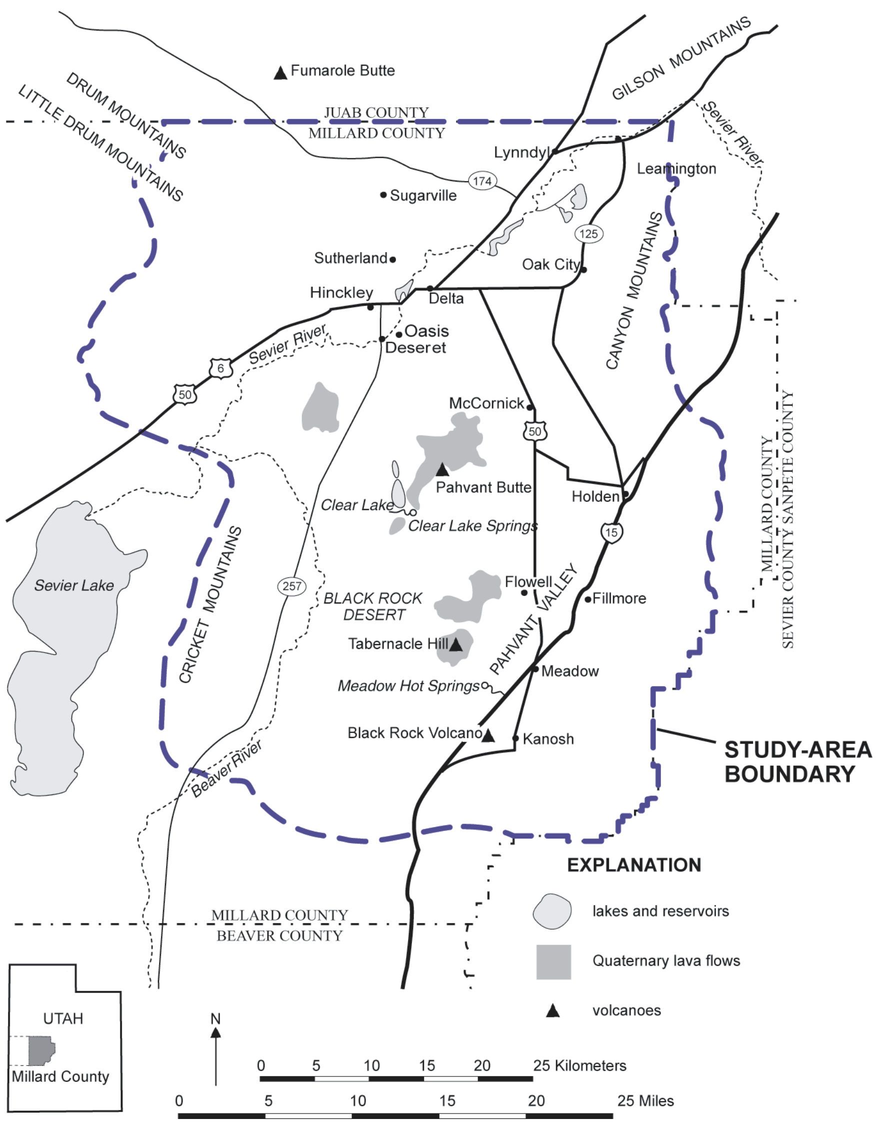


***Figure 1.** Southern Sevier Desert and Pahvant Valley, Utah, study area.*

agricultural lands are irrigated, the crop type, and the amount and type of pesticide applied.

Purpose and Scope

The purpose of this project is to investigate sensitivity and vulnerability of ground-water resources in the southern Sevier Desert and Pahvant Valley, Utah, to contamination from agricultural pesticides. This information may be used by federal, state, and local government officials and pesticide users to reduce the risk of ground-water pollution from pesticides, and to focus future ground-water quality monitoring by the UDAF.

The project scope is limited to the use and interpretation of existing data to produce pesticide sensitivity and vulnerability maps through the application of Geographic Information System (GIS) analysis methods. No new field work was conducted or data collected as part of this project.

General Discusion of Pesticide Issue

Introduction

Ground water is the primary source of water in many rural areas for human consumption, irrigation, and animal watering. Therefore, the occurrence of agricultural pesticides in ground water represents a threat to public health and the environment. Springs and drains flowing from contaminated aquifers may present a hazard to wildlife that live in or consume the water. When we better understand the mechanisms by which pesticides migrate into ground water, we are better able to understand what geographic areas are more vulnerable — and thus deserving of more concentrated efforts to protect ground water — than other less vulnerable areas. The ability to delineate areas of greater and lesser vulnerability allows us to apply mitigating or restrictive measures to vulnerable areas without interfering with the use of pesticides in the less vulnerable areas.

The rise of the United States as the world's foremost producer of agricultural products since the end of World War II may be attributed, to a significant extent, to widespread use of pesticides. Control of insect pests that would otherwise devour the developing crop, together with control of weeds that interfere with growth and optimum crop development, permit higher quality commodities in greater abundance at lower net cost. Effective use of pesticides often means the difference between profitability and financial ruin for an agricultural enterprise.

When evidence shows pesticides are degrading the environment, harming sensitive wildlife, or posing a public health threat, two regulatory courses of action are available: (1) ban further use of the offending chemical, or (2) regulate it so that judicious use mitigates the degradation or threat. Since the four subject herbicides play an essential role in crop production and profitability, banning them outright is unnecessarily severe if the desired environmental objectives can be met by regulation and more judicious use of these herbicides.

The case of DDT illustrates dilemmas faced by pesticide regulators. DDT was removed from widespread use in the United States in the 1970s because of its deleterious effects on bald eagles, ospreys, and peregrine falcons. Populations of these once-endangered species have recovered to a significant extent 25 years later (Environmental Defense Fund, 1997). An ongoing effort to extend the DDT ban worldwide is being hotly contested by advocates of its judicious use as a critical and inexpensive insecticide needed in developing countries to control mosquitoes that transmit the malaria parasite. It is further argued that, given the current regulatory apparatus, were the use of DDT to be re-evaluated today under rigorous scientific and regulatory criteria, it would be restricted to specific uses rather than prohibited (Okosoni and Bate, 2001).

The EPA has developed guidelines and provided funding for programs to address the problem of pesticide contamination of ground water, including a generic PMP to be developed by state regulatory agencies having responsibility for pesticides. Utah's generic plan was approved by the EPA in 1997 (Utah Department of Agriculture and Food, 1997). Its implementation involves, among other things, establishing a GIS database containing results of analyses of samples collected from wells, springs, and drains showing concentrations of pesticides and other constituents that reflect water quality. Implementation of the PMP also involves developing a set of maps showing varying sensitivity and vulnerability of ground water to contamination by pesticides.

Since its inception in 1994, the UDAF sampling program has revealed no occurrences of pesticide contamination in any aquifer in over 1,500 samples tested statewide (Quilter, 2001). Under the generic PMP, should an instance of pesticide contamination be found and verified, a chain of events to monitor and evaluate the contamination is begun that may culminate in cancellation or suspension of the offending pesticide's registration at the specific local level (Utah Department of Agriculture and Food, 1997). Identification of the appropriate area for pesticide registration, cancellation, or suspension requires the specific knowledge presented in this report and on the accompanying maps of varying sensitivity and vulnerability of ground water to pesticide contamination, conditions that result in these variations, and their geographic distribution.

Federal government agencies have been aware of the growing problem of pesticide contamination of ground water since the early 1980s. Cohen and others (1984) reviewed data from occurrences of 12 pesticides in ground water in 18 states. Cohen and others (1986) reported at least 17 occurrences of pesticides in ground water in 23 states. By the early 1990s, EPA began formulating and implementing programs to address the problem.

In 1985, EPA published a standardized system for evaluating the potential for ground-water pollution on the basis of hydrogeologic setting (Aller and others, 1985). The method, known under the acronym DRASTIC, involves assigning numerical values to seven parameters and totaling a score. Under this system, the higher the score, the greater the assumed sensitivity of ground water to pesticide contamination. Ranges in the numerical score are easily plotted on GIS maps. Measured parameters include depth to the water table, recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity of the aquifer — with the beginning letter of key words in these parameters forming the acronym DRASTIC. Eventually, it became apparent that this method is unreliable in some settings, and that it fails to consider the chemical characteristics of the potential contaminants and their interaction with soil and water in the vadose zone. As a result, no significant correlation exists between predicted pesticide detections and observed conditions (Banton and Villenueve, 1989). Other deficiencies are that characteristics of the aquifer media have little bearing on the behavior of pesticides moving through soil in the vadose zone, that areas adjacent to effluent (gaining) rivers and streams are often incorrectly identified as being the most sensitive, and that soil media, impact of the vadose zone, and depth to the water table are all asking the same fundamental questions in different ways. The assigned numerical values in the DRASTIC method poorly represent variables as actually observed. For example, depth to the water table should be logarithmic rather than linear because the potential for impacting ground water decreases much more rapidly with depth than is represented by the linear decrease in numerical scoring used in the method (Siegel, 2000).

Rao and others (1985) developed indices for ranking the potential for pesticide contamination of ground water. The approach has been described as "a nice and widely acknowledged blend of process concepts and indexing methods. Conceptually the science is valid and the approach seems to work well" (Siegel, 2000). The method of Rao and others (1985) involves calculation of a retardation factor and an attenuation factor that characterize movement and persistence of pesticides in the vadose zone, respectively. These factors vary with different soil properties and different characteristics of specific pesticides. Equations for these indices enable calibration of hydrogeologic and other data to more realistically represent actual conditions. These indices, together with hydrogeologic data, provide the basis in this report for delineation of areas that are vulnerable to pesticide contamination of ground water.

Ground-Water Quality Standards

Maximum contaminant levels (MCLs) for pesticides in drinking water are established in R309-103-2.1, Utah Administrative Code, and also in 40 CFR 141.61. MCLs are given in table 1 below. Metolachlor is not listed in either regulation.

***Table 1**. Maximum contaminant levels for pesticides in drinking water.*

Contaminant	Maximum Contaminant Level (MCL)	
Alachlor	0.002 mg/L	2 µg/L
Atrazine	0.003 mg/L	3 µg/L
Metolachlor	--	--
Simazine	0.004 mg/L	4 µg/L

Standards for crop irrigation and livestock watering have not been established. However, some crops would require even higher standards for herbicides than those set for human consumption to avoid crop damage.

Under Utah's PMP, if a pesticide is detected in ground water and confirmed by subsequent sampling and analysis as being greater than 25 percent of the established MCL, a process is set into motion that may eventually result in regulation or revocation of the pesticide's registration for use in the affected area as delineated in this report and the accompanying maps.

Ground-Water Contamination by Pesticides

The interplay between hydrogeological setting, ground-water recharge, soil conditions, pesticide use, and pesticide behavior in the vadose zone determines whether ground water in a particular area is likely to become contaminated with pesticides. The quantity and types of pesticides being applied are critical factors. Although pesticide use is highly variable and cannot be precisely monitored, the distribution of crop types and the quantities of pesticides sold to applicators may be used to obtain a general approximation. Ultimately, the only reliable method for detecting ground-water contamination by pesticides is an adequate ground-water monitoring program, with special emphasis on areas where these pesticides are being applied and areas where such application is most likely to impact ground water.

Vulnerability is determined on the basis of whether irrigation is used, what crops are being grown, and which pesticides are generally applied to particular crops. Areas of corn and sorghum production, in particular, would indicate areas where atrazine and similar herbicides might be used. Pesticide application should be monitored more closely in areas of corn and sorghum production than in other areas to ensure that these herbicides are not impacting ground water.

Mechanisms of Pollution

In areas of the southern Sevier Desert and Pahvant Valley where ground water is unconfined, degradation of the basin-fill aquifers by pesticides would occur whenever chemicals infiltrate through the vadose zone to the aquifer. In confined aquifer settings, pesticides would need to find pathways through confining layers to cause water-quality degradation. Thus, the ability of soils at the application site to retard or attenuate the downward movement of pesticides, and the hydrogeologic setting where the pesticides are applied, have a fundamental effect on the likelihood that a pesticide will travel downward to the basin-fill aquifer. Surface irrigation could cause a decrease in the retardation and attenuation of pesticides in some settings—especially in areas where corn or sorghum are grown—because the types of pesticides evaluated in this study are commonly applied to those crops. Withdrawal of water from the basin-fill aquifers via water wells could cause changes in vertical head gradient that may increase the potential for water-quality degradation. Also, the wells themselves, if not properly constructed, could provide pathways for pesticides to reach the basin-fill aquifers.

PREVIOUS STUDIES

Early Investigations

Many of the more famous early American geologists worked in the study area. The first accurate topographic maps of the Millard County area were made by the Wheeler Survey (Wheeler, 1875-89), which also produced some of the earliest geologic maps of the area. Gilbert (1875) summarized the geology mapped by the Wheeler Survey and produced geologic cross sections of the Pahvant Range, near Fillmore, and Pahvant Butte, and sketches of the Ice Spring cluster of volcanic craters. Gilbert (1890) mapped the shorelines and other features of Pleistocene Lake Bonneville, including shorelines in Millard County. Meinzer (1911) described the water potential of Millard County's major valleys, including Pahvant Valley and the Sevier Desert, but concentrated on ground water and did not describe the just-beginning use of Sevier River water for irrigation in the Delta area. Butler and others (1920) compiled one of the first geologic maps of Utah (scale 1:768,000); it provided a generalized age for rock units in Millard County.

Water Resources

Meinzer's (1911) intitial description of ground-water resources in Millard County was not augmented until the 1940s when the U.S. Geological Survey, in cooperation with the Utah State Engineer, began ground-water investigations following a drought period from 1926 to 1935. Livingston and Maxey (1944) described underground leakage from artesian wells in the Flowell area and made suggestions for the repair of leaking wells. Dennis and others (1946) provided the first in-depth description of ground-water conditions in Pahvant Valley. Woolley (1947) provided information on surface-water resources of the Sevier River Basin, and provided recommendations on how these resources could be utilized to augment ground-water resources.

In the 1950s, the quantity of water and the effects of withdrawals on artesian pressures became the focus of most investigations. Nelson and Thomas (1952) described ground-water development in Pahvant Valley and its effects on ground-water resources. Nelson (1952) and Nelson and Thomas (1953) described ground-water development in the Sevier Desert, but could not determine if this development was affecting ground-water resources. Connor and others (1958) presented water-quality data for ground and surface water in Utah, including eastern Millard County.

In the 1960s, R.W. Mower became the principal investigator of ground-water resources in eastern Millard County. Mower (1961) described the relation between the deep and shallow artesian aquifers near Lynndyl. Mower (1963a) described the effects of pumping the deep artesian aquifer on the shallow artesion aquifer near Sugarville. Mower (1963b) and Mower and Feltis (1964) compiled selected hydrologic data for Pahvant Valley and the Sevier Desert, respectively. Mower (1965) estimated the yield of the ground-water reservoir, delineated areas where additional ground-water development could take place, estimated recharge to the aquifer in Pahvant Valley, and investigated the relation of poor-quality ground water in the Kanosh area to ground-water pumpage. Mower (1967) investigated the causes of fluctuations in discharge rates at Clear Lake Springs. Mower and Feltis (1968) evaluated the quantity of ground-water recharge and storage, water quality, and the effects of pumping on water levels for the basin-fill aquifer in the Sevier Desert. Hahl and Cabell (1965) and Hahl and Mundorff (1968) appraised the quality of surface water in the Sevier Lake basin. Handy and others (1969) provided evidence that water-quality degradation in the Kanosh area was related to water-level declines largely caused by well withdrawals. Whitaker (1969) summarized the maximum discharges in Utah streams, including some of those in eastern Millard County. Whelan (1969) studied the subsurface brines and soluble salts of subsurface sediments in Sevier Lake.

In the 1970s, Hamer and Pitzer (1978) studied the hydrology of the Intermountain Power Project site near Lynndyl.

In the 1980s, W.F. Holmes became the principal ground-water investigator in eastern Millard County. Holmes and Wilberg (1982) reported on the results of an aquifer test near Lynndyl, Enright and Holmes (1982) issued a report on selected ground-water data for the Sevier Desert, and Herbert and others (1982) assessed seepage losses from or gains to canals in streams in eastern Millard County. Holmes (1984) presented an updated summary of ground-water resources in the Sevier Desert, including digital computer modeling of the ground-water system. Bedinger and others (1984a,b) produced maps showing ground-water units, withdrawals, water levels, and depths to ground water in the Basin and Range Province of Utah, and Thompson and Nuter (1984) produced maps showing the distribution of dissolved solids and chemical type in ground water for the same area. Enright (1987) conducted a seepage study for a portion of the Central Utah Canal in Pahvant Valley. Gates (1987) produced a regional summary of ground-water conditions in the Great Basin, including eastern Millard County. Thiros (1988) provided selected hydrologic data for the Pahvant Valley area. Holmes and Thiros (1990) presented an updated summary of ground-water resources in Pahvant Valley, including digital computer modeling of the ground-water system. Snyder (1998) mapped recharge and discharge areas for the basin-fill aquifer in eastern Millard County.

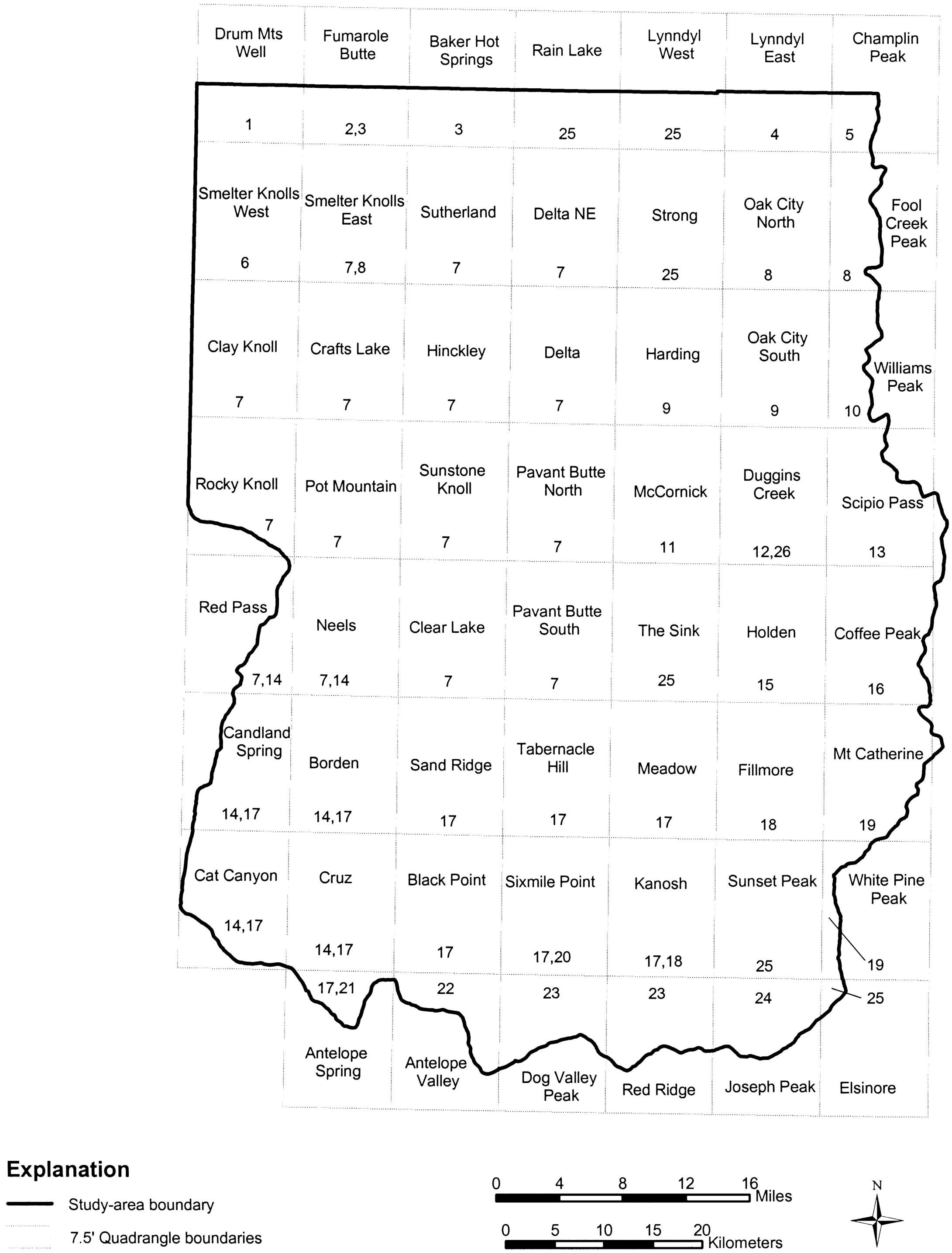
Geologic Mapping

There have been numerous geologic studies in the study area between 1920 and 2000. The geologic map coverages used as part of this project are shown on figure 2.

SETTING

Physiography

The study area (figure 1) is the southern part of the Sevier Desert basin in eastern Millard County, west-central Utah, including the Black Rock Desert, which is the southernmost extension of the Sevier Desert. In previous water-studies, the northern part of the study area has typically been referred to as the "Sevier Desert." Pahvant Valley is in the southeast part of the study area on the east side of the Black Rock Desert. Pahvant Valley proper trends northeast-southwest, is about 34 miles (55 km) long and 9 miles (15 km) wide, and is bounded on the west by a broad, low ridge formed by basalt flows and extending from Kanosh Butte to Pahvant Butte (Dennis and others, 1946; Mower, 1965). The study area includes about 2,700 square miles (7,000 km^2) of the Sevier and Beaver River drainage basins, and is in the Sevier and Black Rock Deserts section of the Great Basin portion of the Basin and Range physiographic province (Stokes, 1977). The study area is bordered by the Pahvant Range to



Geologic Map Sources

1. Dommer, 1980
2. Galyardt and Rush, 1981
3. Oviatt and others, 1994
4. Pampeyan, 1989
5. Higgins, 1982
6. Hintze and Oviatt, 1993
7. Oviatt, 1989
8. Holladay, 1984
9. Hintze, 1991a
10. Millard, 1983
11. Davis, 1994
12. Sayre, 1974
13. Michaels and Hintze, 1994
14. Hintze, 1984
15. Hintze, 1991b
16. Hintze, 1991c
17. Oviatt, 1991
18. George, 1985
19. Lautenschlager, 1952
20. Crosby, 1959
21. Whelan and Bowdler, 1979
22. Zimmerman, 1961
23. Davis, 1983
24. Steven, 1979
25. Hintze, 1980
26. Hintze, 1991d

Figure 2. *Sources of geologic mapping used for this study.*

the southeast, the Cricket Mountains to the southwest, the Canyon Mountains to the northeast, and the Little Drum Mountains to the northwest. The northern boundary of the study area is the Juab County line.

The Sevier River, the main source of surface water in the study area, originates in the high plateaus to the south and flows into the northeast corner of the Sevier Desert basin through Leamington Canyon, between the Cricket and Little Drum Mountains. The Beaver River flows into the Black Rock Desert part of the study area from the south and, during high-precipitation years, joins the Sevier River in the western part of the Sevier Desert. In the western part of the Sevier Desert, the Sevier River is usually dry due to irrigation withdrawals and evaporation; however, in wet years it flows to Sevier Lake, a playa west of the study area (Holmes, 1984). Many small, ephemeral streams flow into the southern Sevier Desert basin and Pahvant Valley from the surrounding mountains during the spring.

The study area is in a complexly faulted structural basin typical of the Basin and Range. The Sevier Desert basin is surrounded by mountain ranges and filled with thick volcanic and unconsolidated sedimentary deposits associated with active faulting, erosion, and volcanism during Quaternary time and earlier.

The mountains surrounding the study area consist of bedrock ranging in age from Precambrian to Tertiary. The Cricket Mountains consist primarily of Cambrian limestone and quartzite (Steven and Morris, 1983). The Pahvant Range includes Cambrian limestone and quartzite, Devonian dolomite and quartzite, and Cretaceous and Tertiary sedimentary rocks of the Price River, North Horn, Flagstaff, and Green River Formations (Steven and Morris, 1983). The Canyon Mountains consist of Precambrian and Cambrian quartzite and limestone, Devonian dolomite, and the conglomeratic Cretaceous to Tertiary Canyon Range Formation (Morris, 1987). Tertiary ash-flow tuff, with minor Precambrian to Cambrian quartzite, limestone, and shale, comprise the Little Drum Mountains (Morris, 1987).

Tertiary- and Quaternary-age volcanic rocks are common surficial geologic units in the study area. The surficial geology of the study area is dominated by the deposits of Lake Bonneville, a large lake which occupied much of northern Utah and part of southern Idaho between approximately 30,000 and 10,000 years ago. Western Pahvant Valley contains several large basalt flows and tuffaceous volcanic cones, including Pahvant Butte, which formed when lava and tuff erupted into Lake Bonneville approximately 15,500 yr B.P. (Oviatt, 1989). Tabernacle Hill, 5 miles (8 km) west of Meadow, erupted basalt into Lake Bonneville at the Provo level in late Pleistocene time (14,500 to 14,000 yr B.P.) (Oviatt, 1991). The Ice Springs basalt flow, west of Flowell, covers more than 20 square miles (50 km^2) and consists of angular (aa) and ropy (pahoehoe) flows that formed about 660 yr B.P. during the most recent volcanic event in the area (Valastro and others, 1972). Pleistocene and Pliocene andesite, rhyolite, and basalt comprise Beaver Ridge and the Coyote Hills in the extreme southern part of the Black Rock Desert (Oviatt, 1991). The Smelter Knolls and Little Drum Mountains in the northwestern part of the basin contain other Pliocene and Pleistocene volcanics (Oviatt 1989, 1991).

The basin floor in the study area ranges in elevation from about 4,550 to 5,400 feet (1,387-1,646 m) and is underlain by various thicknesses of unconsolidated basin fill and volcanic rocks. The basin fill of the Sevier Desert consists of lacustrine and deltaic sediments deposited during several Pleistocene lake cycles, and interlacustrine fluvial and alluvial-fan deposits (Oviatt, 1989, 1991; Snyder, 1998). The alluvial-fan and deltaic deposits are predominant along the margins of the basin and interfinger with the lacustrine deposits and, to a lesser extent, with basalt flows that are predominant in the basin center. Deltaic sediments were deposited where the Sevier and Beaver Rivers flowed into Lake Bonneville, and a large fan-delta extends from Leamington Canyon southwestward to Delta (Oviatt, 1989). Coarse-grained fan-delta sand and gravel were deposited by the Beaver and Sevier Rivers during the regression of Lake Bonneville (Oviatt, 1989, 1991). Eolian sand, mostly reworked deltaic deposits, is found in the northwestern part of the study area (Oviatt, 1989). Most of the surface sediments in the study area are post-Bonneville sand, silt, and clay flood-plain channel and overbank deposits of the Sevier and Beaver Rivers (Oviatt, 1989, 1991).

Climate

Seven weather stations are in the study area; normal climatic information is available for five of these stations (Oak City, 1928-92 period; Delta, 1938-92 period; Deseret, 1928-92 period; Fillmore, 1928-92 period; Kanosh, 1928-92 period; and Black Rock, 1951-92 period), and average climatic data are available for the Clear Lake Refuge station (1963-1984 period). Because the normal climatic information represents a more complete data set, those values are discussed herein. Temperatures reach a normal maximum (Oak City station) of 94.3°F (34.6°C) in July and a normal minimum (Deseret station) of 11.9°F (-11.2°C) in January; the normal mean ranges from 24.3 to 78.7°F (-4.3 to 25.9°C) (Ashcroft and others, 1992). Normal annual precipitation ranges from 8.11 inches (20.6 cm) in Delta on the semiarid basin floor to 16.00 inches (40.6 cm) in Fillmore at the base of the eastern mountains (Ashcroft and others, 1992). The Canyon Mountains and Pahvant Range, on the eastern side of the study area, receive over 30 inches (75 cm) of precipitation annually at the highest elevations (Ashcroft and others, 1992). Normal annual evapotranspiration ranges from 48.35 to 52.85 inches (123-134 cm) at Kanosh and Black Rock, respectively (Ashcroft and others, 1992). The average number of frost-free days ranges from 153 to 221, at the Clear Lake Refuge and Delta stations, respectively (Ashcroft and others, 1992).

Population and Land Use

From 1990 to 1998, population in Millard County increased by about 1,000 individuals (Demographic and Economic Analysis Section, 1999). The July 2001 population of Millard County was estimated at 12,326 (Demographic and Economic Analysis Section, 2002) with a projected population of 13,057 by 2010 (Demographic and Economic Analysis Section, 2000). Delta and Fillmore are the largest cities, having 3,073 and 1,988 people in 1996, respectively (Utah League of Cities and Towns, 1999).

Agriculture is the main land use and source of income for the study area. However, the Intermountain Power Project, a coal-burning electric plant northeast of Delta, began operating in 1986 and employs about 500 people. Economic deposits of sand and gravel, gold, lime, and salt are mined within the study area.

GROUND-WATER CONDITIONS

Basin-Fill Aquifer

Ground water in the southern Sevier Desert and Pahvant Valley occurs under confined and unconfined conditions (Mower, 1965; Mower and Feltis, 1968). The basin fill ranges in thickness from a few feet along the basin margins to over 1,400 feet (430 m) in Pahvant Valley (Holmes and Thiros, 1990) and possibly as much as 2,140 feet (650 m) in the southern Sevier Desert (Mower and Feltis, 1968). In general, coarser grained material – mainly alluvial-fan deposits – are predominant along the mountain fronts, and finer grained material – mainly lacustrine deposits – are predominant in the central portions of the Sevier Desert basin. However, coarse- and fine-grained deposits interfinger to form a complex multiple-aquifer system characterized in general by unconfined conditions in the principal aquifer along basin margins and confined conditions in the principal aquifer in the central parts of the basin. A shallow unconfined aquifer overlies the confined aquifer(s) in the central part of the basin.

The eastern part of the southern Sevier Desert has two confined aquifers that make up the principal unconsolidated basin-fill aquifer system, overlain locally by shallow unconfined aquifers (figure 3) (Mower and Feltis, 1968; Holmes, 1984). The confined aquifers are predominantly sand and gravel (and some basalt flows), and the intervening and overlying confining layers are mostly silt and clay, but the boundaries between aquifers and confining layers are commonly indistinct (Snyder, 1998). The confining layer separating the upper confined aquifer from the lower confined aquifer ranges in thickness from 400 to 500 feet (120-150 m) near Lynndyl to 100 to 175 feet (30-53 m) near Sugarville (Mower and Feltis, 1968; Holmes, 1984). The basin fill fines toward the center of the basin, and west of Sugarville the upper and lower confined aquifers coalesce into a single confined aquifer (Holmes, 1984). In Pahvant Valley, a single confined aquifer exists at a depth between 140 and 200 feet (43 and 61 m) in the Flowell area, and is separated from the overlying shallow unconfined aquifer by a 15- to 75-foot-thick (5-23 m) clay confining layer (Dennis and others,

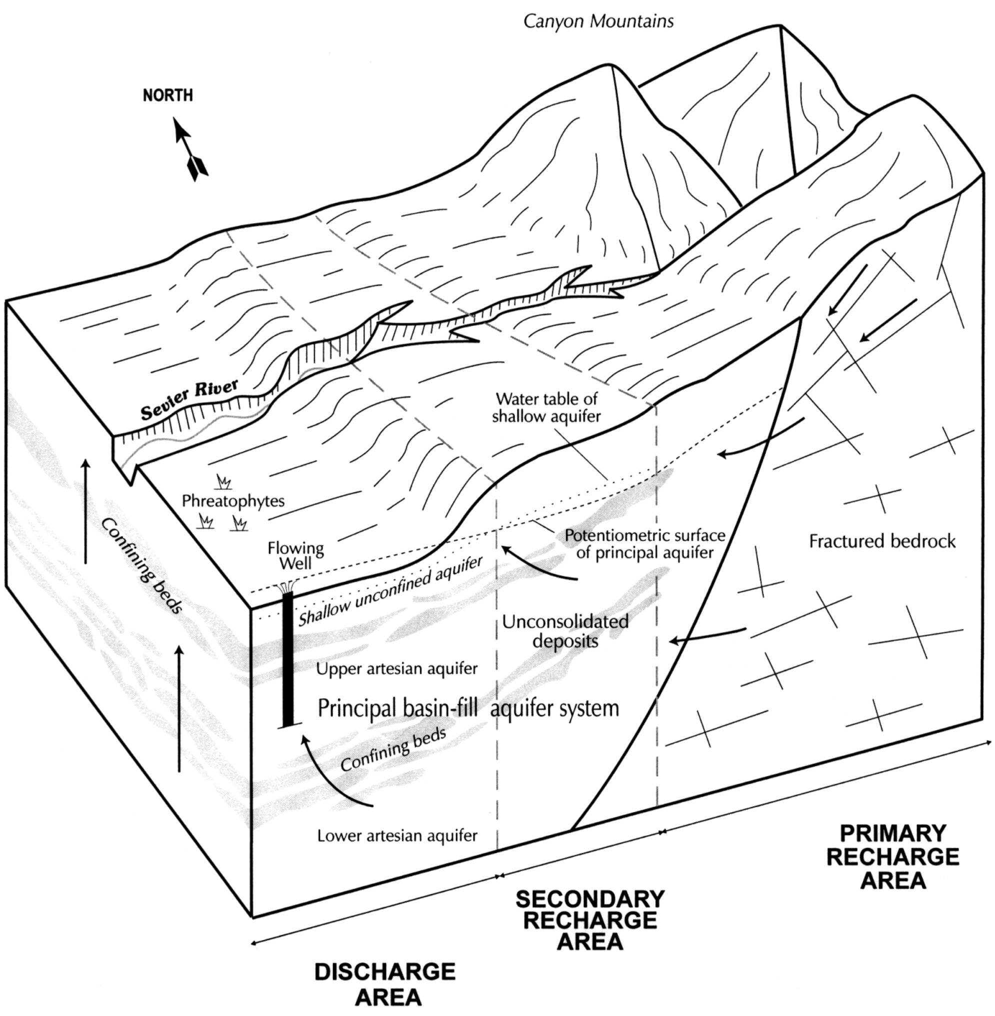


Figure 3. *Schematic block diagram showing the basin-fill ground-water system in the Sevier Desert; arrows show direction of ground-water flow (from Snyder, 1998).*

1946). The shallow unconfined aquifer is estimated to be about 50 feet (15 m) thick in the center of the Sevier Desert basin (Holmes, 1984; Holmes and Thiros, 1990), and is as much as 100 feet (30 m) thick in basalt in the Pahvant Valley area (Holmes and Thiros, 1990).

The potentiometric surface typically ranges from several hundred feet below the land surface along the basin margins to several feet above the land surface in the central part of the Sevier Desert basin (Holmes, 1984). In 1999, the Utah Geological Survey encountered shallow unconfined ground water at depths as shallow as 10 feet (3 m) in monitoring wells in the Sugarville area (Janae Wallace, verbal communication, May 1, 2002). Water levels in wells fluctuate seasonally, principally due to irrigation withdrawals; near Flowell in Pahvant Valley, water-level declines were more than 45 feet (14 m) from March to September, 1960 (Holmes and Thiros, 1990). Long-term changes in water levels in wells have also been noted in the Sevier Desert basin. Mower and Feltis (1968) reported that, in 1964, the potentiometric surface for wells completed in the deep and shallow confined aquifers in the Lynndyl area in the eastern part of the basin were about equal, but in 1981 water levels in the shallow confined aquifer in the Lynndyl area were about 10 to 20 feet (3-6 m) higher than water levels in wells completed in the deep confined aquifer in the same area (Enright and Holmes, 1982); Holmes (1984) attributed this change to water-well pumping. Holmes and Thiros (1990) attributed water-level declines in wells of more than 50 feet (15 m) in some areas of Pahvant Valley between 1953 and 1980 to extensive water-well pumping and a period of less-than-normal precipitation; they noted most water levels in Pahvant Valley recovered between 1983 and 1986 due to reduced water-well withdrawals and a period of above-normal precipitation. Between 1970 and 2000, water levels generally declined for wells completed in both the shallow and deep confined aquifers in the southern Sevier Desert basin (figure 4) (Burden and others, 2000); near Delta, declines of nearly 6 feet (1.8 m) were recorded in the shallow confined aquifer while declines of nearly 7 feet (2.1 m) were recorded in the deep confined aquifer (figure 4). In some areas, rises in water levels in wells were recorded during the same period (Burden and others, 2000); the largest water-level rise (14 feet [4.3 m]) was recorded in a well completed in the shallow confined aquifer north of Oak City, but the largest water-level rise in the deep confined aquifer was only 4 feet (1.2 m) (figure 4). In Pahvant Valley, water levels in wells generally declined in the northern part of the valley and generally rose in the southern part between 1970 and 2000 (Burden and others 2000) (figure 5); declines of about 49 feet (15 m) were recorded southeast of McCornick and rises of about 28 feet (9 m) were recorded north of Meadow and southwest of Kanosh (figure 5).

Ground water in the southern Sevier Desert basin generally moves with the Sevier River to the west-southwest toward Sevier Lake (Holmes, 1984, plate 1). Ground water in Pahvant Valley generally moves west from the recharge areas on the east side of the valley, or north from recharge areas on the south end of the valley, toward the basin center; ground water also moves with the Beaver River to the north (Holmes and Thiros, 1990, plate 2).

Water recharges the principal ground-water system from ephemeral stream runoff from the mountains (including those north of the study area), infiltration from rivers and irrigation, direct precipitation on the valley floor, and subsurface inflow from bedrock. Ground water discharges through evapotranspiration, springs and seepage to rivers, wells, and subsurface outflow to Sevier Lake (Holmes, 1984; Holmes and Thiros, 1990).

Ground-Water Quality

Water quality in the Sevier Desert basin varies with location and depth. Total-dissolved-solids concentrations range from 200 to 20,000 mg/L (mg/L is approximately equal to ppm) in the Sevier Desert basin-fill aquifer system (Mower, 1965; Holmes, 1984); the high values are from the shallow unconfined aquifer at the western edge of the study area near Sevier Lake where salts are concentrated by near-land-surface evaporation. Ground water with lower total-dissolved-solids concentrations is generally of calcium-magnesium-bicarbonate type, and water with the higher total-dissoved-solids concentrations is generally of sodium-chloride or sodium-chloride-sulfate type (Mower and Feltis, 1968, figure 7; Holmes and Thiros, 1990).

The best ground water in the southern Sevier Desert is in the lower confined aquifer between Lynndyl and Delta (Holmes, 1984). In terms of total-dissolved-solids concentration, the poorest quality water in the southern Sevier Desert basin is in the shallow unconfined aquifer, which is partially recharged by returned irrigation water (Mower, 1965; Holmes, 1984). Individual constituents can be of concern in the southern Sevier Desert basin-fill aquifer. Nitrate concentrations are relatively high, ranging from 4 to 22 mg/L, in the Oak City area (Holmes, 1984). This is a primary recharge area, and it may be that septic-tank effluent and irrigation water are contributing to recharge of the principal aquifer system (Holmes, 1984). Ground-water quality in the southern Sevier Desert basin-fill aquifer is also impacted by high arsenic concentrations from volcanic rocks (Holmes, 1984).

In the eastern part of Pahvant Valley, ground water generally has total-dissolved-solids concentrations less than 1,000 mg/L (Holmes and Thiros, 1990). Elsewhere in Pahvant Valley, total-dissolved-solids concentrations range from 1,000 to over 5,000 mg/L; the highest total-dissolved-solids concentrations in Pahvant Valley exist west and northwest of Kanosh (Holmes and Thiros, 1990).

METHODS

This study is limited to the use and interpretation of existing data to produce pesticide sensitivity and vulnerability maps through the application of GIS analysis methods. No new field work was conducted nor data collected as part of this project.

Ground-Water Sensitivity to Pesticide Pollution

Ground-water sensitivity to pesticides is determined by assessing natural factors favorable or unfavorable to the degradation of ground water by pesticides applied to or spilled on the land surface. Hydrogeologic setting (vertical ground-water gradient and presence or absence of confining layers), soil hydraulic conductivity, retardation of pesticides,

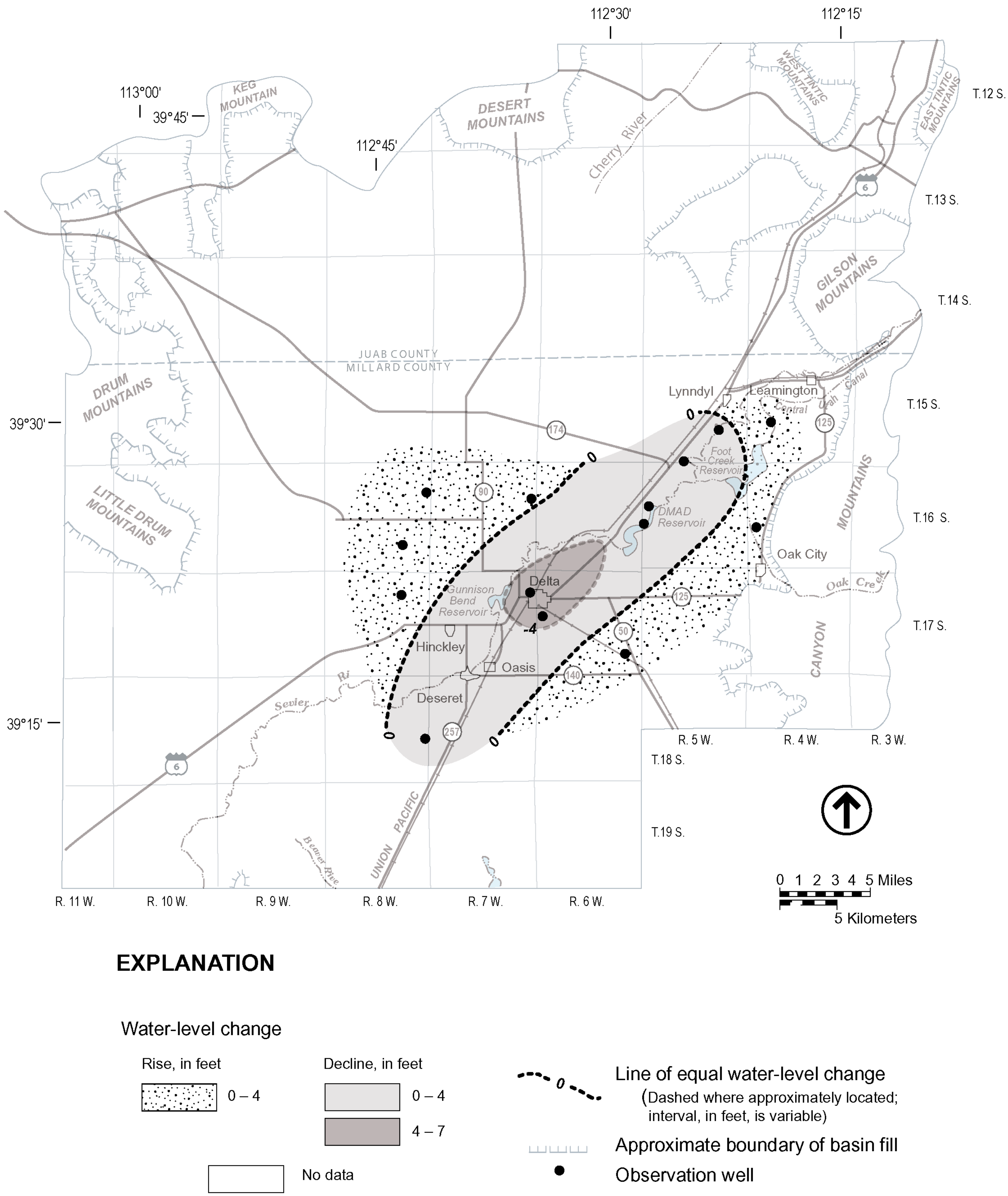


Figure 4. *Change of ground-water level in the Delta area from March 1970 to March 2000 (modified from Burden and others, 2000).*

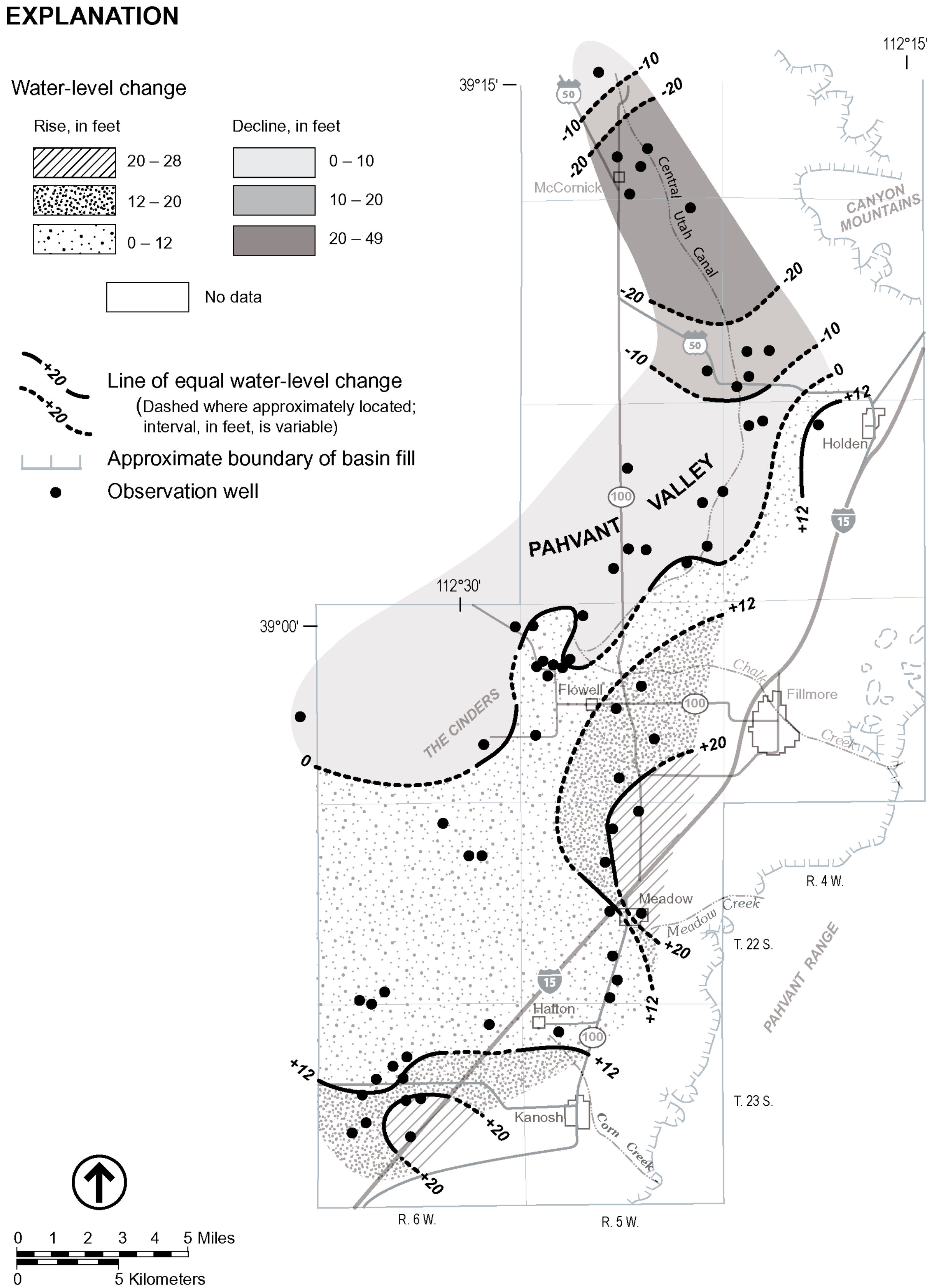


***Figure 5.** Change of water level in Pahvant Valley from March 1970 to March 2000 (modified from Burden and others, 2000).*

attenuation of pesticides, and depth to ground water are the factors primarily determining ground-water sensitivity to pesticides in the southern Sevier Desert and Pahvant Valley.

Hydrogeologic Setting

Hydrogeologic setting is delineated on ground-water recharge-area maps which typically show: (1) primary recharge areas, (2) secondary recharge areas, and (3) discharge areas (Anderson and others, 1994); for our GIS analyses, we assigned hydrogeologic setting to one of these three categories. Primary recharge areas, commonly the uplands and coarse-grained unconsolidated deposits along basin margins, do not contain thick, continuous, fine-grained layers (confining layers) and have a downward ground-water gradient (figure 6). Secondary recharge areas, commonly mountain-front benches, have fine-grained layers thicker than 20 feet (6 m) and a downward ground-water gradient (figure 6). Ground-water discharge areas are generally in basin lowlands. Discharge areas for unconfined aquifers occur where the water table intersects the ground surface to form springs, seeps, lakes, wetlands, or gaining streams (Lowe and Snyder, 1996) (figure 6). Discharge areas for confined aquifers occur where the ground-water gradient is upward and water is discharging to a shallow unconfined aquifer above the upper confining bed, or to a spring (figure 6). Water from wells that penetrate confined aquifers may flow to the surface naturally. The extent of both recharge and discharge areas may vary seasonally and from dry years to wet years.

Snyder (1998) used drillers' logs of water wells in the southern Sevier Desert and Pahvant Valley to delineate primary and secondary recharge areas and discharge areas, based on the presence of confining layers and relative water levels in the principal and shallow unconfined aquifers. Although this technique is useful for gaining a general idea of where recharge and discharge are likely located, it is subject to a number of limitations. The use of drillers' logs requires interpretation because of the variable quality of the logs. Correlation of geology from well logs is difficult because lithologic descriptions prepared by various drillers are generalized and commonly inconsistent. Use of water-level data from well logs is also problematic because levels in the shallow unconfined aquifer are often not recorded and because water levels were measured during different seasons and years.

Confining layers are any fine-grained (clay and/or silt) layer thicker than 20 feet (6 m) (Anderson and others, 1994). Some drillers' logs show both clay and sand in the same interval, with no information descibing relative percentages; these are not classified as confining layers (Anderson and others, 1994). If both silt and clay are checked on the log and the word "sandy" is written in the remarks column, then the layer is assumed to be a predominantly clay confining layer (Anderson and others, 1994). Some drillers' logs show both clay and gravel, cobbles, or boulders; these also are not classified as confining layers although in some areas in the southern Sevier Desert and Pahvant Valley, layers of clay containing gravel, cobbles, or boulders do, in fact, act as confining layers.

The primary recharge area for the principal aquifer system in the southern Sevier Desert and Pahvant Valley consists of uplands surrounding the basin, together with basin fill not containing confining layers, generally located along mountain fronts (figures 3 and 6). Ground-water flow in primary recharge areas has a downward component. Secondary recharge areas, if present, are locations where there are confining layers, but ground-water flow still has a downward component. Secondary recharge areas generally extend toward the center of the basin to the point where ground-water flow is upward (figures 3 and 6). The ground-water flow gradient, also called the hydraulic gradient, is upward when the potentiometric surface of the principal aquifer system is higher than the water table in the shallow unconfined aquifer (Anderson and others, 1994). Water-level data for the shallow unconfined aquifer are not abundant, but exist on some well logs. When the confining layer extends to the ground surface, secondary recharge areas occur where the potentiometric surface in the principal aquifer system is below the ground surface.

Ground-water discharge areas, if present, generally occur at lower elevations than recharge areas. In discharge areas, the water in confined aquifers discharges to the land surface or to a shallow unconfined aquifer (figures 3 and 6). For this to happen, the hydraulic head in the principal aquifer

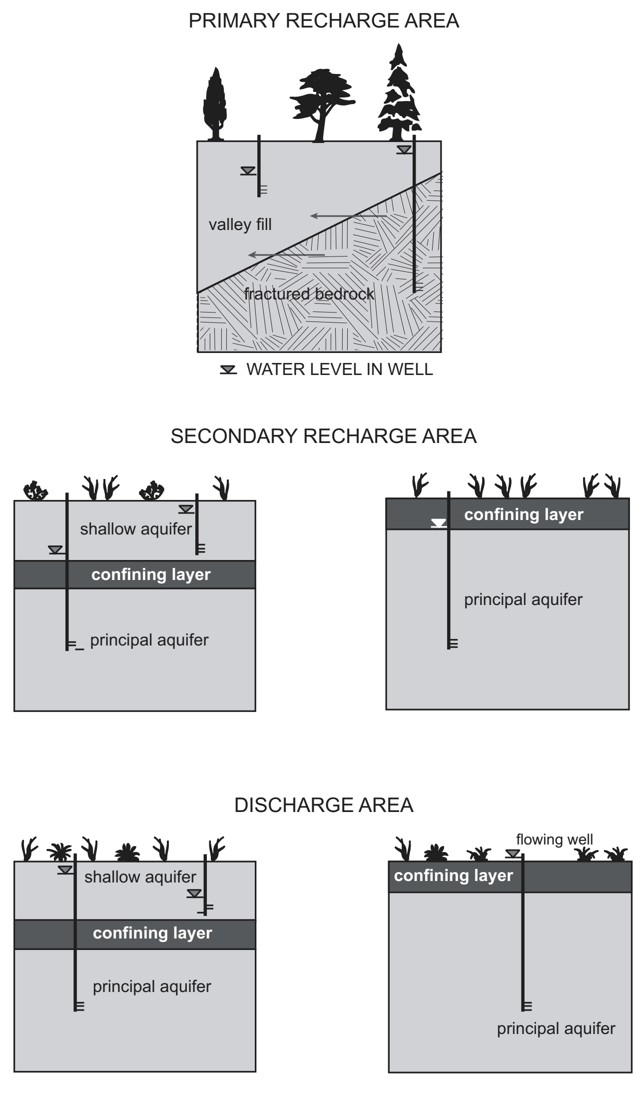


Figure 6. *Relative water levels in wells in recharge and discharge areas (from Snyder, 1998).*

system must be higher than the water table in the shallow unconfined aquifer. Otherwise, downward pressure from the shallow aquifer exceeds the upward pressure from the confined aquifer, creating a net downward gradient indicative of secondary recharge areas. Flowing (artesian) wells, indicative of discharge areas, are marked on drillers' logs and sometimes on U.S. Geological Survey 7.5-minute quadrangle maps. Wells with potentiometric surfaces above the top of the confining layer can be identified from well logs. Surface water, springs, or phreatophytic plants characteristic of wetlands can be another indicator of ground-water discharge. In some instances, however, this discharge may be from a shallow unconfined aquifer. An understanding of the topography, surficial geology, and ground-water hydrology is necessary before using these wetlands to indicate discharge from the principal aquifer system.

Hydraulic Conductivity of Soils

Hydraulic conductivity is a measure of the rate at which soils can transmit water. Even though fine-grained soils may have low transmissivities, water is nevertheless eventually transmitted. Values for hydraulic conductivity of soils were obtained from soil percolation tests and "permeability" (hydraulic conductivity) ranges assigned to soil units mapped by the U.S. Department of Agriculture's Natural Resources Conservation Service (formerly Soil Conservation Service; Wilson and others, 1959; Stott, 1977). For our GIS analysis, we divided soil units into two hydraulic conductivity ranges: greater than, and less than or equal to 1 inch (2.54 cm) per hour. We categorized these by following criteria applied by the Utah Department of Environmental Quality's Division of Water Quality in permitting or not permitting septic tanks. For areas with insufficient hydraulic conductivity data, we applied the greater than 1 inch (2.54 cm) per hour GIS attribute ranking, described below, to be protective of ground-water quality.

Pesticide Retardation

Retardation (Rao and others, 1985) is a measure of the differential between movement of water and the movement of pesticide in the vadose zone. Since pesticides are adsorbed to organic carbon in soil they move more slowly through the soil than water, depending on the proportion of organic carbon in the soil. This relatively slower movement allows pesticides to be degraded more readily by bacteria and chemical interaction than would be the case if they traveled at the same speed as pore water in the vadose zone. The retardation factor (RF) is a function of bulk density, organic carbon fraction, and field capacity of the soil and the organic carbon sorption distribution coefficient of the specific pesticide. Rao and others (1985) present the following equation:

$$R_F = 1 + (\rho b\ F_{oc}\ K_{oc})/\theta_{FC} \qquad (1)$$

where:

R_F = retardation factor;
ρb = bulk density (kg/L);
Foc = fraction, organic carbon;
Koc = organic carbon sorption distribution coefficient (L/kg); and
θ_{FC} = field capacity (volume fraction).

For this study we used data from the Soil Survey Geographic (SSURGO) database (National Soil Survey Center, 1994), which provides digitized data for some soil areas of the state of Utah, including the southern Sevier Desert and Pahvant Valley, at a scale of 1:24,000. Data include derived values for bulk density, organic carbon fraction, and field capacity (table 2).

We set variables in equation 1 at values that represent conditions likely to be encountered in the natural environment to establish a rationale for dividing high and low pesticide retardation for our GIS analysis. We used the organic carbon sorption distribution coefficient (table 3) for atrazine at a pH of 7, the pesticide among the four having the least tendency to adsorb to organic carbon in the soil (Weber, 1994).

Applying a bulk density of 2.0 kilograms per liter (kg/L) and a field capacity of 5 percent, which represent the naturally occurring extremes that would result in the greatest sensitivity to ground-water contamination, retardation of pesticides relative to vertical ground-water movement ranges from a factor of 1 to 201 times, depending on soil organic carbon content. Average organic carbon content in soils in the southern Sevier Desert and Pahvant Valley is shown in figure 7; note that the lowest category of organic carbon content in soils in the area is 0.1 to 0.75 percent. Next, we standardized organic carbon content at a value of 0.1 percent — a value representing a reasonable minimum found in the natural environment at which ground-water quality would still be protected. At this level of organic carbon content, equation 1 results in a retardation factor of 5, meaning that pesticides would travel 5 times slower through soils in the vadose zone than water. Pesticides under these circumstances traveling downward in the vadose zone would reach the water table at a depth of 3 feet (1 m) within one year if ground-water recharge amounted to 6 inches (5 cm) or greater during the year. Greater proportions of the pesticide reach ground water at that depth with greater annual quantities of ground-water recharge. When ground-water recharge is less than 6 inches (15 cm), no pesticides reach a depth of 3 feet (1 m) in a one-year period (see attenuation discussion below). A natural division between low and high retardation exists at a value of 5 percent. Accordingly, values lower than 5 percent are designated as low retardation and are assigned a ranking value of 1. Values equal to or higher than 5 percent are designated as high retardation and are assigned a ranking value of 0.

Pesticide Attenuation

Attenuation (Rao and others, 1985) is a measure of the rate at which a pesticide degrades under the same conditions as characterized above under retardation. The rate of attenuation indirectly controls the depth to which a pesticide may reasonably be expected to migrate, given the specific conditions. The attenuation factor (A_F) is a function of depth (vertically) or length (horizontally) of the soil layer through which the pesticide is traveling, net annual ground-water recharge, half-life of the specific pesticide considered, and field capacity of the soil. Rao and others (1985) present the following equation:

$$A_F = \exp(-0.693\ z\ R_F\ \theta_{FC}/q\ t_{1/2}) \qquad (2)$$

where:

A_F = attenuation factor;
z = reference depth (or length);
R_F = retardation factor;
θ_{FC} = field capacity (volume fraction);
q = net annual ground-water recharge (precipitation minus evapotranspiration); and
$t_{1/2}$ = pesticide half-life (years).

We set variables in equation 2 at values that represent conditions likely to be encountered in the natural environment, similar to what was done to establish high and low pesticide retardation, to establish a rationale for dividing high and low pesticide attenuation for our GIS analysis. We used a retardation factor of 5 percent, calculated as described above; the half-life for simazine (table 3), the pesticide among the four with the longest half-life (Weber, 1994); a field capacity of 5.0 percent, together with the bulk density value of 2.0 used in the retardation factor calculation described above, which represent the naturally occurring extremes that would result in the greatest sensitivity to ground-water contamination. For a net annual ground-water recharge value of 6 inches (15 cm), equation 2 results in an attenuation factor of 0.02. This means that two percent of the pesticide originally introduced into the system at the ground surface would be detected at a depth of 3 feet (1 m) and would enter the ground water. For rates of annual ground-

Table 2. *Hydrologic Soil Groups and rankings for retention capacity, bulk density of soils, and fraction of organic content generalized for Utah soils. Soil description and organic content from National Soil Survey Center (1994). Field capacity calculated from specific-retention data based on sediment grain size (from Bear, 1972). Bulk density from Marshall and Holmes (1988).*

Soil Group	Soil Description	Grain size (mm) (Field Capacity)	Bulk Density Range (kg/L)	Organic Content, Fraction (F_{oc})
A	Sand, loamy sand, or sandy loam; low runoff potential and high infiltration rates even when thoroughly wetted; consists of deep, well to excessively drained sands or gravels with high rate of water transmission.	0.1 - 1 (5-6%)	1.6 – 2	2.44%
B	Silt loam or loam; moderate infiltration rate when thoroughly wetted; consists of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures.	0.015 - 0.15 (6-7%)	1.3 - 1.61	3.31%
C	Sandy clay loam; low infiltration rates when thoroughly wetted; consists of soils with layer that impedes downward movement of water; soils with moderately fine to fine structure.	0.01 - 0.15 (7-7.5%)	1.3 – 1.9	3.99%
D	Clay loam, silty clay loam, sandy clay, silty clay, and/or clay; highest runoff potential of all soil groups; low infiltration rates when thoroughly wetted; consists of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious material.	0.0001 - 0.1 (6-15%)	1.12	3.35%

Table 3. *Pesticide organic carbon sorption distribution coefficients (K_{oc}) and half-lives ($T\,^1/_2$) for typical soil pHs (data from Weber, 1994).*

	K_{oc} (L/kg)		$T_{1/2}$ (Days)		$T_{1/2}$ (Years)
	pH 7	pH 5	pH 7	pH 5	-
Atrazine	100	200	60	30	0.16
Simazine	200	400	90	-	0.25
Alachlor	170	-	20	60	0.05
Metolachlor	150	-	40	-	0.11

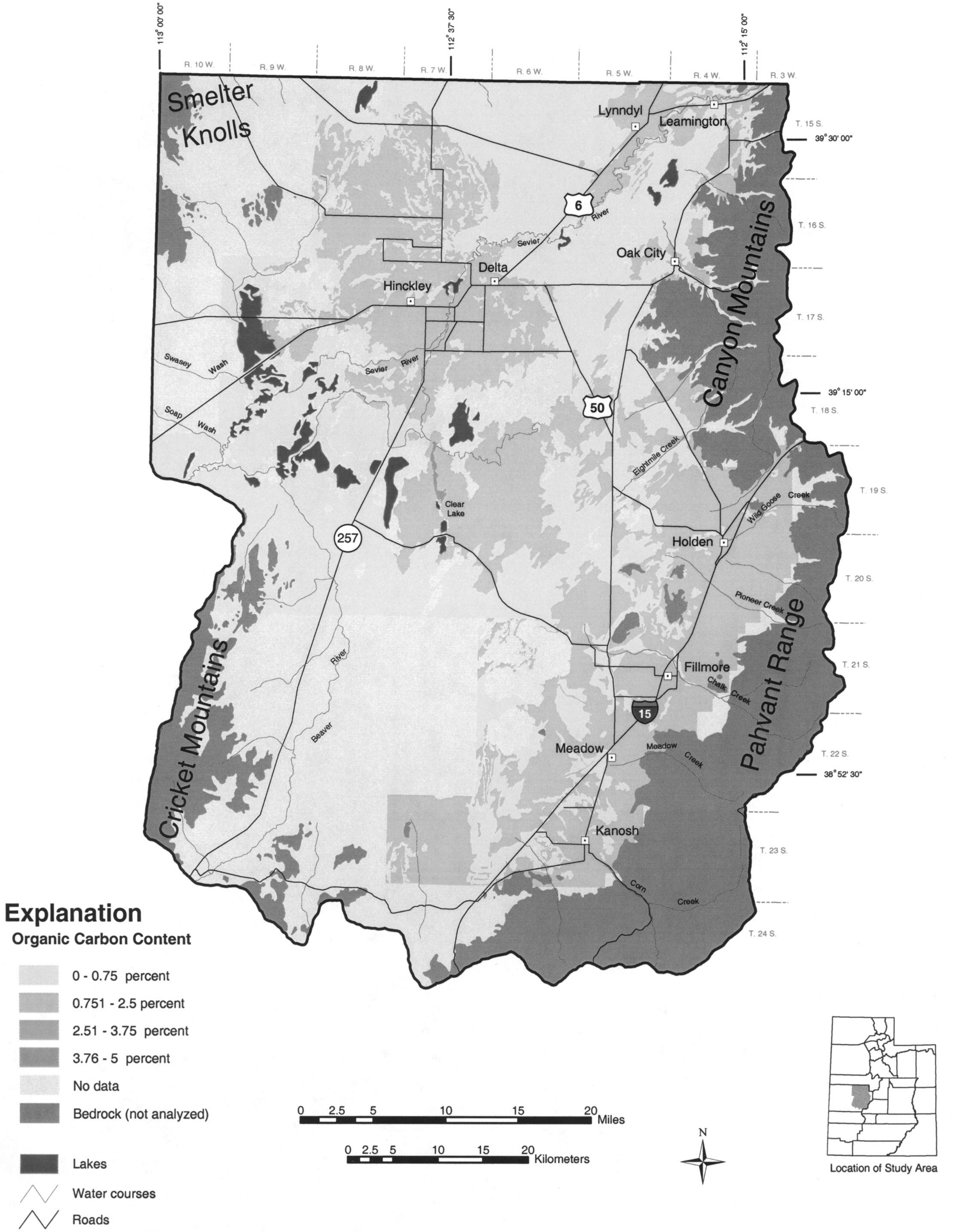


Figure 7. *Average organic carbon content in soils in southern Sevier Desert and Pahvant Valley, Millard County, Utah (data from National Soil Center, 1994).*

water recharge greater than 6 inches (15 cm), the calculated attenuation factor increases proportionally such that 50 percent of the original volume of pesticide would still be present at a depth of 3 feet (1 m) and would enter the ground water when the annual ground-water recharge rate is 3 feet (1 m). Accordingly, an attenuation factor of 0 is considered low, whereas 0.02 (2 percent) and above is considered high.

For this study, we calculated (using GIS analysis) net annual recharge by subtracting mapped normal annual evapotranspiration (Jensen and Dansereau, 2001) for the 30-year period from 1971 to 2000 from mapped normal annual precipitation (Utah Climate Center, 1991) for the 30-year period from 1961 to 1990. Data from two different 30-year periods were used because normal annual precipitation GIS data are not currently available for the 1971 to 2000 period and normal annual evapotranspiration GIS data are not available for the 1961 to 1990 period. This analysis revealed that most of the moisture produced by precipitation is consumed by evapotranspiration in most parts of the state, including the southern Sevier Desert and Pahvant Valley. Therefore, ground-water recharge from precipitation is relatively low in many areas of Utah, including the southern Sevier Desert and Pahvant Valley. The only localities in which evapotranspiration is less than precipitation are high-elevation forested areas. These are typically the source areas for surface streams which flow to valleys at lower elevations where they infiltrate the valley-fill sediment, accounting for a large part of ground-water recharge. Irrigation is another component of ground-water recharge, but it is not easily measured.

To evaluate the relationship between ground-water recharge and pesticide attenuation, we used the same array of values for variables in the attenuation equation of Rao and others (1985) (equation 2) that we applied to the retardation equation (equation 1), described earlier. We used the organic carbon sorption distribution coefficient for atrazine (table 3) at a pH of 7 – the pesticide among the four having the least tendency to adsorb to organic carbon in the soil – and the half-life for simazine (table 3), the pesticide among the four with the longest half-life (Weber, 1994). Applying a bulk density of 2.0 kg/L (the maximum anticipated value to be encountered in soil types represented in the southern Sevier Desert and Pahvant Valley, a field capacity of 5.0 percent (the minimum anticipated value), and an organic carbon content of 0.1 percent (the minimum value expected in these soils), 100 percent of pesticides would be attenuated before reaching a soil depth of 3 feet (1 m) until ground-water recharge reached a rate of 6 inches (15 cm) per year. In the southern Sevier Desert and Pahvant Valley, ground-water recharge would be derived mainly from irrigation. At higher values for organic carbon content, both the retardation factor and the attenuation factor increase dramatically. With greater proportions of organic carbon in the soil, calculations show no amount of pesticide reaching ground water even at hypothetical levels of ground-water recharge as high as 3 feet (1 m) per year.

The exercise of calculating values for retardation and attenuation factors according to hypothetical values for the equation variables enabled us to calibrate assigned rankings of pesticide sensitivity meaningfully according to naturally occurring conditions, thus overcoming one of the major objections to the DRASTIC method. Further, the exercise illustrates that organic soil content exerts a major control on the complex interplay of conditions that increase or decrease the likelihood that pesticides will find their way into the ground water. We found that even with a moderate organic carbon content in the soil, it is unlikely that pesticides will impact the ground water.

Although quantities of pesticides applied to the ground surface would intuitively seem to have a direct bearing on the amount of pesticide impacting ground water, Rao and others' (1985) equations do not support this. Note that the quantity of pesticide applied to the ground surface does not enter into either equation as a variable; the half-life of the pesticide, however, is essential. The half-life of a pesticide under typical field conditions remains fairly constant. The larger the quantity of pesticide that is applied, the greater are the number of bacteria that develop to decompose and consume the pesticide over the same period of time. Furthermore, the quantity of pesticide needed to control weeds is quite small. The following recommended application rates (table 4) are provided by the manufacturers of the four herbicides evaluated as part of this study. Pre-emergent herbicides are typically applied once per year, either in the fall after post-season tillage or in early spring before weeds begin to germinate.

Table 4. *Maximum recommended application rates* for the four pesticides discussed in this report.*

Herbicide	Max. Application rate (lbs. AI** per acre)	Time interval
Atrazine	2.5	calendar year
Alachlor	4.05	Preemergence
Metolachlor	1.9	Preemergence
Simazine	4.0	Preemergence

*Data derived from labeling documentation provided by manufacturers; latest update as of January 2001.
**Active ingredient.

Depth to Ground Water

The closer ground water is to the land surface the more sensitive it is to being degraded by pesticides. Based on soil mottling, water encountered in test pits, or other information, soils with shallow ground water seasonally less than 3 feet (1 m) deep is one attribute of soil units mapped by the U.S. Department of Agriculture's Natural Resources Conservation Service (formerly Soil Conservation Service; Wilson and others, 1959; Stott, 1977). Three feet (1 m) was selected as the depth-to-ground-water attribute used to evaluate sensitivity of geographic areas to pesticides. For areas where depth-to-ground-water data were not available in GIS format, we applied the less-than-3-feet (1 m) GIS attribute ranking, described below, to be protective of ground-water quality.

GIS Analysis Methods

We divided pesticide sensitivity into "low," "moderate," and "high" categories using hydrogeologic setting, soil hydraulic conductivity, soil retardation of pesticides, soil attenuation of pesticides, and depth to shallowest ground-water attributes as shown on table 5. Numerical ranking for each attribute category is arbitrary, but reflects the level of

Table 5. *Pesticide sensitivity and attribute rankings used to assign it for the southern Sevier Desert and Pahvant Valley, Millard County, Utah.*

Pesticide Retardation		Pesticide Attenuation		Hydrogeologic Setting		Soil Hydraulic Conductivity		Depth to Ground Water		Sensitivity	
Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking
High	0	High	0	Discharge Area	-4	Less than 1 inch/hour	1	Greater than 3 feet	1	Low	-2 to 0
				Secondary Recharge Area	-1					Moderate	1 to 4
Low	1	Low	1	Primary Recharge Area	2	Greater than 1 inch/hour	2	Less than 3 feet	2	High	5 to 8

importance we believe the attribute plays in determining sensitivity of areas to application of agricultural pesticides; for instance, we believe hydrogeologic setting is the most important attribute with respect to ground-water sensitivity to pesticides, and therefore weighted this attribute three times more heavily than the other attribute categories. A sensitivity attribute of low was assigned when the numerical ranking ranged from –2 to 0, a sensitivity attribute of moderate was assigned when the numerical ranking ranged from 1 to 4, and a sensitivity attribute of high was assigned when the numerical ranking ranged from 5 to 8.

Ground-Water Vulnerability to Pesticide Pollution

Ground-water vulnerability to pesticides is a measure of how natural factors favorable or unfavorable to the degradation of ground water by pesticides applied to or spilled on the land surface are modified by the activities of humans. We selected ground-water sensitivity to pesticides, presence of applied water (irrigation), and crop type as the three factors primarily determining ground-water vulnerability to pesticides. Our vulnerability map is based on 1995 land-use data.

Ground-Water Sensitivity

We consider ground-water sensitivity to be the principal factor determining the vulnerability of the basin-fill aquifer in the southern Sevier Desert and Pahvant Valley to degradation from agricultural pesticides. Low, moderate, and high sensitivity rankings were assigned numerical values as shown in table 6.

Irrigated Lands

Irrigated lands are mapped from the Utah Division of Water Resources 1:24,000-scale Land Use/Water Related Use GIS data set. Areas of various water-use categories were either mapped from aerial photographs (pre-2000) or 5-meter (16 ft) resolution infrared satellite data and then field checked (Utah Division of Water Resources metadata). The southern Sevier Desert and Pahvant Valley inventory was conducted in 1994-95 (Utah Division of Water Resources metadata). All polygons with standard type codes beginning with IA were selected to produce the irrigated land coverage for this study. These data do not distinguish areas of sprinkler irrigation versus areas of flood irrigation; areas of flood irrigation are likely to be more vulnerable to degradation from pesticides than areas of sprinkler irrigation.

Agriculture Types

Agricultural lands are mapped from the Utah Division of Water Resources 1:24,000-scale Land Use/Water Related Use GIS data set, which includes categories of crop types. Areas of various crop-type categories were either mapped from aerial photographs (pre-2000) or 5-meter (16 ft) resolution infrared satellite data and then field checked (Utah Division of Water Resources metadata). The southern Sevier Desert and Pahvant Valley inventory was conducted in 1994-95 (Utah Division of Water Resources metadata). We selected all polygons with standard type codes IA2a1 (corn), IA2a2 (sorghum), and IA2b5 (sweet corn; none in this category were in the data set) to produce the crop type land cov-

Table 6*. Pesticide vulnerability and attribute rankings used to assign it for the southern Sevier Desert and Pahvant Valley, Millard County, Utah.*

Sensitivity		Corn/Sorghum Crops		Irrigated Land		Vulnerability	
Attribute	Ranking	Attribute	Ranking	Attribute	Ranking	Attribute	Ranking
Low	-2	No	0	No	0	Low	-2 to -1
Moderate	0					Moderate	0 to 2
High	2	Yes	1	Yes	1	High	3 to 4

erage for this study, as these are the crop types to which the pesticides addressed are applied in Utah. Although the specific fields with these crops may vary from year to year, the general areas and average percentages of these crop types likely do not.

GIS Analysis Methods

We divided pesticide vulnerability into "low," "moderate," and "high" categories using pesticide sensitivity, areas of irrigated lands, and crop type as shown in table 6. Once again, numerical ranking for each attribute category is arbitrary, but reflects the level of importance we believe the attribute plays in determining vulnerability of areas to application of agricultural pesticides. For instance, we believe ground-water sensitivity to pesticides is the most important attribute with respect to ground-water vulnerability to pesticides, and therefore weighted this attribute two times more heavily than the other attribute categories.

RESULTS

Ground-Water Sensitivity

To assess ground-water sensitivity to pesticide contamination, several attribute layers were assembled as intermediate steps. Attribute layers include pesticide retardation/attenuation, hydrogeologic setting (recharge/discharge areas), hydraulic conductivity of soils, and depth to shallow ground water. Data from these attribute layers were used to produce a ground-water sensitivity map (plate 1) using GIS analysis methods as outlined in table 5, and are described and summarized in the following sections.

Retardation/Attenuation

Retardation/attenuation was ranked as high throughout the southern Sevier Desert and Pahvant Valley because net annual evapotranspiration exceeds net annual precipitation. Net annual recharge from precipitation is negative in basin floor areas (figure 8). Most recharge that does occur from precipitation likely occurs during spring snowmelt, principally along the basin margins along the Pahvant Range and Canyon Mountains. Pesticides are generally applied after snowmelt. Up to several months may elapse between pesticide application and first irrigation, sufficient time for attenuation to occur before downward migration of pesticides in the vadose zone commences under the influence of irrigation.

Hydrogeologic Setting

Ground-water recharge areas in the southern Sevier Desert and Pahvant Valley (figure 9) were mapped by Snyder (1998). His map shows that primary recharge areas, the areas most susceptible to contamination from pesticides applied to the land surface, make up about 37 percent of the surface area of the basin-fill aquifer. Primary recharge areas form a band around the outer margin of the basin-fill deposits, as well as a north-trending area between Meadow and Clear Lake (figure 9). Secondary recharge areas make up about 48 percent of the surface area of the basin-fill aquifer, forming a band between primary recharge areas and discharge areas, primarily in western and northern parts of the southern Sevier Desert basin (figure 9). Parts of the central, lower elevations of the southern Sevier Desert basin and Pahvant Valley are ground-water discharge areas (figure 9). Discharge areas, which provide extensive protection to the principal aquifer from surface contamination from the application of pesticides, make up about 15 percent of the surface area of the basin-fill aquifer.

Hydraulic Conductivity of Soils

Surface application of pesticides is more likely to cause ground-water quality problems in areas where soils have higher hydraulic conductivity than in areas where hydraulic conductivity is low. Hydraulic conductivity data are from the National Soil Survey Center (1994). About 40 percent of the surface area of the basin-fill aquifer has soil units mapped as having hydraulic conductivity greater than or equal to 1 inch per hour (2.54 cm/hour). Soils in this category are found over much of the study area, but are particularly common along the basin margins on the east side of the study area (figure 10). About 27 percent of the surface area of the basin-fill aquifer has soil units mapped as having hydraulic conductivity less than 1 inch per hour; these soil units are pri-

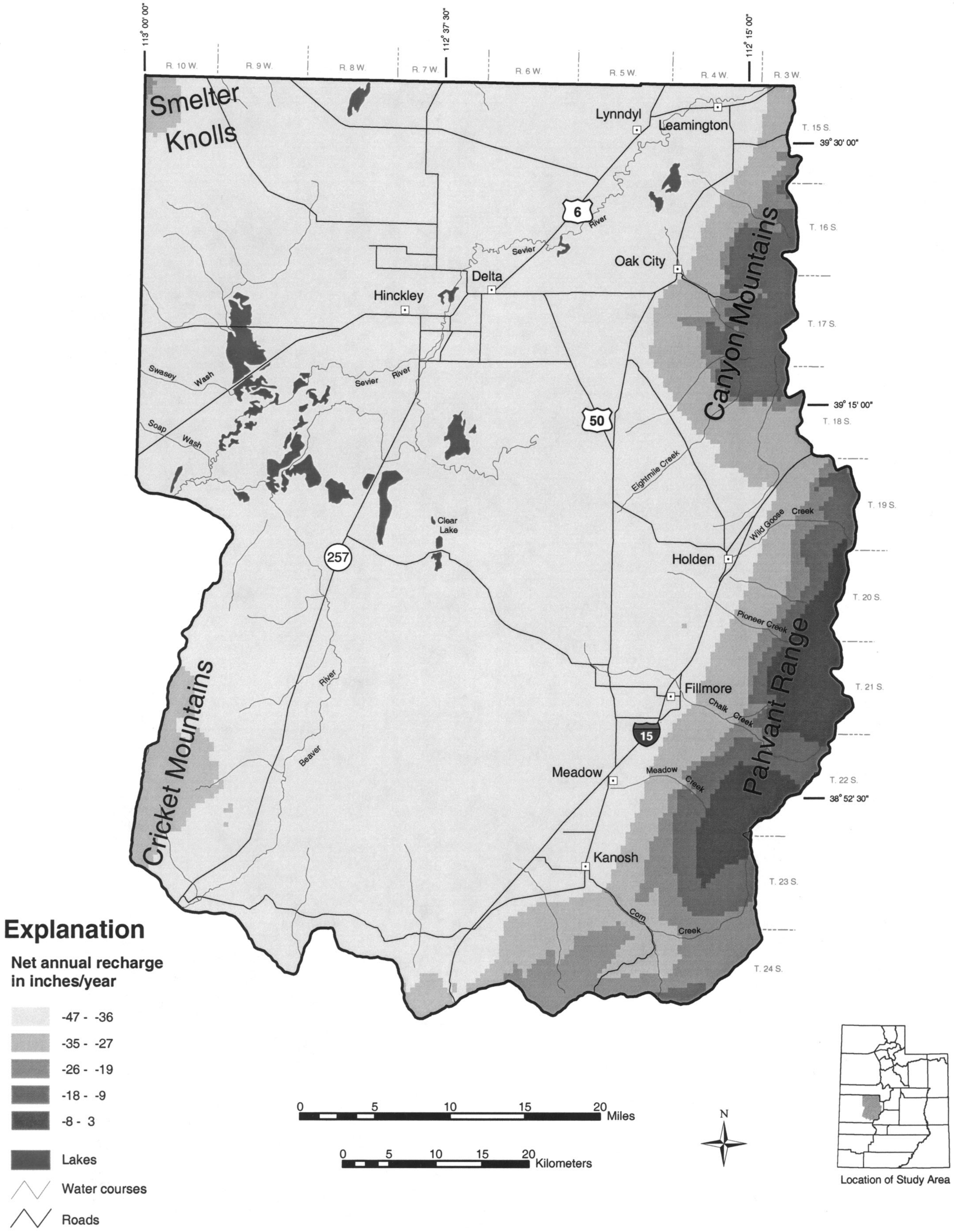


Figure 8. *Net annual recharge for the southern Sevier Desert and Pahvant Valley, Millard County, Utah calculated using data from the Utah Climate Center (1991) and Jensen and Dansereau (2001). Although net annual recharge may be negative in some areas, seasonally some recharge from precipitation may occur.*

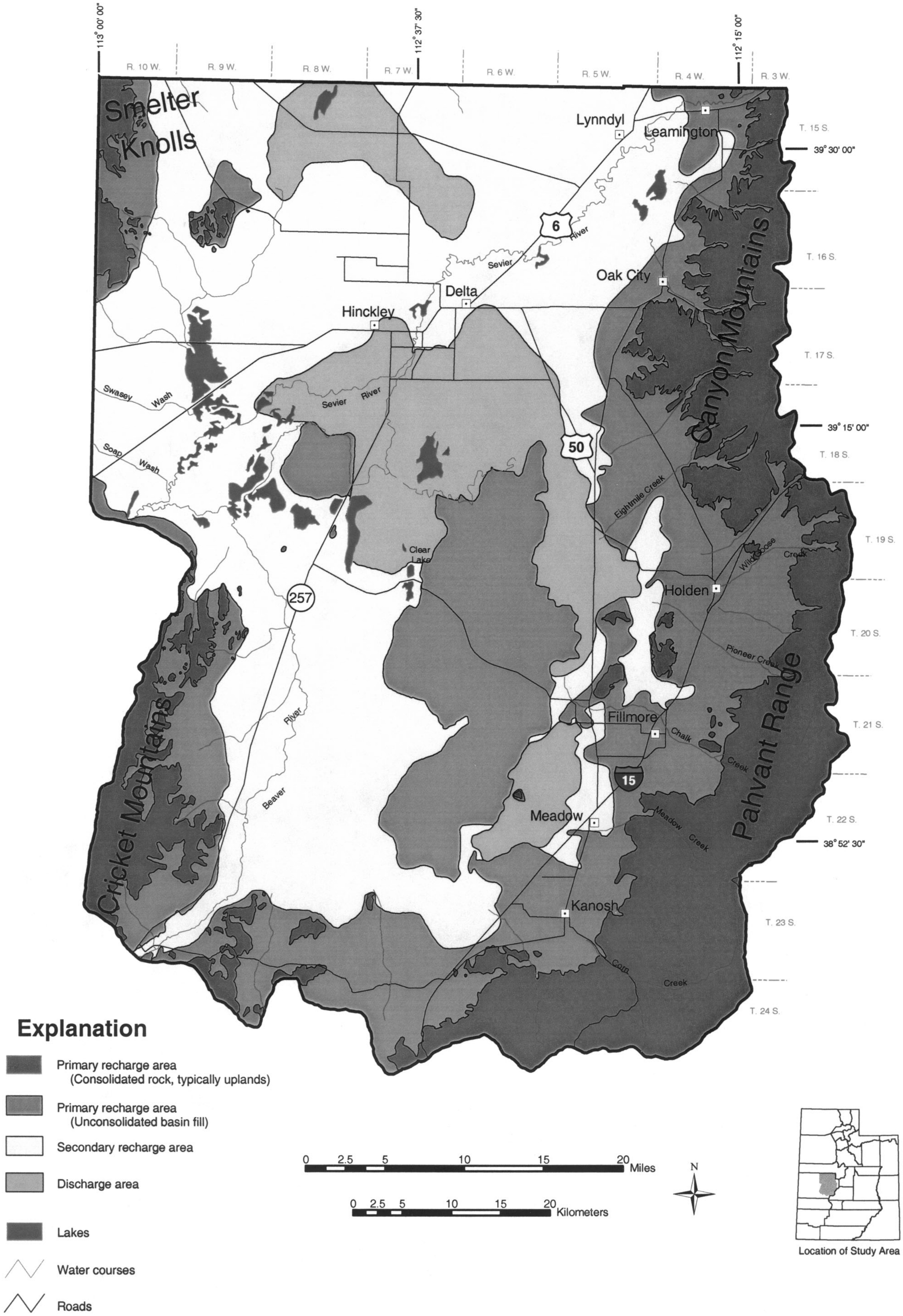


Figure 9. *Recharge and discharge areas in the southern Sevier Desert and Pahvant Valley, Millard County, Utah (after Snyder, 1998).*

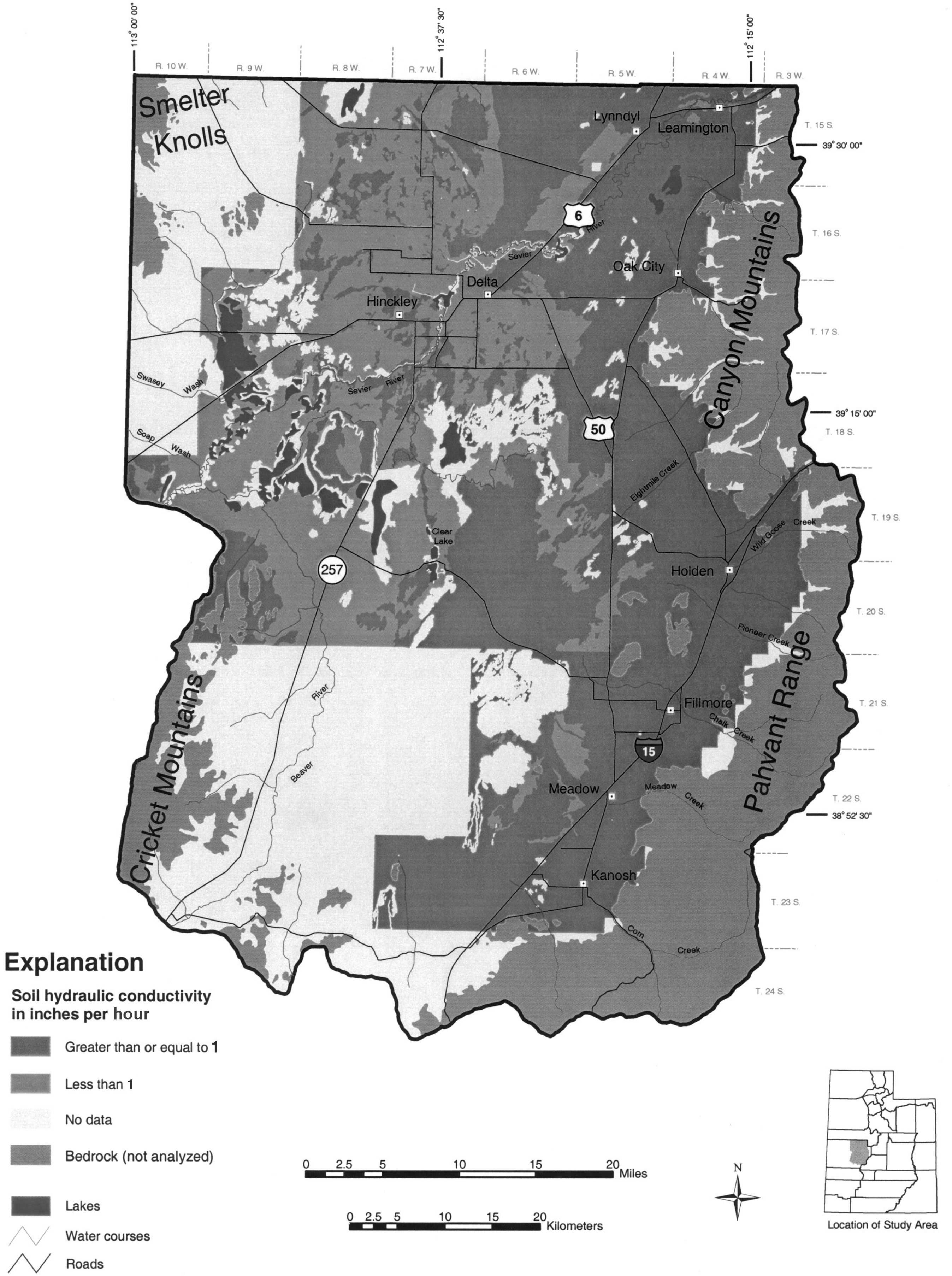


Figure 10. *Soil hydraulic conductivity in the southern Sevier Desert and Pahvant Valley, Millard County, Utah (data from National Soil Survey Center, 1994).*

marily in the central part of the valley at lower elevations (figure 10). About 33 percent of the surface area of the basin-fill aquifer has soil units for which hydraulic conductivity values have not been assigned; these soils are primarily along the northwest and southwest parts of the study area (figure 10), and were lumped into the greater than or equal to 1 inch per hour (2.54 cm/hour) category for analytical purposes to be protective of water quality.

Depth to Shallow Ground Water

Surface application of pesticides is more likely to cause ground-water quality problems in areas of shallow ground water than where ground water is relatively deeper. Depth to shallow ground-water data are from the National Soil Survey Center (1994). About 4 percent of the area overlying the basin-fill aquifer has soil units mapped as having depths to shallow ground water less than or equal to 3 feet (1 m); these areas are primarily in the central part of the valley at lower elevations (figure 11). About 31 percent of the surface area of the basin-fill aquifer has soil units mapped as having depths to shallow ground water greater than 3 feet (1 m); these areas are mapped principally in the eastern part of the study area (figure 11). However, almost 65 percent of the surface area of the basin-fill aquifer is underlain by soil units for which depth to shallow ground water is unknown. Most of these areas with no data are located in the central and western parts of the southern Sevier Desert (figure 11). Areas without assigned depths to shallow ground water were lumped into the less than or equal to 3 feet depth category for analytical purposes to be protective of water quality.

Pesticide Sensitivity Map

Plate 1 shows ground-water sensitivity to pesticides for the southern Sevier Desert and Pahvant Valley, obtained using GIS methods and ranking techniques described above. Our analysis evaluates only the basin-fill aquifer; the surrounding uplands are designated on plate 1 as "bedrock" and consist mainly of shallow or exposed bedrock in mountainous terrain.

The central part of the southern Sevier Desert basin is of low sensitivity (plate 1) because it is a discharge area characterized by ground-water gradients having upward flow, as are the areas northwest of Meadow and north of Hinckley. Pesticides used in these areas are unlikely to degrade ground water because they have little opportunity to get into the aquifer. In this area, pesticides spilled or misapplied have a much greater potential to contaminate surface water than ground water.

Surrounding the areas of low sensitivity, especially in the northern part of the study area, is an area of moderate sensitivity (plate 1). This consists of primary and secondary recharge areas where pesticides spilled or misapplied have a greater potential for impacting ground water. In areas of moderate sensitivity, the ground-water gradient has a downward component, but the aquifer is somewhat protected because it is partially confined or is at sufficient depth that pesticides would undergo chemical breakdown before migrating to such depths.

Areas of high sensitivity are located primarily along the margins of the central Sevier Desert and Pahvant Valley, and in the central, southwest, and northwest parts of the study area (plate 1). In these areas, ground water is either shallow with no overlying confining layers, or insufficient data are available to make a less conservative assessment. Additionally, these areas typically have higher hydraulic conductivity. In some localities, perched water may be present above lenticular or discontinuous bodies of fine-grained sediment that form aquicludes. In some cases, shallow ground water may be erroneously reported on drillers' logs. Improved data quality is required to substantiate or discount these as areas of concern.

Ground-Water Vulnerability

To assess ground-water vulnerability to pesticide contamination — the influence of human activity added to natural sensitivity — we assembled two attribute layers as intermediate steps. Pertinent attribute layers include irrigated cropland and corn- and sorghum-producing areas in the southern Sevier Desert basin and Pahvant Valley, combined into one attribute-layer map (figure 12). Using GIS methods as outlined in table 6, pertinent attribute layers, in turn, are combined with ground-water sensitivity, discussed in the previous sections, to produce a map showing ground-water vulnerability to pesticides (plate 2). Pertinent attribute layers, along with ground-water sensitivity, are described in the following sections.

Ground-Water Sensitivity

The most influential factor in ground-water vulnerability to pesticide contamination is ground-water sensitivity, described in the previous section. Sensitivity represents the sum of natural influences that facilitate the entry of pesticides into ground water. The fact that sensitivity is the prevailing influence is manifested in the similarity between the sensitivity and vulnerability maps (plates 1 and 2, respectively). However, a vulnerability assessment for a particular tract of land should not be made from the sensitivity map despite this similarity.

Irrigated Cropland

Irrigated cropland areas in the southern Sevier Desert basin and Pahvant Valley are shown on figure 12. Irrigation is potentially significant because it is a source of ground-water recharge in the basin-fill aquifer.

Corn and Sorghum Crops

From the point of view of human impact, areas where corn and sorghum are grown (figure 12) are significant because the four herbicides considered in this report — alachlor, atrazine, metolachlor, and simazine — are used to control weeds in these crops. Areas of corn and sorghum crops are shown on figure 12 as rectangles or circles (where center-pivot irrigation systems are used) concentrated in the Delta area, the eastern margin of the southern Sevier Desert basin, and in Pahvant Valley. Corn and sorghum production raises vulnerability from low to moderate.

PesticideVulnerability Map

Plate 2 shows ground-water vulnerability to pesticides of the basin-fill aquifer for the southern Sevier Desert and Pah-

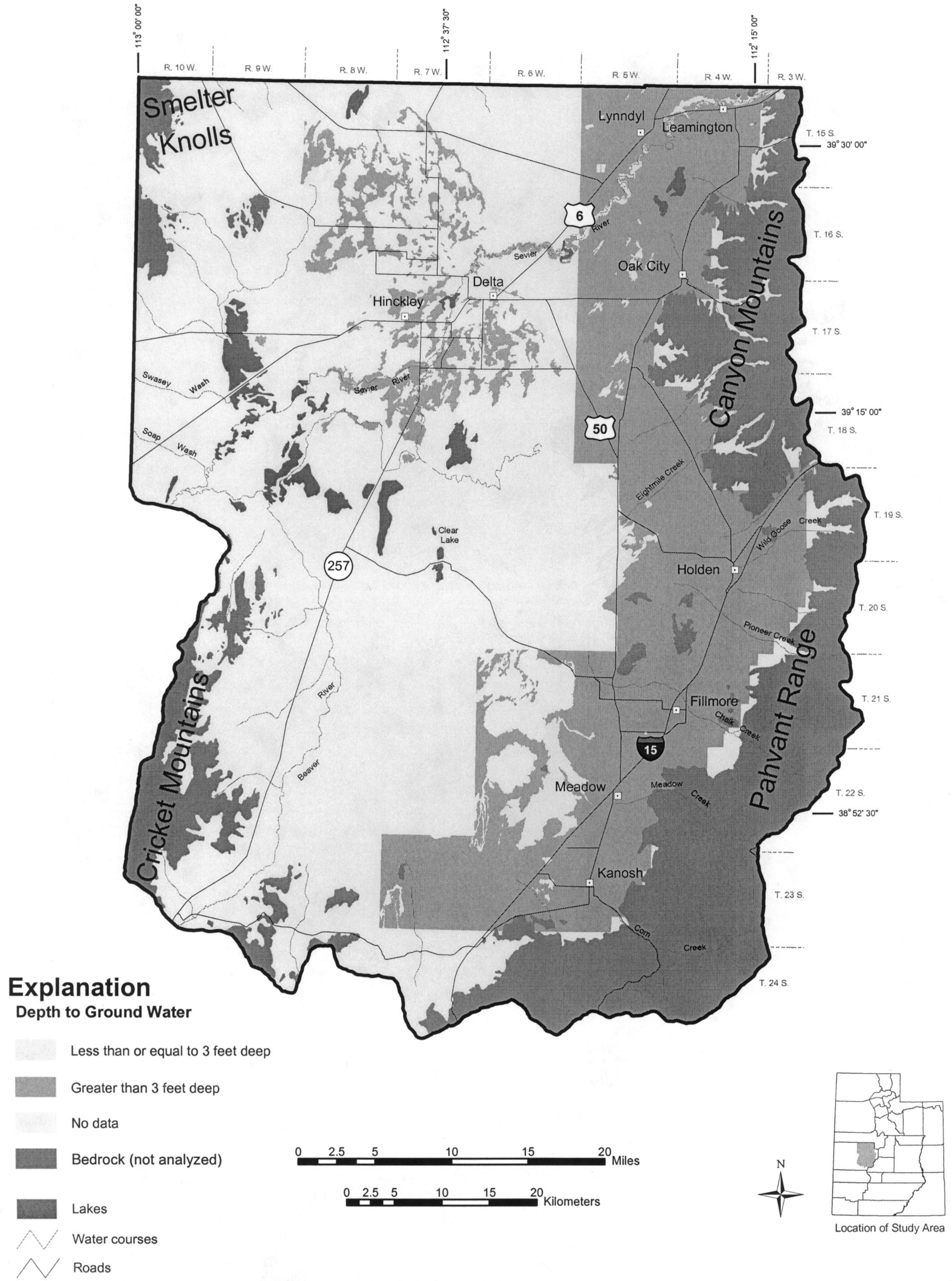


Figure 11. *Depth to ground water in the southern Sevier Desert and Pahvant Valley, Millard County, Utah (data from National Soil Survey Center, 1994).*

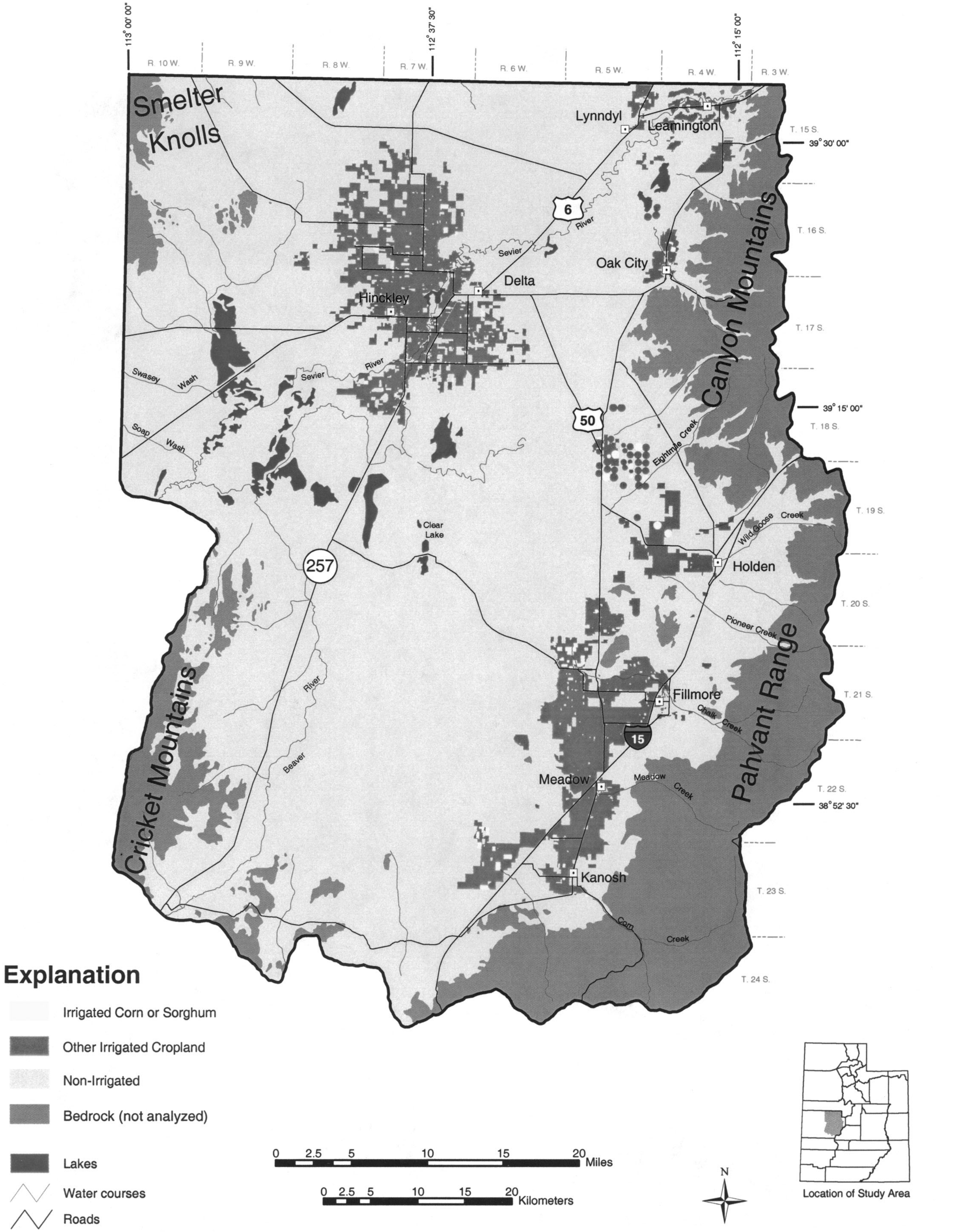


Figure 12. *Irrigated and non-irrigated cropland in the southern Sevier Desert and Pahvant Valley, Millard County, Utah (data from Utah Division of Water Resources, 1995). The pesticides addressed in this study are mainly applied to corn and sorghum.*

vant Valley, obtained using GIS methods and ranking techniques described above. The surrounding uplands are not included in the analysis because of shallow bedrock and mountainous terrain, and because they are not areas of significant agricultural activity.

Low-sensitivity areas and low-vulnerability areas roughly coincide, but have minor differences. Localities where corn and sorghum are grown appear as rectangle-like shapes of moderate vulnerability on plate 2 in the central part of the valley where low vulnerability otherwise predominates.

Areas of moderate vulnerability coincide, in general, with areas of moderate or high sensitivity. The moderate-vulnerability areas occur along valley-margin benches where ground water is at great depths or confining layers protect the deeper basin-fill aquifer. An area of high sensitivity would be categorized as having moderate vulnerability if the land is not irrigated or if corn or sorghum are not raised there.

Areas of high vulnerability are primarily located in primary recharge areas along valley margins where corn/sorghum crops are grown, or where the depth to shallow ground water is unknown. Of particular concern are areas where streams originating in mountainous areas cross the valley margin. Some of these localities fall within the high-vulnerability range. Recharge of ground water by such streams at these points is an important means of basin-fill aquifer recharge (table 3). Therefore, efforts to preserve water quality in streams at these points would help to preserve ground-water quality in the entire basin.

CONCLUSIONS AND RECOMMENDATIONS

Precipitation is not the major source of ground-water recharge within the southern Sevier Desert and Pahvant Valley, especially where ground-water gradients in the basin-fill aquifer are upward (ground-water discharge areas). Areas where rivers and streams cross valley-bounding faults or coarse-grained alluvial fans represent the most urgent need for protection to preserve ground-water quality, based on the results of our ground-water sensitivity and vulnerability mapping. Other valley-margin areas, particularly those with unlined or poorly lined irrigation canals, also warrant measures to protect ground-water quality based on our mapping. However, because of relatively high retardation (long travel times of pesticides in the vadose zone) and attenuation (short half-lives) of pesticides in water in the soil environment, the application of pesticides to crops and fields in the central parts of the southern Sevier Desert and Pahvant Valley likely does not represent a serious threat to ground-water quality.

Based on these conclusions, we believe ongoing ground-water sampling in the southern Sevier Desert and Pahvant Valley should be concentrated in areas of moderate and high sensitivity or vulnerability, typically along valley margins. Sampling in the central areas of the valleys characterized by low sensitivity and low vulnerability should continue, but at a lower density than in the areas of higher sensitivity and vulnerability. Areas where data are unavailable, particularly areas lacking shallow ground-water data, were treated conservatively (in a manner protective of ground-water quality), by assuming that the conditions most susceptible to pesticide pollution of ground water are present. This conservative approach is particularly evident in valley-margin areas where depth to the water table is generally deep, but where GIS analysis presumed the water table to be shallow due to a lack of map data to the contrary. Therefore, our maps show higher sensitivity and vulnerability to pesticides than what actually may be the case in those areas. Ground-water sensitivity and vulnerability to pesticides in such areas should be re-evaluated if better data become available. The maps and accompanying report are based on analyses of 1:24,000 or smaller scale data and are not meant for site-specific evaluations.

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Plate 1

GROUND-WATER SENSITIVITY TO PESTICIDES IN THE SOUTHERN SEVIER DESERT AND PAHVANT VALLEY, MILLARD COUNTY, UTAH

by Ivan Sanderson and Mike Lowe

Digital Compilation by Matt Butler and Anne M. Johnson

Miscellaneous Publication 03-1
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Explanation

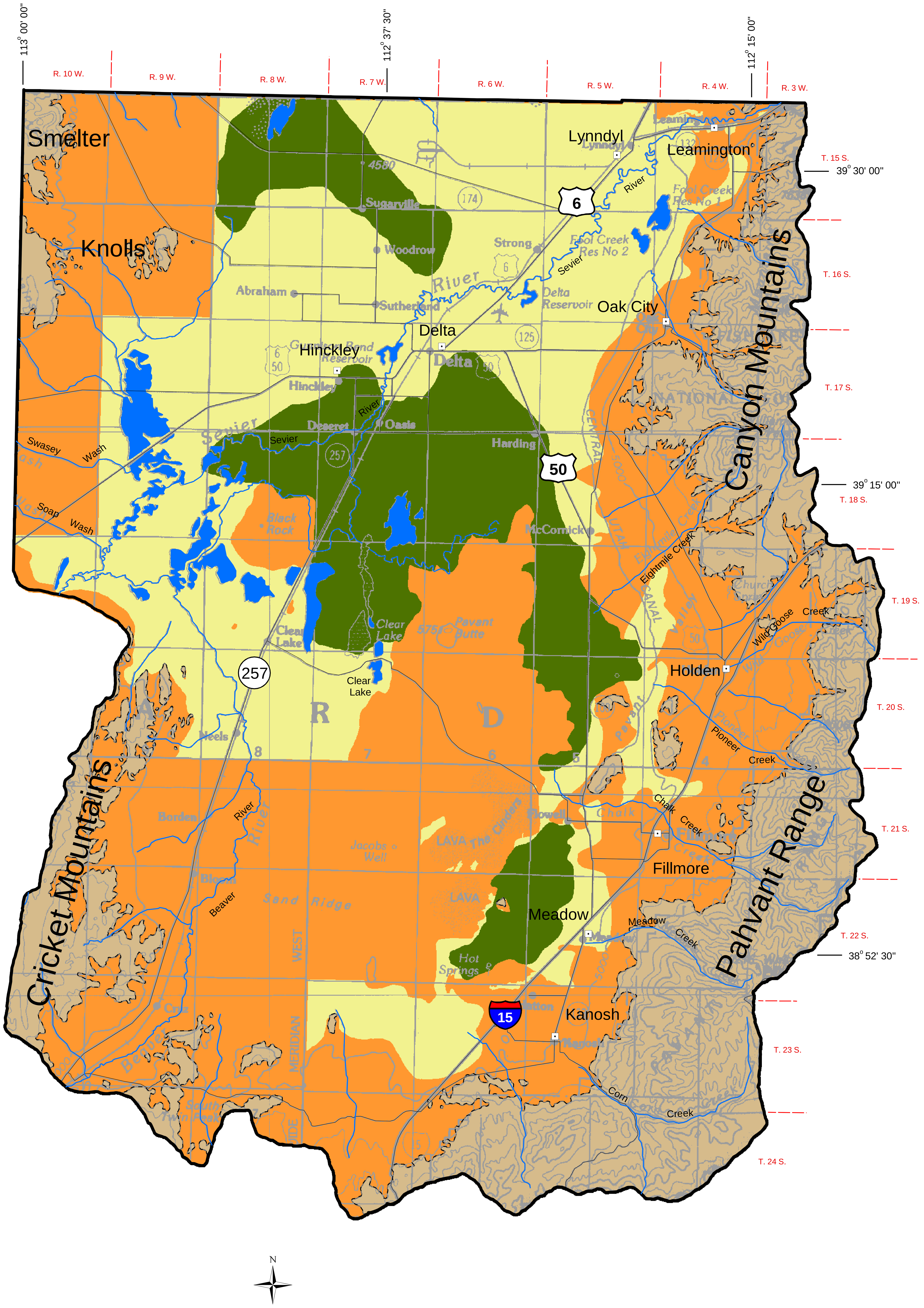
Pesticide Sensitivity Ranking

(determined by natural factors favorable or unfavorable to the degradation of ground water by pesticides)

- Low sensitivity
- Moderate sensitivity
- High sensitivity
- Bedrock (not analyzed)

- Water bodies
- Roads
- Water courses
- Basin-fill boundary
- Study-area boundary

Location of Study Area



0 5 10 20 Miles

0 5 10 20 Kilometers

This map is a GIS product derived from a recharge/discharge area map by Anderson and others (1994), soil data from the National Soil Survey Center (1994), precipitation data from the Utah Climate Center (1991), evapotranspiration data from Jensen and Dansereau (2001), and land-use data from the Utah Division of Water Resources (1995). No additional field work was performed or data collected.

This map is based on 1:24,000 or smaller scale data and should not be used for site-specific evaluations.

Projection: UTM
Zone: 12
Units: Meters
Datum: NAD27
Spheroid: Clarke 1866

Topographic basemap from U.S. Geological Survey 1:500,000-scale image (1988)

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UTAH DEPARTMENT OF AGRICULTURE AND FOOD

Plate 2

GROUND-WATER VULNERABILITY TO PESTICIDES IN THE SOUTHERN SEVIER DESERT AND PAHVANT VALLEY, MILLARD COUNTY, UTAH

by Ivan Sanderson and Mike Lowe

Digital Compilation by Matt Butler and Anne M. Johnson

Explanation

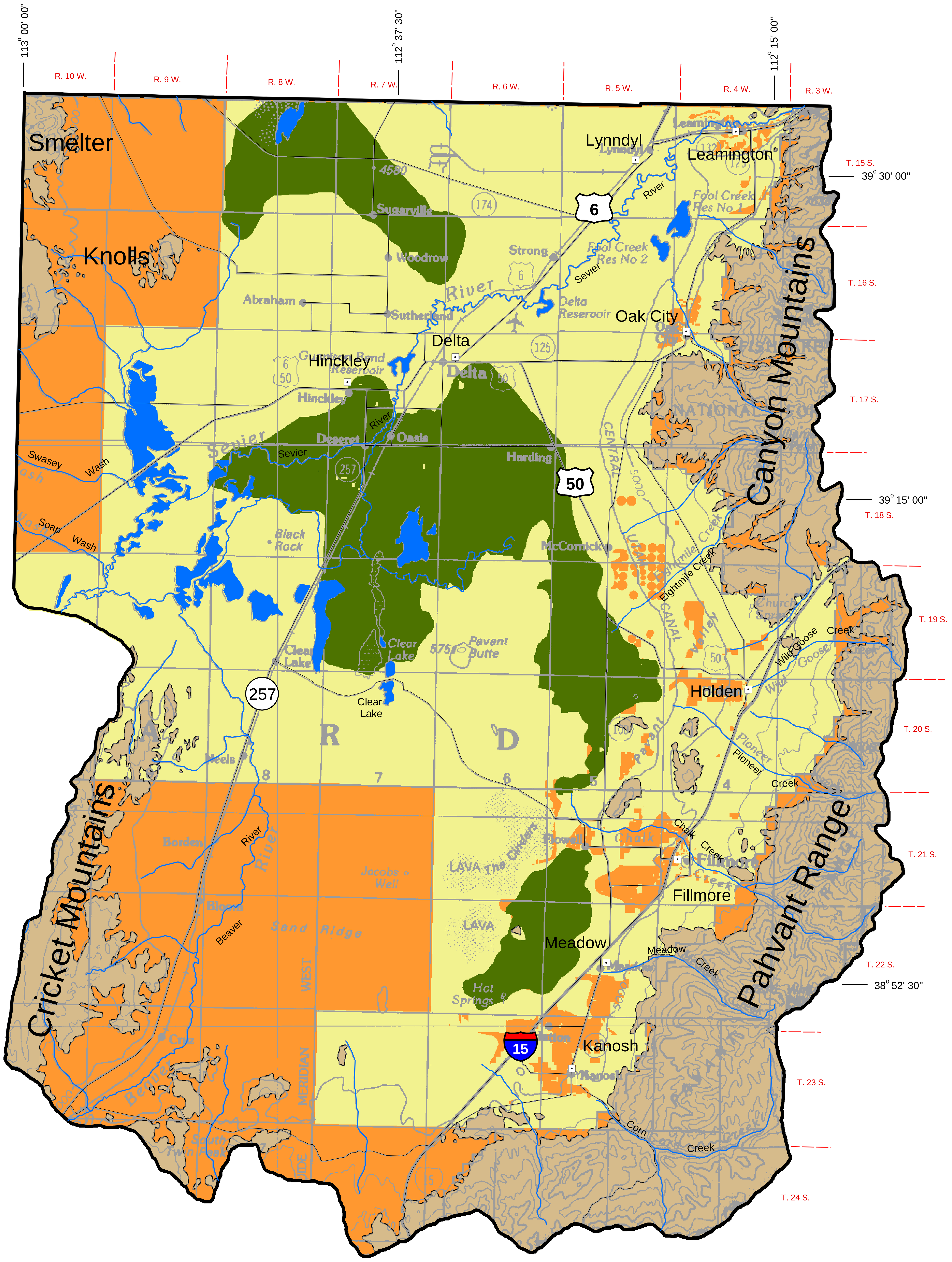
Pesticide Vulnerability Ranking

(a measure of how natural factors favorable or unfavorable to the degradation of ground water by pesticides are modified by the activities of humans)

- Low vulnerability
- Moderate vulnerability
- High vulnerability
- Bedrock (not analyzed)

- Water bodies
- Roads
- Water courses
- Basin-fill boundary
- Study-area boundary

Location of Study Area



1:175,000

0 5 10 20 Miles

0 5 10 20 Kilometers

This map is a GIS product derived from a recharge/discharge area map by Anderson and others (1994), soil data from the National Soil Survey Center (1994), precipitation data from the Utah Climate Center (1991), evapotranspiration data from Jensen and Dansereau (2001), and land-use data from the Utah Division of Water Resources (1995). No additional field work was performed or data collected.

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Zone: 12
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Topographic basemap from U.S. Geological Survey 1:500,000-scale image (1988)

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