GROUND-WATER SENSITIVITY AND VULNERABILITY TO PESTICIDES, MORGAN VALLEY, MORGAN COUNTY, UTAH

by

Mike Lowe, Janae Wallace, Neil Burk, and Matt Butler, Utah Geological Survey

and

Anne Johnson and Rich Riding, Utah Department of Agriculture and Food

MISCELLANEOUS PUBLICATION 04-4
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Cover photo: View looking northwest of Morgan Valley. The city of Morgan is on the right side of photograph (photo by Greg McDonald).

ISBN 1-55791-716-7

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ABSTRACT

The U.S. Environmental Protection Agency has recommended 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 Morgan Valley, Morgan 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. This is a first attempt at developing pesticide sensitivity and vulnerability maps; additional data and tools may become available in the future so that better maps can be produced.

Ground-water sensitivity (intrinsic susceptibility) 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 Morgan Valley. Much of Morgan Valley has moderate to high ground-water sensitivity to pesticides due to the absence of protective clay layers above the valley-fill aquifer.

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity is modified by human activity. 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 Morgan Valley. Areas of high vulnerability are primarily located in areas where irrigation occurs and ground-water sensitivity to pesticides is high. Of particular concern are areas adjacent to the Weber River, the most important source of recharge to the valley-fill aquifer; efforts to preserve water quality in these areas would help to preserve ground-water quality throughout Morgan Valley.

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 Morgan Valley likely do not present a serious threat to ground-water quality. To verify this conclusion, future ground-water sampling by the Utah Department of Agriculture and Food in Morgan Valley should be concentrated in areas of high sensitivity or vulnerability. Sampling in areas characterized by moderate sensitivity and vulnerability should continue, but at a lower density than in the areas of high sensitivity and vulnerability.

INTRODUCTION

Background

The U.S. Environmental Protection Agency (EPA) has recommended 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 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 Morgan Valley, Morgan County, Utah (figure 1). This cooperative study, conducted by the Utah Geological Survey and the Plant

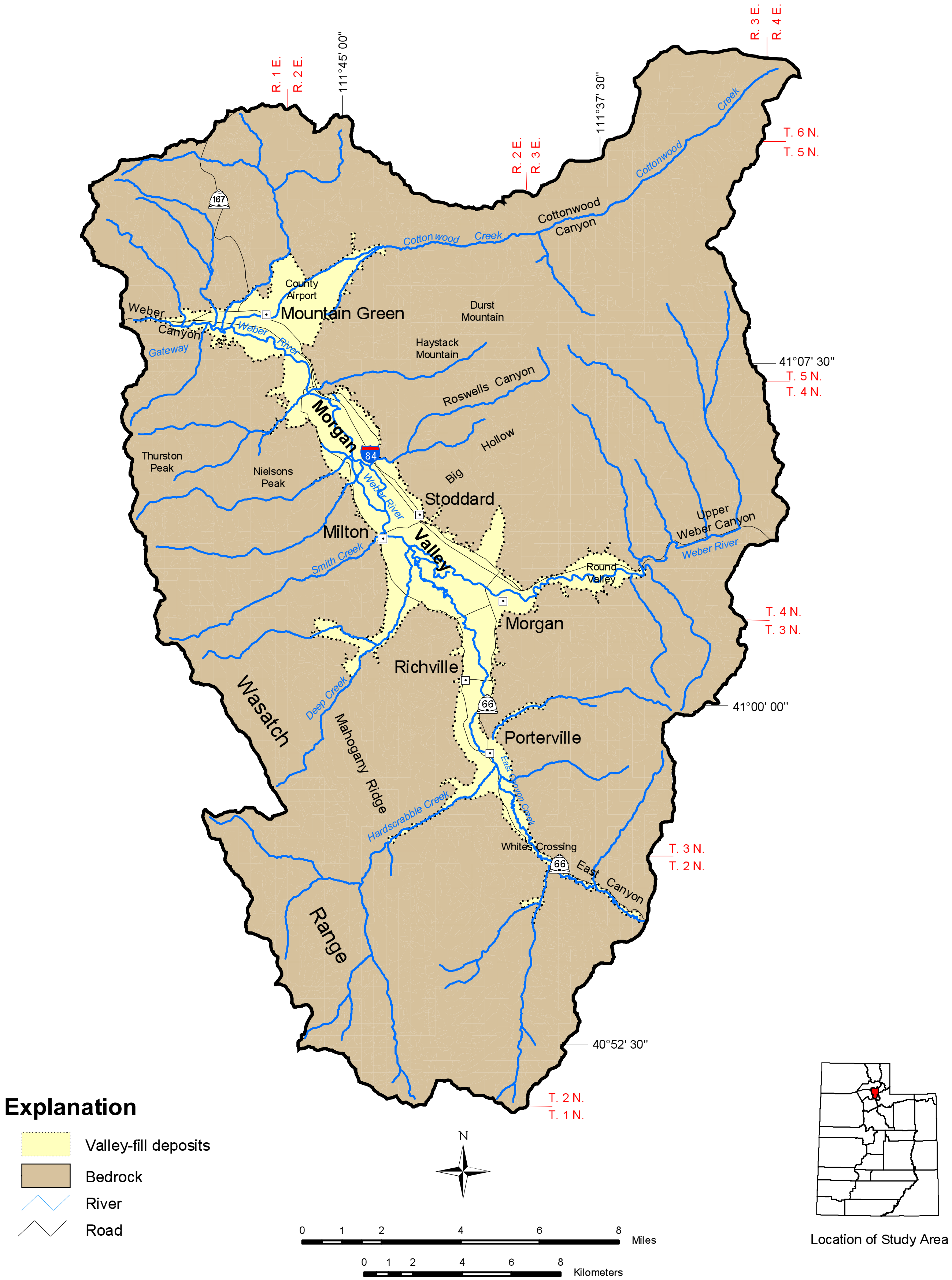

Figure 1. Morgan Valley, Morgan County, Utah, study area.

Industry Division of the Utah Department of Agriculture and Food (UDAF), provides needed information on ground-water sensitivity and vulnerability to pesticides in the unconsolidated valley-fill aquifer of Morgan 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 valley-fill aquifers in Morgan 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 how ground-water sensitivity is modified by human activity. 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 hydraulic conductivity, bulk density, organic carbon content, and field capacity of soils. 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 agricultural lands are irrigated, crop type, and 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 Morgan Valley, Morgan County, 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 fieldwork was conducted nor data collected as part of this project. This is a first attempt at developing pesticide sensitivity and vulnerability maps; additional data and tools may become available in the future so that better maps can be produced. For example, maps that show the quantity of recharge to aquifers in Utah are not available. We used a GIS coverage developed by subtracting average annual evapotranspiration from average annual precipitation to estimate average annual recharge from precipitation. This coverage provides a rough estimate of the largely elevation-controlled distribution of ground-water recharge, but does not account for recharge at low elevations during spring snowmelt or during protracted storm events. Additionally, the digital soil maps used in this study are too generalized to accurately depict areas of soil versus bedrock outcrop. Because organic carbon in soils is one controlling factor determining the potential for pesticides to reach ground water, the higher sensitivity and vulnerability of rock outcrop areas are not reflected in our maps. To produce these maps, we needed to make some arbitrary decisions based on our knowledge of the hydrogeology, and of the quality and types of data available; for example, we selected 3 feet (1 m) as the reference depth for applying pesticide retardation and attenuation equations.

GENERAL DISCUSSION OF PESTICIDE ISSUE

The information presented in this section was taken directly from Lowe and Sanderson (2003).

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, in part, 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. Because 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 2200 samples tested statewide (Quilter, 2004). Under the generic PMP, should an instance of pesticide contamination be found and verified, a chain of events to monitor and evaluate the contamination would begin that could 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, and 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; the beginning letter of key words in these parameters forms the acronym DRASTIC. Eventually, many scientists concluded 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 with the DRASTIC method 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.

Rao and others (1985) developed indices for ranking the potential for pesticide contamination of ground water, which we have implemented in this study. 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 mg/L
Atrazine	0.003 mg/L	3 mg/L
Metolachlor	--	--
Simazine	0.004 mg/L	4 mg/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, an administrative process begins 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 hydrogeologic 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 type of pesticide being applied is a critical factor. 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 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 Morgan Valley where ground water is unconfined, degradation of the valley-fill aquifer 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 valley-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 valley-fill aquifer 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 valley-fill aquifer.

PREVIOUS STUDIES

Saxon (1972) studied ground-water conditions in Morgan Valley, including ground-water quality, and produced a water budget for the Morgan area. Haws and others (1970) produced a hydrologic inventory and water budget for the entire Weber River drainage basin. Mundorff (1970) studied the major thermal springs in Utah, including Como Warm Springs east of Morgan City. Thompson (1982) conducted a reconnaissance of surface-water quality in the Weber River basin. Gates and others (1984) conducted a ground-water reconnaissance of the central Weber River area.

The geologic map coverages that we use as part of this project are shown on figure 2.

SETTING

Physiography

Morgan Valley is a northwest-trending valley approximately 16 miles (26 km) long and 2 miles (3 km) wide with a valley-fill area of 28 square miles (70 km^2). Morgan Valley is in the Wasatch Hinterlands section of the Rocky Mountain physiographic province (Stokes, 1977), and is in the central part of the Weber River watershed. The study area watershed covers 312 square miles (800 km^2). Morgan Valley is bounded by Weber Canyon and the Wasatch Range to the west, and Upper Weber Canyon east of Morgan City to the east. Elevation ranges from 9706 feet (2958 m) at Thurston Peak, the highest point in Morgan County, to approximately 4835 feet (1474 m) at the town of Mountain Green, near Weber Canyon.

The Weber River enters the study area at the mouth of Upper Weber Canyon near Morgan City, flows northwest through the middle of Morgan Valley, and leaves the study area near Mountain Green at the head of Weber Canyon. Major tributaries include East Canyon Creek and Hardscrabble Creek at the southeast end of the study area, and Cottonwood Creek at the northwest end of the study area. Smaller drainages include the northeast-flowing Deep and Smith Creeks, and southeast-flowing streams in Big Hollow and Roswells Canyon.

Morgan Valley is situated in a structural trough shared by Ogden Valley to the north (Saxon, 1972). The Wasatch Range bounding Morgan Valley to the west consists predominantly of Precambrian metamorphic rocks of the Farmington Canyon Complex (Bryant, 1988). Most of the area surrounding Morgan Valley consists of Tertiary tuffaceous sandstone and tuff; Cretaceous to Tertiary conglomerate and conglomeratic sandstone with some siltstone, mudstone, and limestone; and Quaternary alluvial, colluvial, and mass-movement deposits (Hintze, 1980). Precambrian crystalline basement rocks and Paleozoic and Cretaceous sedimentary rocks crop out on the north side of Upper Weber Canyon (Hintze, 1980).

Most of the alluvium in Morgan Valley greater than 10 feet (3 m) thick is located along the major tributaries and the flood plain of the Weber River (Gates and others, 1984). The alluvium is mainly derived from the Cretaceous and Tertiary sedimentary rocks that surround the valley. The main aquifer in Morgan Valley is in these alluvial valley-fill deposits, which consist primarily of clay, silt, sand, and gravel up to 200 feet (60 m) thick (Gates and others, 1984). The silt and clay, which may be derived primarily from weathering of the Tertiary Norwood Tuff, form discontinuous lenses in the valley-fill alluvium (Saxon, 1972). Eardley (1944) suggests that Morgan Valley did not accumulate the large thickness of alluvium found in Odgen Valley to the north because Morgan Valley alluvium was eroded by the Weber River in response to uplift and faulting.

Climate

The only weather station in the study area is in the town of Morgan at an elevation of 5060 feet (1540 m). Climatic information for the Morgan station is for the 1948-92 period (Ashcroft and others, 1992). Temperatures reach a normal minimum of 10.6°F (-11.9°C) in January and a normal maximum of 88.9°F (31.6°C) in July (Ashcroft and others, 1992). The normal mean annual temperature is 46.0°F (7.8°C) (Ashcroft and others, 1992). The normal annual precipitation is 19.72 inches (50.9 cm), and the normal annual evapotranspiration is 47.08 inches (119.58 cm) (Ashcroft and others, 1992). The average number of frost-free days is 96 (Ashcroft and others, 1992).

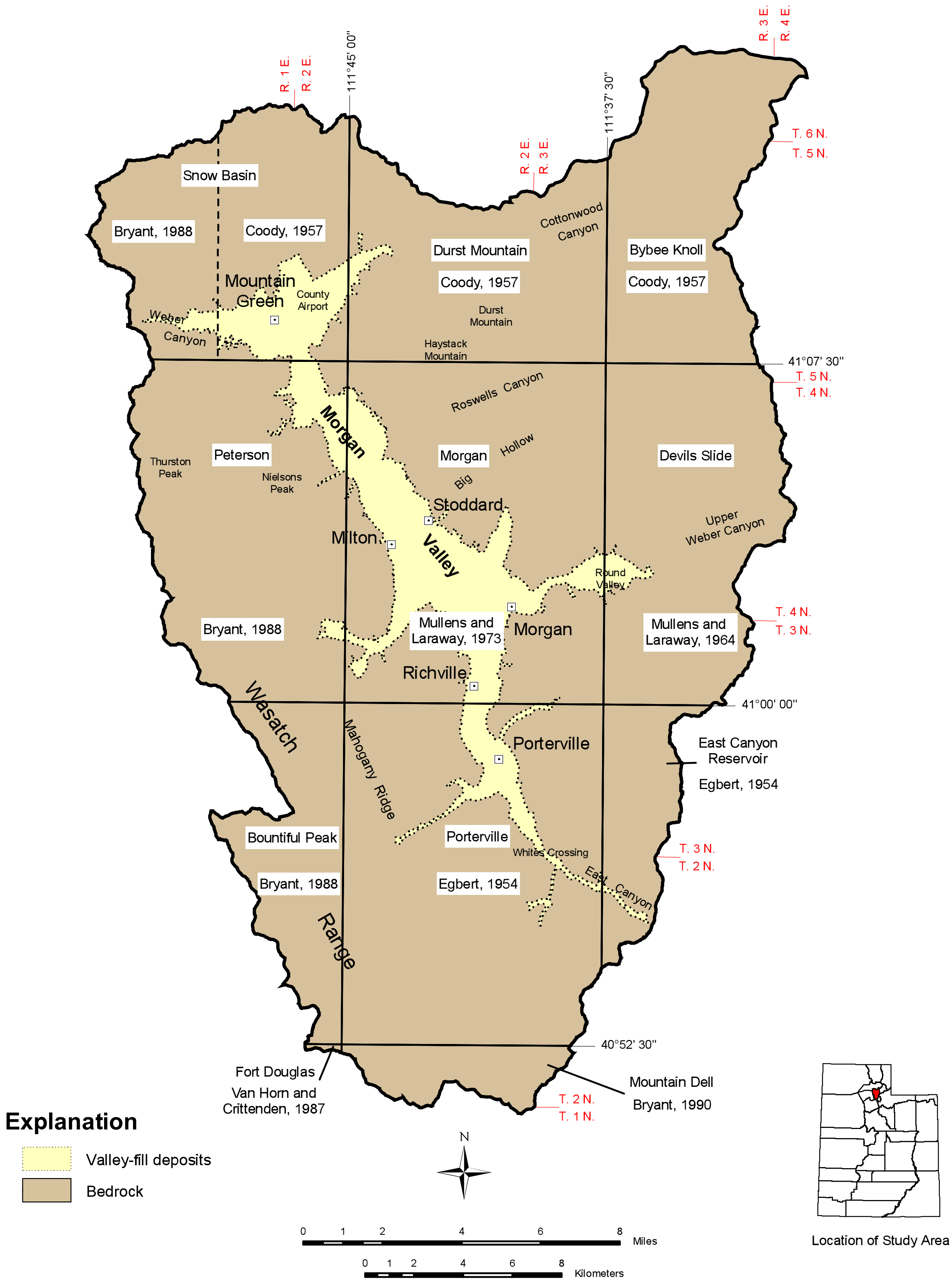

***Figure 2.** Existing geologic mapping for 7.5′ quadrangles in Morgan Valley, Morgan County, Utah.*

Population and Land Use

Morgan County, like many bedroom communities to the Wasatch Front, is experiencing growth. From 1990 to 2000 the population of Morgan County increased 29%, from 5528 to 7129 (Demographic and Economic Analysis Section, 2001). In 2002, the population of Morgan County was 7380; Morgan City, the county seat, had a population of 2680, and the unincorporated areas in Morgan County had a population of 4700 (Demographic and Economic Analysis Section, 2003). By 2030, the population in Morgan County is expected to increase to 12,435; Morgan City and the unincorporated areas in Morgan County are expected to increase to 4261 and 8174, respectively (Demographic and Economic Analysis Section, 2000).

The dominant industries in Morgan County are agriculture and manufacturing (Utah Reach, 2004). Browning Arms Company is one of the major industries operating in the Morgan Valley drainage basin. Historically, Morgan Valley was an agricultural community. Currently, few farmers have farming as their sole source of income due to poor profitability; much of the farmland is being sold for residential development (Utah Reach, 2004). More than half of the people employed in Morgan County work outside of the county, mostly in the Ogden area (Utah Reach, 2004).

GROUND-WATER CONDITIONS

Ground-water resources, which are locally used for domestic and public supplies and livestock watering, are of secondary importance compared to surface water in Morgan Valley in terms of development issues (impoundment, diversion, and regulation) and annual supply. However, the data collected by Gates and others (1984) indicate that most reaches of the Weber River in Morgan Valley and the downstream reaches of East Canyon Creek are gaining reaches, so factors affecting surface-water resources in the Morgan Valley area can also affect ground-water resources.

Valley-Fill Aquifer

Valley-fill alluvium is the most important aquifer in the Morgan Valley area due to its permeability and because it contains fresh water. Ground-water resources in Morgan Valley are developed by means of small-capacity wells for domestic use at farms and individual residences, and in large-capacity wells for public supply and some industrial uses (such as Browning Arms Company) (Gates and others, 1984). Many wells are screened in both Quaternary alluvium and Cretaceous and Tertiary semiconsolidated rocks such as the Norwood Tuff and Wasatch Formation (Gates and others, 1984).

Ground water in the unconsolidated alluvium is generally under water-table conditions (Saxon, 1972). Ground water moves from the valley margins toward East Canyon Creek and the Weber River, and then downstream toward the head of Weber Canyon (figure 3) (Gates and others, 1984).

Recharge to the valley-fill aquifer in Morgan Valley is from precipitation, downward seepage from losing stretches of perennial and ephemeral streams (mostly along the valley margins), underflow to alluvium from older rock units, infiltration from irrigation, and seepage from irrigation canals

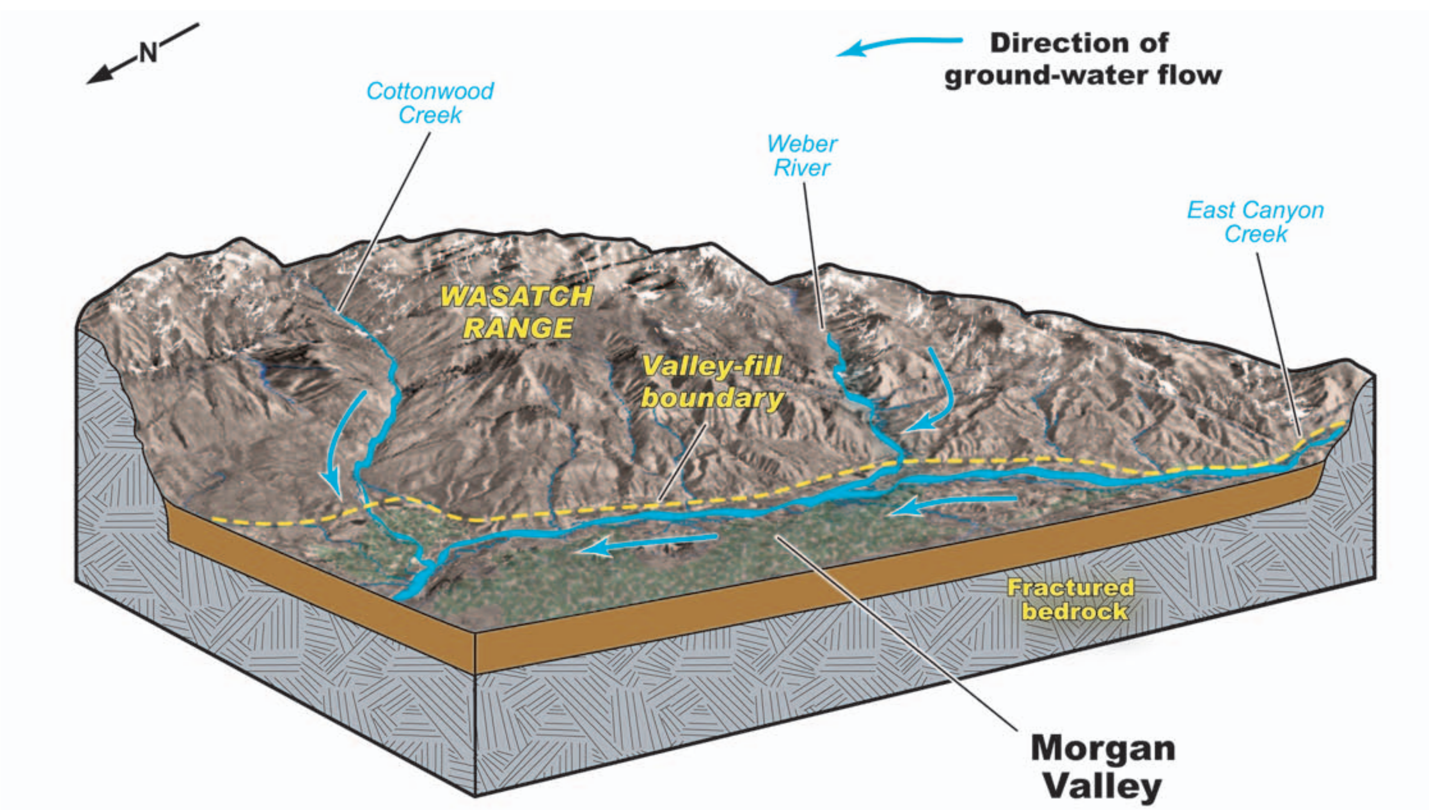

Figure 3. *Schematic block diagram showing ground-water flow in Morgan Valley, Utah.*

located along the valley margins (Gates and others, 1984). In terms of quantity, the main sources of recharge are seepage from streams, infiltration from irrigation, and canal losses (Gates and others, 1984).

Discharge of ground water from the valley-fill aquifer in the Morgan Valley area is by seepage to the Weber River and East Canyon Creek; transpiration by phreatophytes, crops, and pasture vegetation; discharge from wells and springs; and underflow out of the valley through valley-fill alluvium at the head of Weber Canyon (Gates and others, 1984). Gates and others (1984) estimate that the minimum ground-water discharge from the area is about 40,000 acre-feet per year (16,000 hm^2); not included in that estimate is discharge from phreatophytes, which Gates and others (1984) estimated to be about 5000 acre-feet per year (2000 hm^2). Total ground-water discharge from wells and springs for public, domestic, and industrial use is estimated to be about 1200 acre-feet per year (500 hm^2) (Gates and others, 1984). Ground-water underflow in valley-fill alluvium that leaves Morgan Valley in Weber Canyon is estimated to be about 1000 acre-feet per year (400 hm^2); (Gates and others, 1984).

Gates and others (1984) estimate the volume of water stored in valley-fill in the study area to be 1,700,000 acre-feet (700,000 hm^2) and, assuming a specific yield of 0.10, the estimated theoretically recoverable ground water is 170,000 acre-feet (70,000 hm^2). This is about 50 percent of the annual flow of the Weber River at Gateway. Long-term water-level measurements from wells in Morgan Valley indicate long-term changes in ground-water storage have not occurred (Gates and others, 1984); this suggests that, during the 40 to 50 years prior to 1984, ground-water recharge and discharge have been in equilibrium. Hydrographs from wells in the study area show seasonal and year-to-year fluctuations in ground-water levels; this illustrates the relationships among ground-water levels, run-off, and seepage from irrigation canals (Gates and others, 1984). In many cases, ground-water levels are higher during late summer and fall than during the spring, showing the effects of recharge during the irrigation season (Gates and others, 1984).

Ground-Water Quality

Ground-water samples collected by Gates and others (1984) indicate that ground water within Morgan Valley is fresh. Total-dissolved-solids concentrations from 57 samples collected in 1979 from wells completed in a variety of geologic units range from 127 to 754 mg/L and average 387 mg/L (Gates and others, 1984). Average total-dissolved-solids concentration is 361 mg/L for alluvium, 375 mg/L for the Norwood Tuff, and 478 mg/L for the Wasatch Formation. Some wells in several areas of Morgan Valley, including the Hardscrabble Creek area, have yielded nitrate-plus-nitrate concentrations above 3 mg/L (Quilter, 1997); the source of the nitrate is currently unknown.

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. As outlined in Siegel (2000), we combine a process-based model with an index-based model to produce sensitivity and vulnerability maps for Morgan Valley. The index-based model assigns ranges of attribute values and ranks the ranged attribute values as conducive or not conducive to ground-water contamination by pesticides. The process-based model incorporates physical and chemical processes through mathematical equations addressing the behavior of certain chemicals in the subsurface, in this case, retardation and attenuation of pesticides using methods developed by Rao and others (1985). No new fieldwork 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, attenuation of pesticides, and depth to ground water are the factors primarily determining ground-water sensitivity to pesticides in Morgan Valley. Sensitivity represents the sum of natural influences that facilitate the entry of pesticides into ground water.

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, illustrated schematically in figure 4. 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. Secondary recharge areas, commonly mountain-front benches, have fine-grained layers thicker than 20 feet (6 m) and a downward ground-water gradient. 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). 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. 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.

We used drillers' logs of water wells in Morgan Valley to delineate primary 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 areas 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

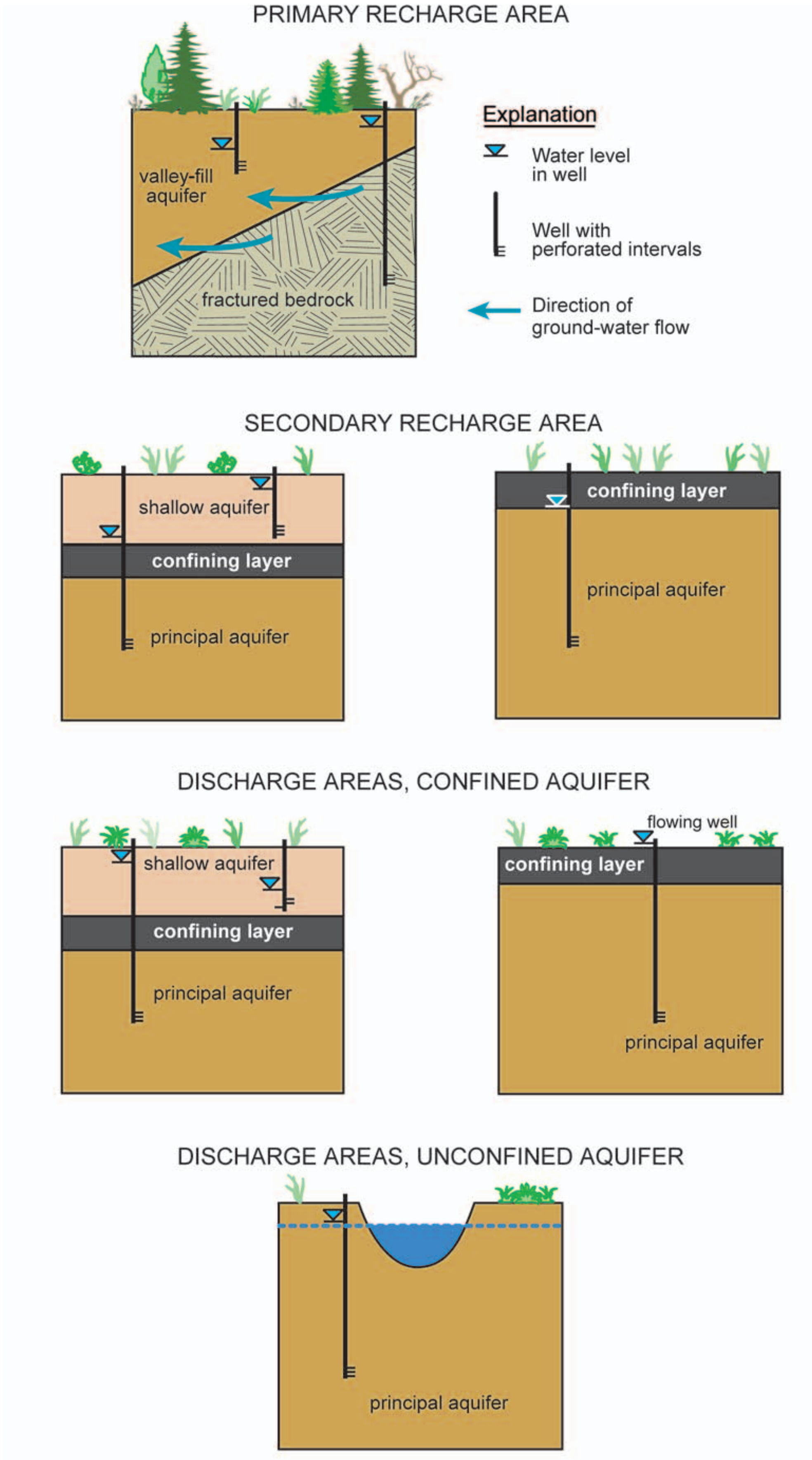

Figure 4. *Relative water levels in wells in recharge and discharge areas (modified from Snyder and Lowe, 1998).*

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; Anderson and Susong, 1995). Some drillers' logs show both clay and sand in the same interval, with no information describing 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 of Utah 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 Morgan Valley consists of the uplands along the margins of the valley, together with valley fill not containing confining layers (figure 4), generally located along the mountain fronts. Ground-water flow in primary recharge areas has a downward component. Secondary recharge areas, if present, are locations where confining layers exist, but ground-water flow maintains a downward component. Secondary recharge areas generally extend toward the center of the basin to the point where ground-water flow is upward (figure 4). 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. There are no secondary recharge areas in Morgan Valley.

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 (figure 4). For this to happen, the hydraulic head in the principal aquifer 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 wetland areas to indicate discharge from the principal aquifer system. Discharge areas for the unconfined aquifer in Morgan Valley occur along gaining reaches of the Weber River.

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. We obtained values for hydraulic conductivity of soils from soil percolation tests and "permeability" (hydraulic conductivity) ranges assigned to soil units mapped by the U.S. Department of Agriculture's Soil Conservation Service (now Natural Resources Conservation Service; Carly and others, 1980). For GIS analysis, we divided soil units into two hydraulic conductivity ranges: greater than or equal to, and less than, 1 inch (2.5 cm) per hour. We chose 1 inch (2.5 cm) per hour because it corresponds to the minimum allowable percolation rate permitting septic tanks under Utah Division of Water Quality administrative rules. For areas having no hydraulic conductivity data, we applied the greater than or equal to 1 inch (2.5 cm) per hour GIS attribute ranking, described below under Results, to be protective of ground-water quality.

Pesticide Retardation

Pesticide retardation is a measure of the differential between movement of water and the movement of pesticide in the vadose zone (Rao and others, 1985). Because pesticides are adsorbed to organic carbon in soil, they move more slowly through the soil than water; the relative rate of movement of pesticides depends 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 rate as pore water in the vadose zone. The retardation factor (R_F) is a function of dry bulk density, organic carbon fraction, field capacity of the soil, and the organic carbon sorption distribution coefficient of the specific pesticide; a relatively low R_F indicates a higher potential for ground-water pollution. 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 (dimensionless);
ρ_b = bulk density (kg/L);
F_{oc} = fraction, organic carbon;
K_{oc} = organic carbon sorption distribution coefficient (L/kg); and
θ_{FC} = field capacity (volume fraction).

Retardation factors typically range from (1 + 4Kd) to (1 + 10Kd) (Freeze and Cherry, 1979), where Kd is the product of the organic carbon sorption distribution coefficient (K_{oc}) and the fraction of organic carbon (F_{oc}), and based on typical unconsolidated sediment properties of dry bulk density (0.06-0.08 lb/in^3 [1.6-2.1 kg/L]) and porosity range (0.2 to 0.4). Dissolved constituents in ground water having low R_F values (around 1) such as nitrate (a relatively mobile anion), move through the subsurface at the same rate as the ground water, whereas dissolved constituents in ground water having R_F values orders of magnitude larger than one are essentially immobile (Freeze and Cherry, 1979). The relative velocity is the reciprocal of the retardation factor and describes the rate a mixture of reactive contaminant moves relative to solvent-free ground water.

For this study, we used data from the Soil Survey Geographic (SSURGO) database (National Soil Survey Center, 2001), which provides digitized data for some soil areas of the state of Utah, including Morgan Valley, at a scale of 1:24,000. Data include derived values for bulk density, organic carbon fraction, and field capacity (table 2). For areas in the SSURGO database lacking information on hydrologic soil group, fraction of organic carbon, field capacity, and/or bulk density, we assigned values to them based on values from adjacent areas having similar geologic characteristics.

We set variables in equation 1 to values that represent conditions likely to be encountered in the natural environment (table 2) to establish a rationale for dividing high and low pesticide retardation for our GIS analysis, and we applied digital soil information unique for particular soil groups from SSURGO data for organic carbon. We used the organic carbon sorption distribution coefficient (table 3), at a pH of 7, for atrazine, the pesticide among the four having the least tendency to adsorb to organic carbon in the soil (Weber, 1994). We derived bulk density and field capacity from a soil texture triangle hydraulic properties calculator (Saxton, undated). To compute R_F values, we applied bulk density end members of 0.04 and 0.07 pounds per cubic inch (1.2 and 2.0 kg/L) and field capacity end members of 14 and 42%, which represent naturally occurring conditions in Morgan Valley, and variable soil organic carbon content using a water depth of 3 feet (1 m). Average organic carbon content in soils in Morgan Valley is shown in figure 4 and ranges from 0.9 to 4.4%, with a valley-wide average of 2%; the mass fraction of organic carbon was computed by dividing the organic matter

Table 2. *Hydrologic soil groups, field capacity, bulk density, and fraction of organic carbon content generalized for Utah soils. Soil description and organic content from National Soil Survey Center (2001). Field capacity based on sediment grain size calculated from a soil texture triangle hydraulic properties calculator (Saxton, undated). Bulk density from Marshall and Holmes (1988) and Saxton (undated).*

Soil Group	Soil Description	Grain size (mm) (Field Capacity %)	Bulk Density Range (kg/L) (average)	Organic Carbon 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 (14-21)	1.5 - 2 (1.75)	Variable and ranges from 0.9 to 4.4 %
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 (25-28)	1.3 - 1.61 (1.4)	Variable and ranges from 0.9 to 4.4 %
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 (26)	1.3 - 1.9 (1.6)	Variable and ranges from 0.9 to 4.4 %
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 (32-42)	1.2-1.3 (1.25)	Variable and ranges from 0.9 to 4.4 %
G	Gravel	2.0 and greater (less than 12)	2 (2)	0.9 %**

* F_{oc} is calculated from SSURGO organic matter data divided by 1.72 and is unique for soil polygons.
**No value for F_{oc} exists in the SSURGO database for gravel; we assigned the lowest value in the SSURGO database.

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

parameter in the SSURGO data by a conversion factor of 1.72 (Siegel, 2000). We then applied the organic carbon content end members to compute the extreme R_F values; equation 1 results in retardation factors ranging from 3.5 to 64. This means the highest relative velocity from our data is 0.3 and the lowest, 0.016; the former indicates pesticide in ground water moves at a rate about 30 percent that of ground water free of pesticides, whereas the latter indicates that pesticides in ground water are essentially immobile.

Approximately 20 percent of the pesticides traveling downward in vadose-zone material having an R_F of 7 could reach the water table at a depth of 3 feet (1 m) within one year if ground-water recharge amounted to 67 inches (1.7 m) or greater during the year, which is the highest amount of recharge documented for the mountains adjacent to Morgan Valley (where pesticides are not likely to be applied). When ground-water recharge is less than 12 inches (30 cm) per year, as is the case for the valley floor of Morgan Valley, no amount of pesticide will likely reach a depth of 3 feet (1 m) in a one-year period (see attenuation discussion below). For our GIS analysis, we divided pesticide retardation into two ranges: greater than, or less than or equal to 7.

Pesticide Attenuation

Pesticide attenuation is a measure of the rate at which a pesticide degrades under the same conditions as characterized above under pesticide retardation (Rao and others, 1985). 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. Attenuation factors range between 0 and 1 (Rao and others, 1985); note that high attenuation factors represent conditions of low attenuation. Rao and others (1985) present the following equation:

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

where:

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

For this study, we calculated (using GIS analysis) net annual ground-water 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 Morgan Valley (figure 5). Therefore, ground-water recharge from precipitation is relatively low in many areas of Utah, including Morgan 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 that 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, and is not evaluated in our analysis.

Using equation 2, we calculated attenuation factors for ranges of values common to soils in Morgan Valley, similar to our approach for retardation, to delineate high and low pesticide attenuation factors for our GIS analysis. To represent naturally occurring conditions in this area that would result in the greatest sensitivity to ground-water contamination, we used a retardation factor of 7, calculated as described above; the half-life for simazine (table 4), the pesticide among the four with the longest half-life (Weber, 1994); a field capacity of 14 percent; and a bulk density value of 0.04 pounds per cubic inch (1.2 kg/L). For a negative net annual ground-water recharge values, as are typical of the valley-floor areas of Morgan Valley, equation 2 results in an attenuation factor that approaches 0. This means that at the above-described values for variables in the equation, negligible amounts (0.1%) of the pesticide originally introduced into the system at the ground surface would be detected at a

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	Pre-emergence
Metolachlor	1.9	Pre-emergence
Simazine	4.0	Pre-emergence

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

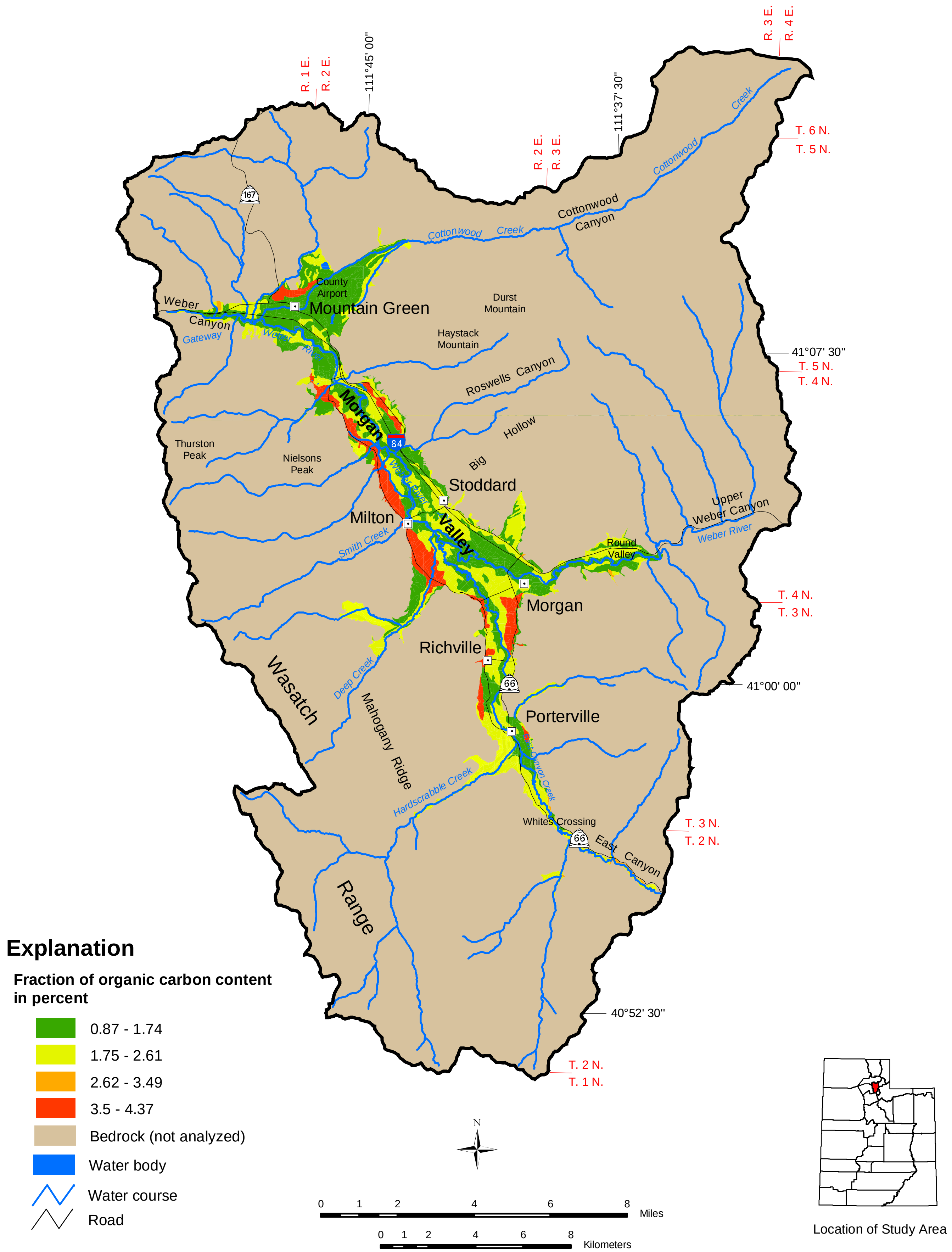

Figure 5. *Fraction of organic carbon content in soils in Morgan Valley, Morgan County, Utah (data from National Soil Survey Center, 2001).*

depth of 3 feet (1 m) – no pesticides would reach 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 applied, the greater 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.

Depth to Shallow 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 having shallow ground water seasonally less than or equal to 3 feet (1 m) deep is one attribute of soil units mapped by the Soil Conservation Service (now Natural Resources Conservation Service; Carly and others, 1980). We selected 3 feet (1 m) as the depth-to-ground-water attribute used to evaluate sensitivity of geographic areas to pesticides. For areas where depth-to-ground-water data are 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 characterize pesticide sensitivity (intrinsic susceptibility) as "low," "moderate," and "high" based on the sum of numerical values (rankings) assigned to hydrogeologic setting, soil hydraulic conductivity, soil retardation of pesticides, soil attenuation of pesticides, and depth to shallow ground-water attributes as shown in table 5. Numerical ranking for each attribute category is arbitrary, but reflects the relative level of importance the attribute plays in determining sensitivity of areas to application of agricultural pesticides; for Morgan Valley we weighted all attribute categories equally. A sensitivity attribute of low was assigned when the summed numerical ranking ranged from 0 to 1, a sensitivity attribute of moderate was assigned when the summed numerical ranking ranged from 2 to 4, and a sensitivity attribute of high was assigned when the summed numerical ranking ranged from 5 to 6.

Ground-Water Vulnerability to Pesticide Pollution

Ground-water vulnerability to pesticides is determined by assessing how ground-water sensitivity to pesticides is modified by human activity. In addition to ground-water sensitivity to pesticides, the presence of applied water (irrigation) and crop type are the factors primarily determining ground-water vulnerability to pesticides. Our analysis is based on 1999 land-use data.

Ground-Water Sensitivity

We consider ground-water sensitivity (intrinsic susceptibility) to be the principal factor determining the vulnerability of the basin-fill aquifer in Morgan Valley to degradation from agricultural pesticides. We assigned numerical values for low, moderate, and high sensitivity rankings as shown in table 6.

Irrigated Lands

We mapped irrigated lands 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 mapped from either aerial photographs (pre-2000) or 5-meter (16-ft) resolution infrared satellite data and then field checked (Utah Division of Water Resources metadata). The Morgan Valley inventory was conducted in 1999 (Utah Division of Water Resources metadata). All polygons having 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.

Crop Type

We mapped agricultural lands using 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 mapped from either aerial photographs (pre-2000) or 5-meter (16 ft) resolution infrared satellite data and then field checked (Utah Division of Water Resources metadata). The Morgan Valley inventory was conducted in 1999 (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 coverage for this study; these are the crop types the pesticides addressed in this report are applied to in Utah. Although the specific fields growing these crops may vary from year to year, the general areas and average land-area percentages of these crop types likely do not.

GIS Analysis Methods

We characterize pesticide vulnerability as "low," "moderate," and "high" based on the sum of numerical values (rankings) assigned to 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 relative level of importance the attribute plays in determining vulnerability of ground water to contamination associated with application of agricultural pesticides. For instance, ground-water sensitivity to pesticides is the most important attribute with respect to ground-water vulnerability to pesticides, and therefore we weighted this attribute two times more heavily than the other attribute categories.

Table 5. *Pesticide sensitivity and the attribute rankings used to assign sensitivity for Morgan Valley, Morgan County, Utah.*

Pesticide Retardation Factor		Pesticide Attenuation Factor		Hydrogeologic Setting		Soil Hydraulic Conductivity		Depth to Ground Water		Sensitivity	
Attribute	**Ranking**	**Attribute**	**Ranking**	**Attribute**	**Ranking**	**Attribute**	**Ranking**	**Attribute**	**Ranking**	**Attribute**	**Ranking**
High	0	Low	0	Confined Aquifer Discharge Area	-2	Less than 1 inch/hour	1	Greater than 3 feet	1	Low	0 to 1
				Secondary Recharge Area	-1					Moderate	2 to 4
Low	1	High	1	Primary Recharge Area and Unconfined Aquifer Discharge Area	0	Greater than or equal to 1 inch/hour	2	Less than or equal to 3 feet	2	High	5 to 6

Table 6. *Pesticide vulnerability and the attribute rankings used to assign vulnerability for Morgan Valley, Morgan 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

RESULTS

Ground-Water Sensitivity

To assess ground-water sensitivity (intrinsic susceptibility) to pesticide contamination, several GIS 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 factors are variable and attenuation factors are ranked as low throughout the Morgan Valley area; the low attenuation factors are due to net annual evapotranspiration exceeding net annual precipitation. Net annual recharge from precipitation is negative in basin-floor areas (figure 6). Most recharge from precipitation likely occurs during spring snowmelt. 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

We mapped ground-water recharge areas in Morgan Valley as part of this study (figure 7). Primary recharge areas, the areas most susceptible to contamination from pesticides applied to the land surface, comprise 100% of the surface area of the valley-fill aquifer. We did not map any secondary recharge areas or ground-water discharge areas in Morgan Valley, although many wells penetrate intervals of fine-grained material in the valley-fill aquifer, because water-level information from the drillers' logs of water wells indicates the valley-fill aquifer is under unconfined (water table) conditions. The Weber River is a gaining stream (ground water provides flow to the river) over much of its reaches (Gates and others, 1984), but we believe ground-water discharge is limited to the river bed.

Hydraulic Conductivity of Soils

Surface application of pesticides is more likely to cause ground-water quality problems in areas where soils have

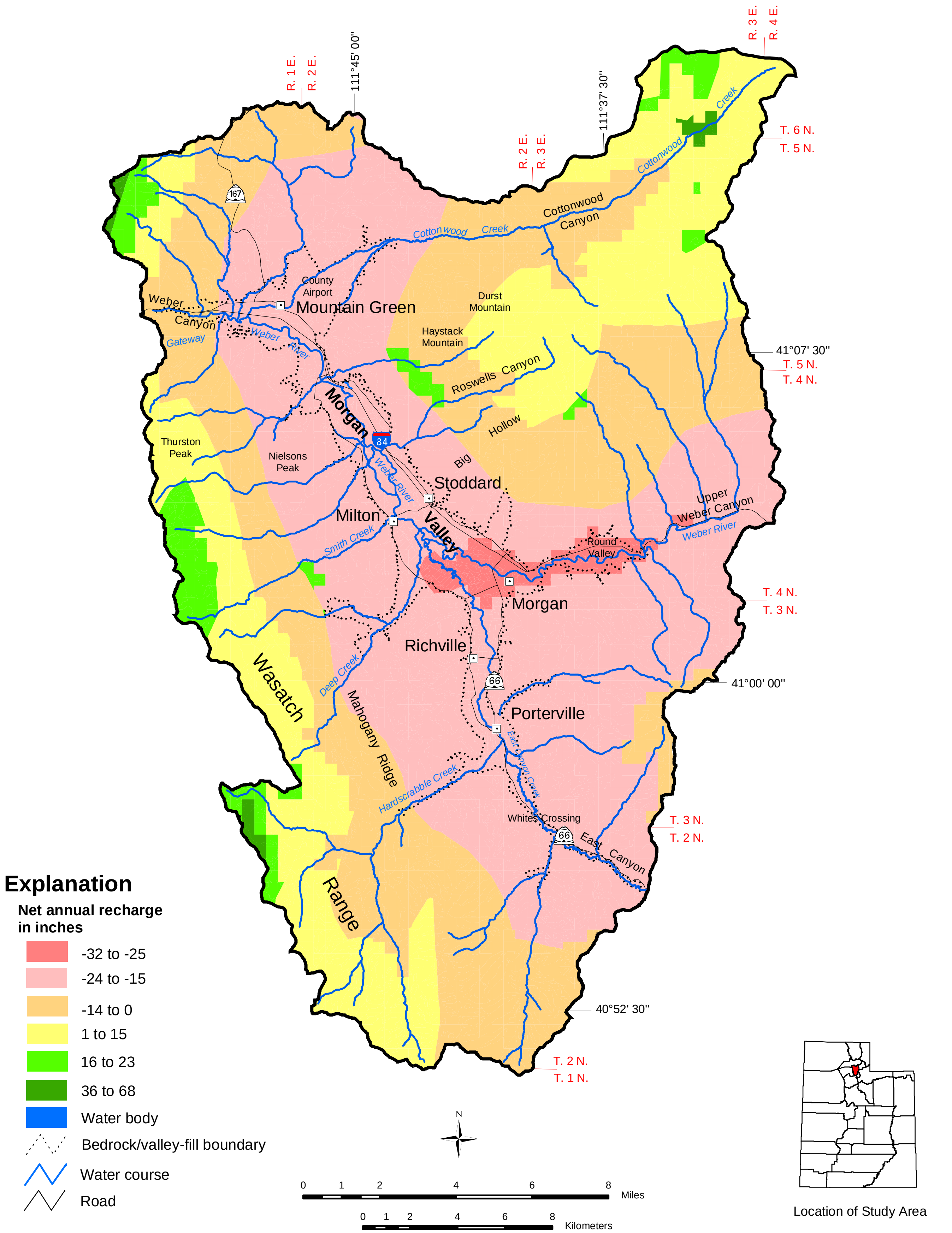

Figure 6. Net annual ground-water recharge from precipitation in Morgan Valley, Morgan County, Utah. Recharge calculated using data from the Utah Climate Center (1991) and Jensen and Dansereau (2001). Although net annual recharge may be negative in some areas, seasonally some recharge from precipitation may occur.

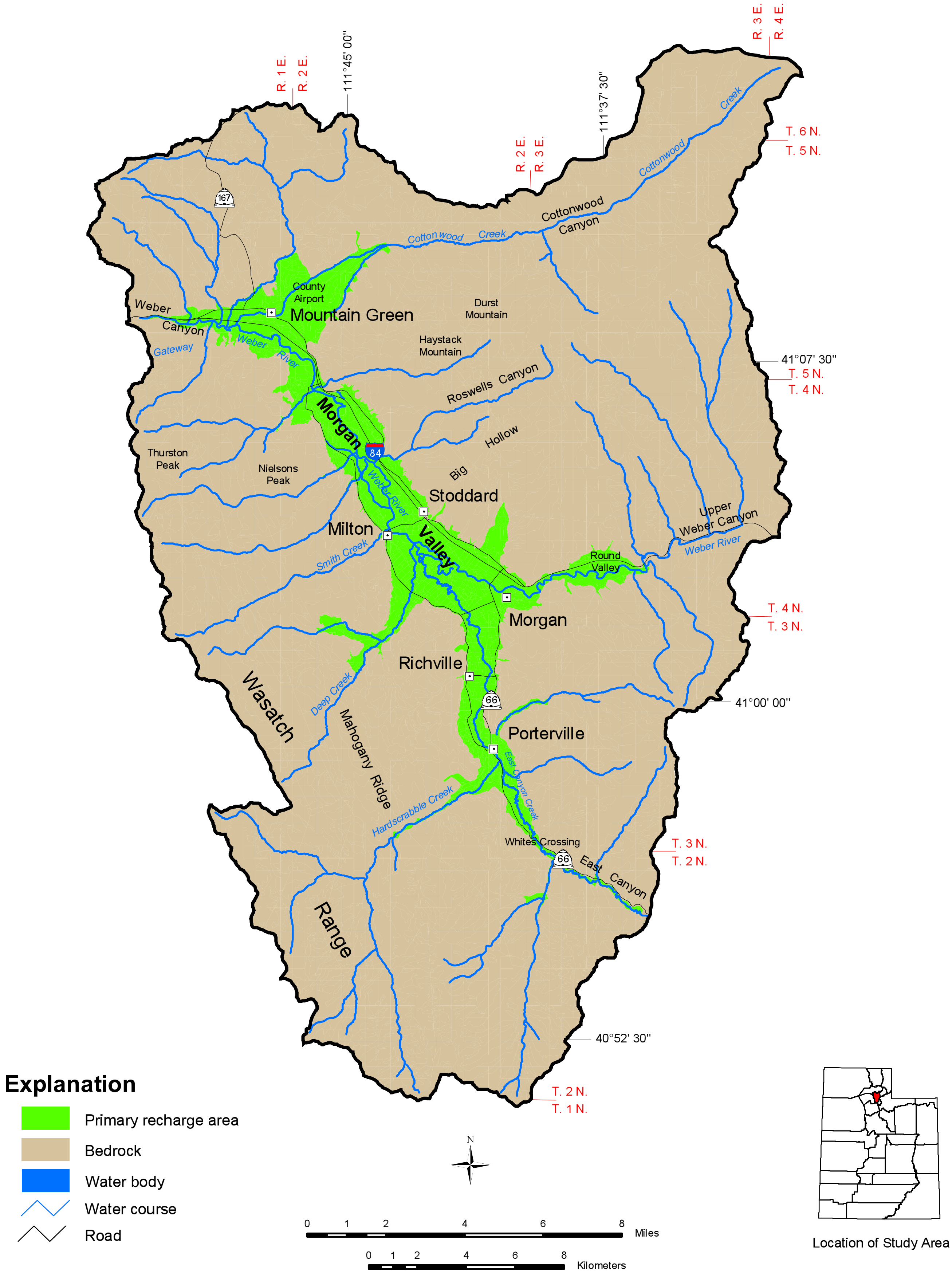

Figure 7. *Recharge areas in Morgan Valley, Morgan County, Utah. Discharge areas occur along some reaches of the Weber River.*

higher hydraulic conductivity than in areas where hydraulic conductivity is low. Hydraulic conductivity data are from the National Soil Survey Center (2001). About 82% of the surface area of the valley-fill aquifer in Morgan Valley has soil units mapped as having hydraulic conductivity greater than or equal to 1 inch (2.5 cm) per hour (figure 8). About 18% of the surface area of the valley-fill aquifer has soil units mapped as having hydraulic conductivity less than 1 inch (2.5 cm) per hour (figure 8).

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 deep. Depth to shallow ground-water data are from the National Soil Survey Center (2001). About 34% of the area overlying the valley-fill aquifer in Morgan Valley has soil units mapped as having shallow ground water less than or equal to 3 feet (1 m) deep (figure 9). About 4% of the surface area of the valley-fill aquifer has soil units mapped as having shallow ground water greater than 3 feet (1 m) deep (figure 9). About 62% of the surface area of the valley-fill aquifer has soil units mapped as having no data (figure 9). Areas without assigned depths to shallow ground water were grouped with the less than or equal to 3 feet (1 m) depth category for analytical purposes to be protective of water quality.

Pesticide Sensitivity Map

Plate 1 shows ground-water sensitivity (intrinsic susceptibility) to pesticides for Morgan Valley, constructed using the GIS methods and ranking techniques described above. We analyzed only the valley-fill aquifer; the surrounding uplands are designated on plate 1 as "bedrock" and consist mainly of shallow or exposed bedrock in mountainous terrain.

Morgan Valley has a moderate to high sensitivity to the application of pesticides (plate 1) because of the lack of protective clay layers (primary recharge area) and shallow depths to ground water. About 16% of the area overlying the valley-fill aquifer is mapped as having high sensitivity (plate 1). The remaining 84% of the study area is of moderate sensitivity.

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 statewide attribute layers include irrigated cropland and corn- and sorghum-producing areas in Morgan Valley (figure 10). 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). The pertinent attribute layers, irrigated cropland and corn and sorghum crops, along with ground-water sensitivity, are described in the following sections.

Irrigated Cropland

Figure 10 shows irrigated land areas in Morgan Valley. About 54% of the valley floor is irrigated, and about 46% is not. Irrigation is potentially significant because it is a source of ground-water recharge in the valley-fill aquifer.

Corn and Sorghum Crops

From the point of view of human impact, areas where corn and sorghum are grown are significant because the four herbicides considered in this report — alachlor, atrazine, metolachlor, and simazine — are used to control weeds in these crops. Corn and sorghum crops are mainly grown in the central and southern Morgan Valley (figure 9). The use of pesticides on corn and sorghum crops raises the vulnerability of areas where these crops are grown by one vulnerability category (for instance, moderate to high) compared to areas where they are not grown.

PesticideVulnerability Map

Plate 2 shows ground-water vulnerability to contamination from pesticides of the valley-fill aquifer for Morgan 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.

Areas of high vulnerability are primarily in irrigated areas where ground-water sensitivity to pesticides is high. About 11% of the surface area of the valley-fill aquifer is mapped as having high vulnerability (plate 2). Of particular concern are areas where ground water is shallow or near the Weber River, as these are the areas most likely to be impacted by pesticide pollution. Areas of moderate vulnerability coincide, in general, with non-irrigated areas. About 89% of the surface area of the valley-fill aquifer is mapped as having moderate vulnerability (plate 2).

CONCLUSIONS AND RECOMMENDATIONS

In Morgan Valley, areas of irrigated land where the ground-water table is near the land surface have the highest potential for water-quality degradation associated with surface application of pesticides. However, because of the relatively high attenuation (short half-lives) of pesticides in water in the soil environment, pesticides likely do not represent a serious threat to ground-water quality. We believe ground-water monitoring for pesticides should be concentrated in areas of high sensitivity and high vulnerability, especially in those areas where corn or sorghum are grown. Sampling and testing in areas of the valley characterized by moderate sensitivity and moderate vulnerability should continue, but at a lower density than in the areas of higher sensitivity and vulnerability.

ACKNOWLEDGMENTS

This project was funded by the U.S. Environmental Protection Agency. Critical review comments were provided by Kimm Harty and Mike Hylland, Utah Geological Survey. Kim Nay, Utah Geological Survey, produced some of the computer drawings for the project.

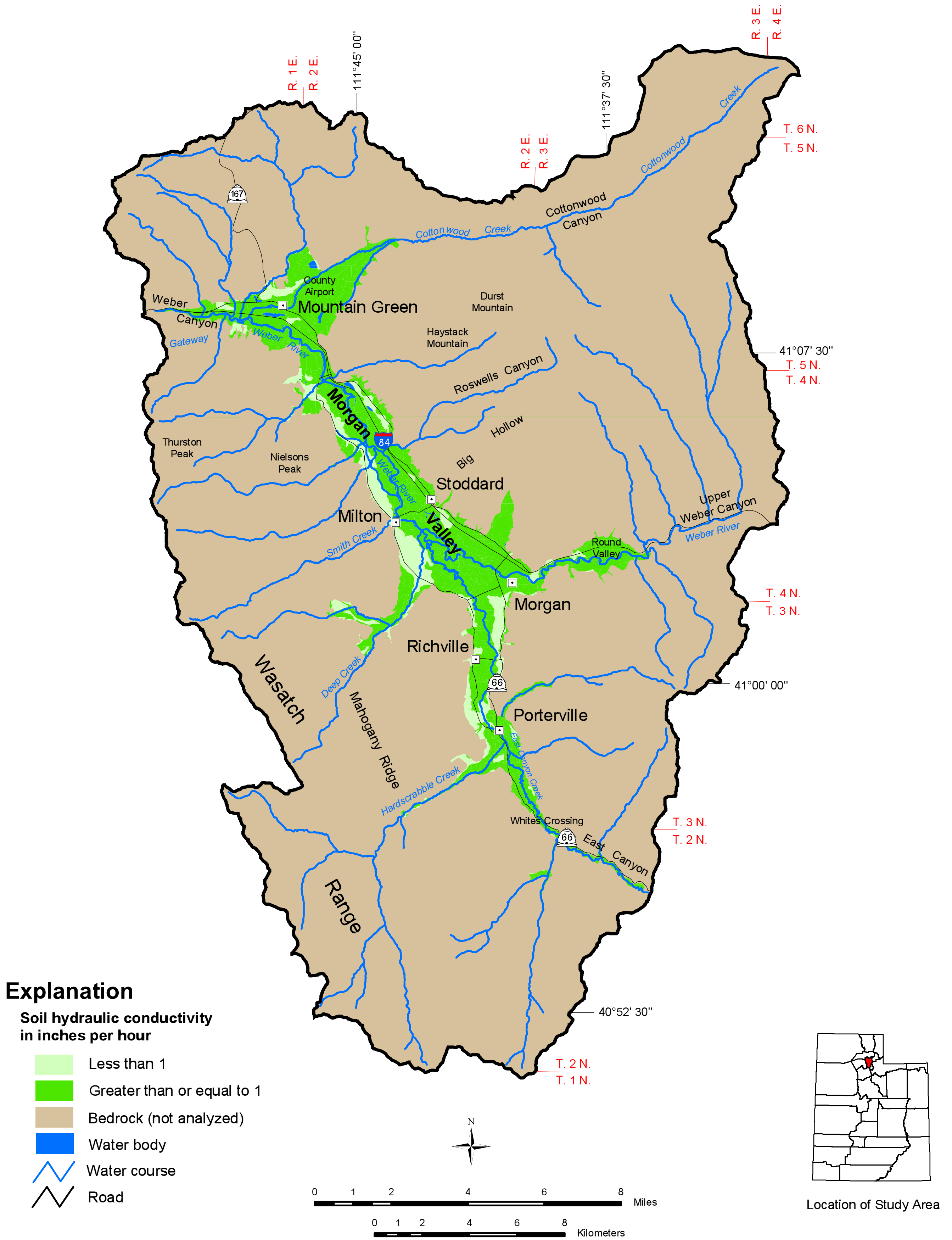

Figure 8. *Soil hydraulic conductivity in Morgan Valley, Morgan County, Utah (data from National Soil Survey Center, 2001).*

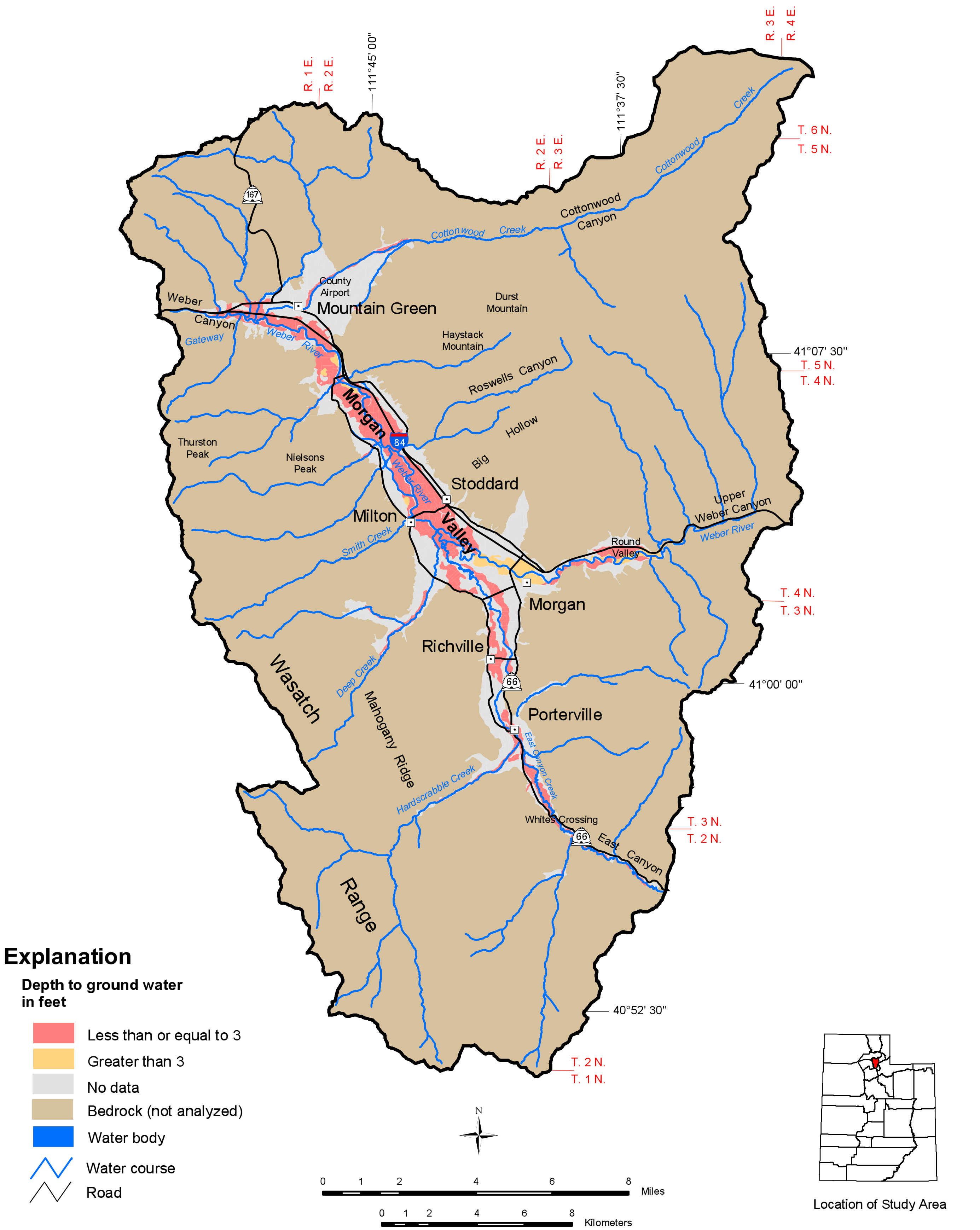

Figure 9. Depth to shallow ground water in Morgan Valley, Morgan County, Utah (data from National Soil Survey Center, 2001).

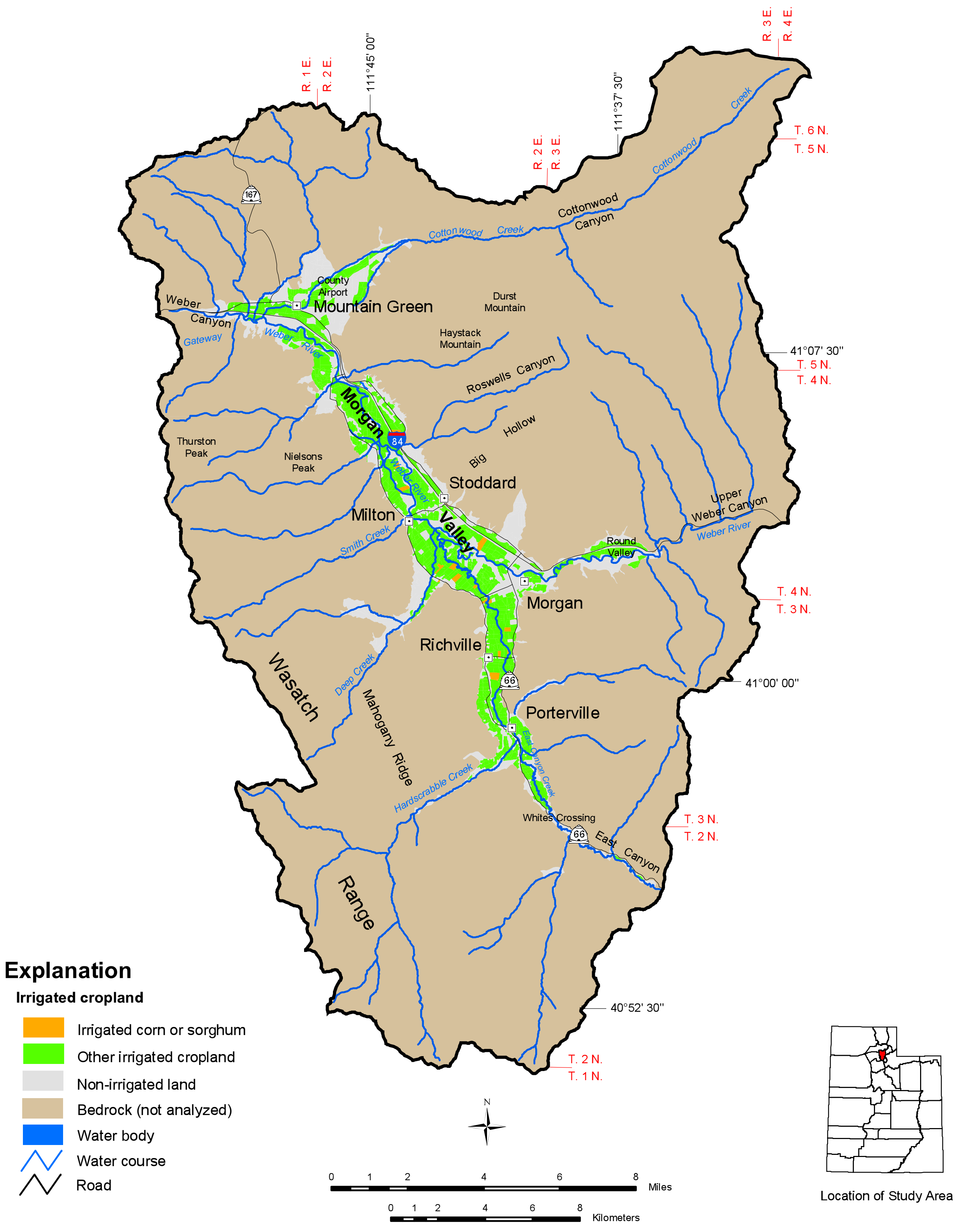

Figure 10. *Irrigated and non-irrigated cropland in Morgan Valley, Morgan County, Utah (data from Utah Division of Water Resources, 1999). The pesticides addressed in this study are mainly applied to corn and sorghum.*

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Plate 1

GROUND-WATER SENSITIVITY TO PESTICIDES IN MORGAN VALLEY, MORGAN COUNTY, UTAH

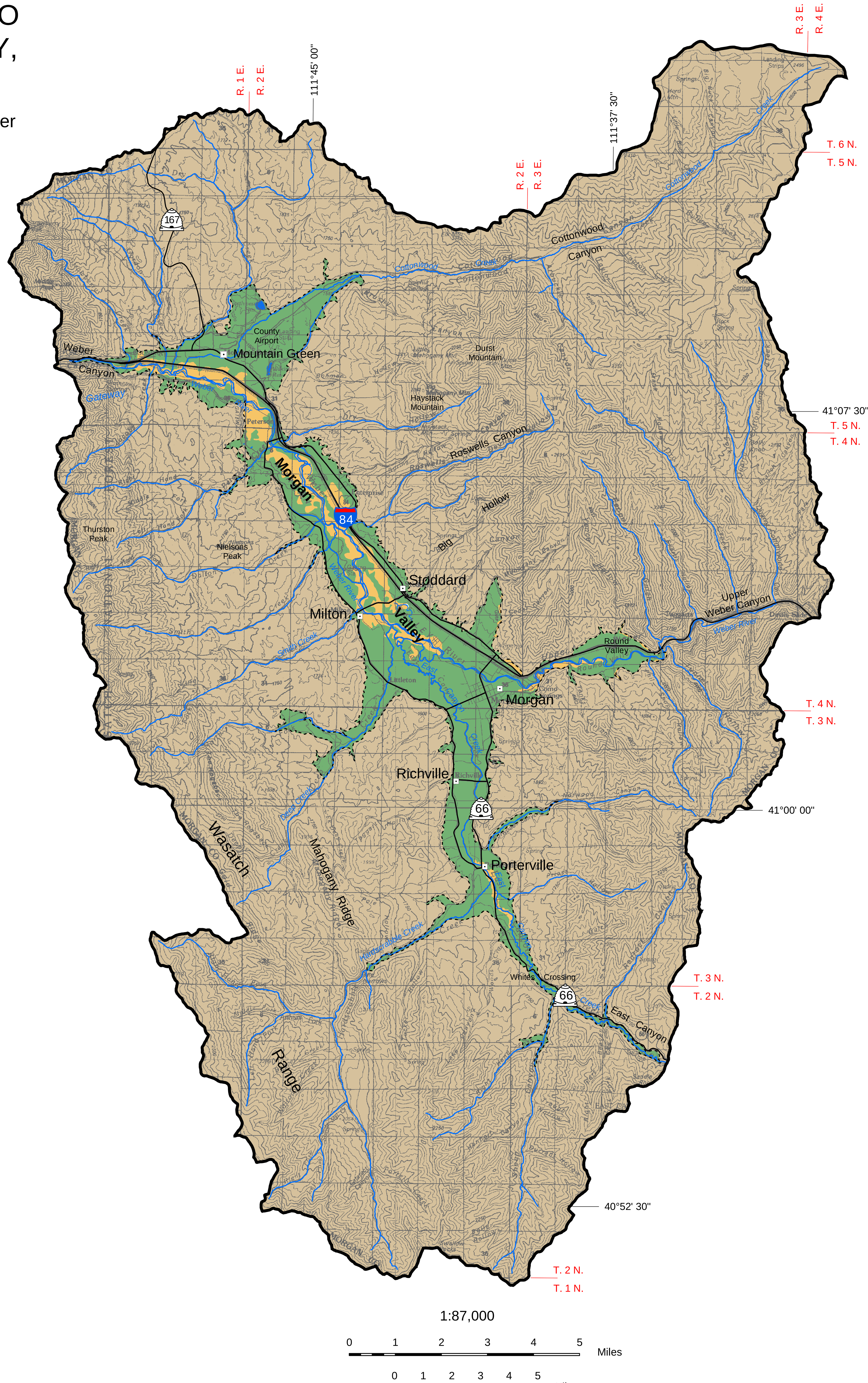
By Mike Lowe, Janae Wallace, Neil Burk, and Matt Butler
Utah Geological Survey
and
Anne Johnson and Rich Riding
Utah Department of Agriculture and Food

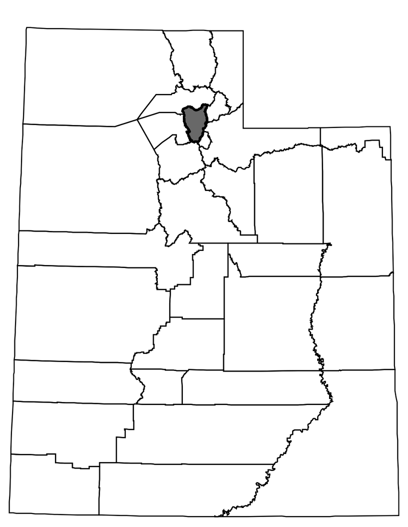
Miscellaneous Publication 04-4
2004

Explanation

Ground-Water Sensitivity Ranking

- Moderate Sensitivity
- High Sensitivity
- Bedrock (not analyzed)
- Water body
- Water course
- Valley-fill boundary
- Road
- Boundary of study area





Location of Study Area

Projection: UTM
Zone: 12
Units: Meters
Datum: NAD 27
Spheroid: Clarke 1866

Topographic base map from U. S. Geological Survey
1:100,000-scale images: Ogden (1981), Salt Lake City (1976).

This map is a GIS product derived from soil data from the National Soil Survey Center (2001), 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 (1999). No additional fieldwork 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.

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Plate 2

GROUND-WATER VULNERABILITY TO PESTICIDES IN MORGAN VALLEY, MORGAN COUNTY, UTAH

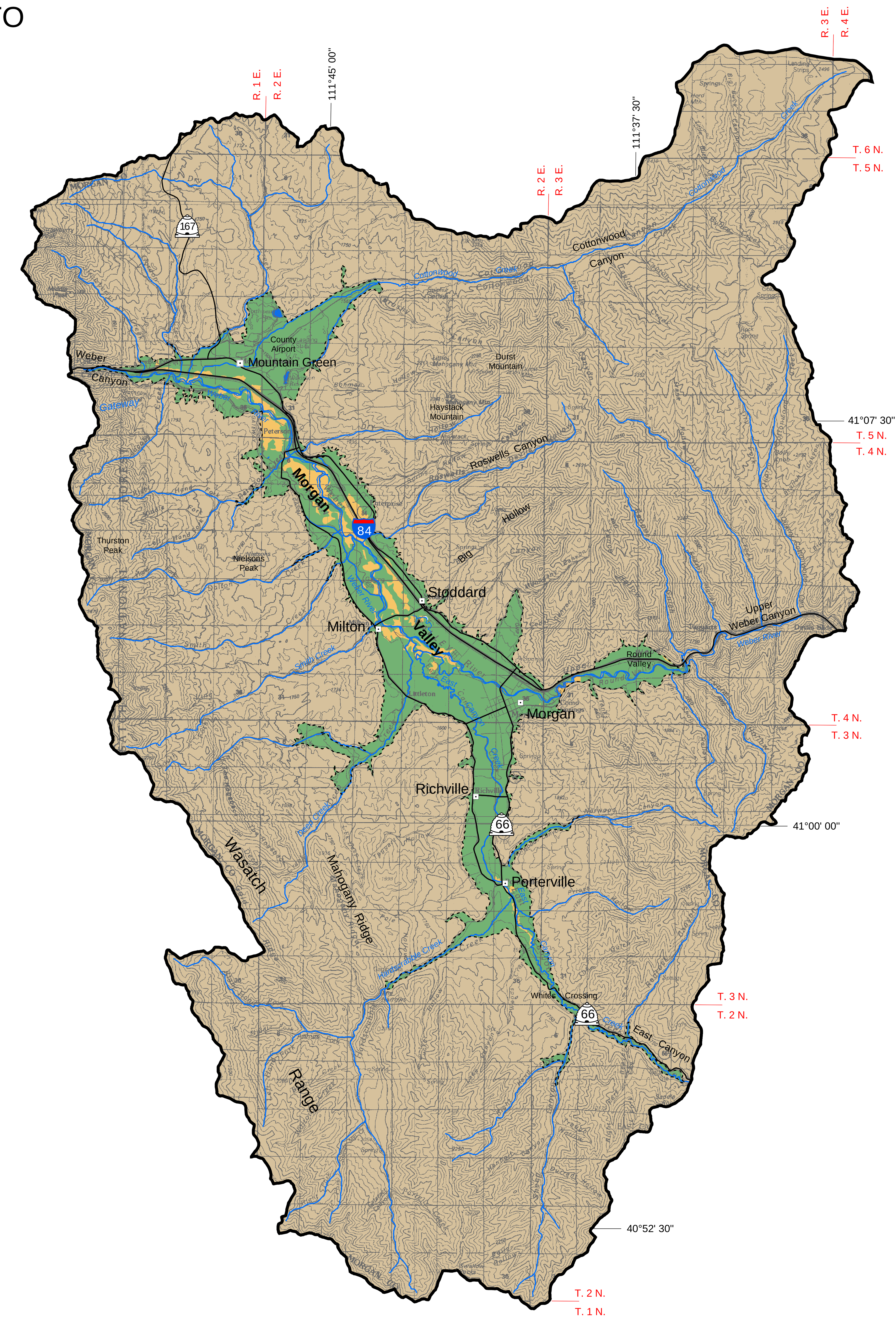
By Mike Lowe, Janae Wallace, Neil Burk, and Matt Butler
Utah Geological Survey
and
Anne Johnson and Rich Riding
Utah Department of Agriculture and Food

Miscellaneous Publication 04-4
2004

Explanation

Ground-Water Vulnerability Ranking

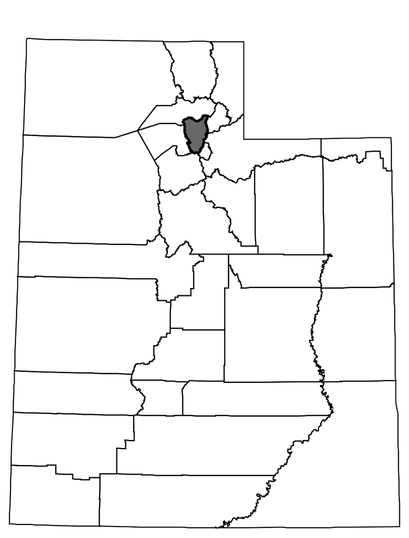
- Moderate Vulnerability
- High Vulnerability
- Bedrock (not analyzed)
- Water body
- Water course
- Valley-fill boundary
- Road
- Boundary of study area



1:87,000

0 1 2 3 4 5 Miles

0 1 2 3 4 5 Kilometers



Location of Study Area

Projection: UTM
Zone: 12
Units: Meters
Datum: NAD 27
Spheroid: Clarke 1866

Topographic base map from U. S. Geological Survey
1:100,000-scale images: Ogden (1981), Salt Lake City (1976).

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