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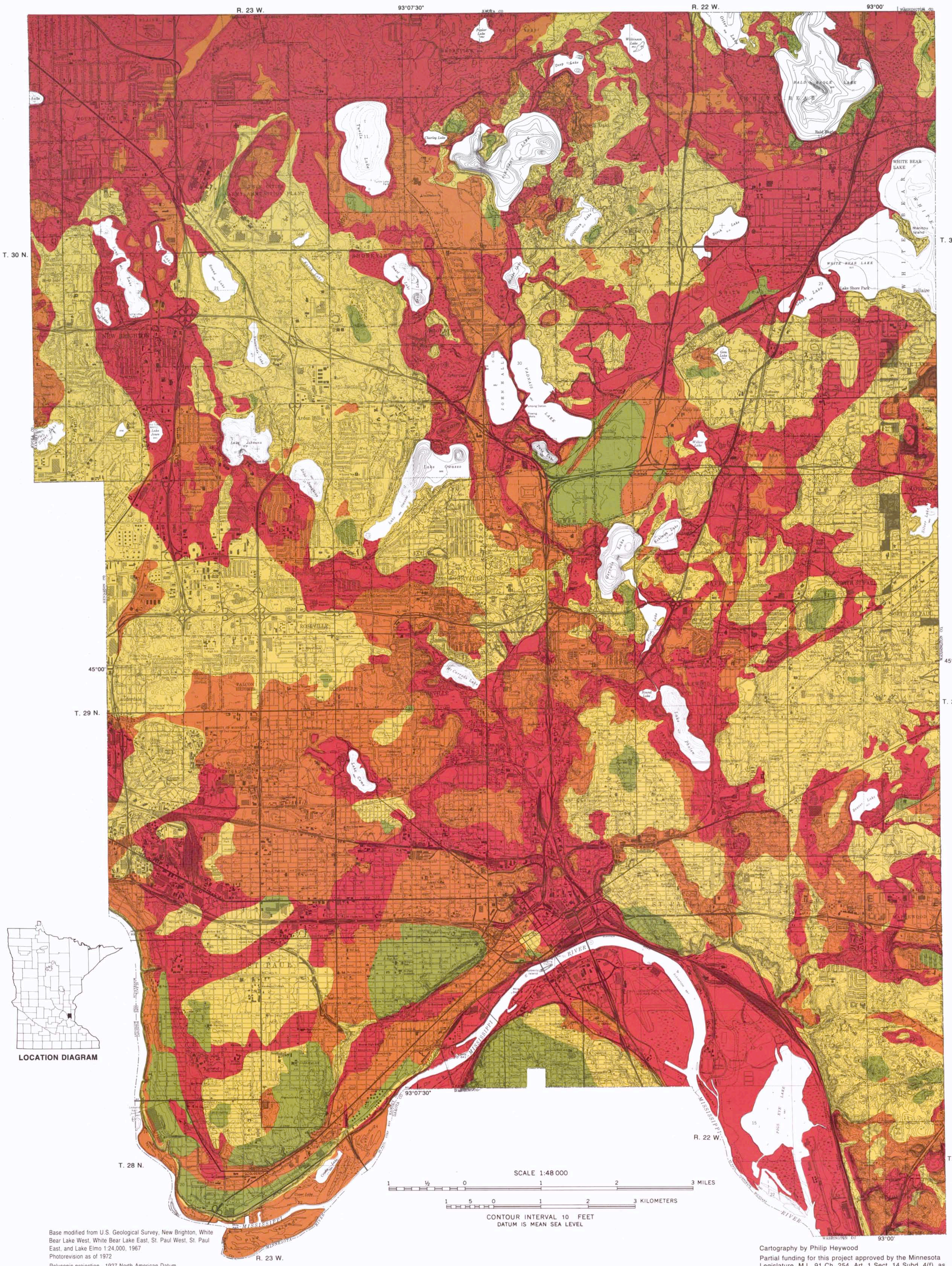

Base modified from U.S. Geological Survey, New Brighton, White Bear Lake West, White Bear Lake East, St. Paul West, St. Paul East, and Lake Elmo 1:24,000, 1967
Photorevision as of 1972
Polyconic projection. 1927 North American Datum

Cartography by Philip Heywood

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SENSITIVITY OF THE WATER-TABLE SYSTEM TO POLLUTION

By

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SENSITIVITY RATINGS

Estimated travel time for water-borne contaminants at the land surface to reach the water-table system

VH
Very high
Hours to months

H
High
Weeks to years

M
Moderate
Years to decades

L
Low
Decades to a century

ASSESSING THE SENSITIVITY OF THE WATER-TABLE SYSTEM TO POLLUTION

The water table is the uppermost ground-water resource. Sensitivity of the water-table system to pollution was assessed on the basis of the depth to the local water table and the vertical permeability of geologic materials in the unsaturated zone. A depth-to-the-water-table map was created by extrapolating lake and wetland elevations and subtracting the elevation of the water table (Plate 6) from the land-surface elevation. U.S. Geological Survey 7.5-minute topographic maps provided the lake-level and land-surface data. Water-table sensitivity was evaluated by overlaying the depth-to-water-table surface with the surficial and bedrock geology maps (Plates 2 and 3) and rating areas according to the matrix. The data bases (Plate 1) supplied additional subsurface information for evaluating areas where the water-table depth is greater than 20 feet.

The top 10 feet of the unsaturated zone were not evaluated. Estimating vertical flow at this shallow depth is very difficult, owing to the large number of existing natural flow paths (macropores) for infiltrating water. Sensitivity ratings were first based on the geologic materials at the water table. Ratings were then adjusted according to the type and amount of confining materials in the unsaturated zone (Fig. 1). Areas where the water-table depth is less than 20 feet from the land surface were evaluated only according to the material present at the water table. In areas where the unsaturated zone is more than 20 feet, ratings were adjusted on the basis of the presence of overlying Moderate or Low confining materials. For an original rating to be changed, at least 20 feet of Moderate or 10 feet of Low materials had to be present above the water table and below the top 10 feet.

Sensitivity was divided into four rating levels, according to the permeability of Quaternary and near-surface bedrock deposits. Among the unconsolidated materials, lacustrine clay, associated with the Grantsburg sublobe, has the lowest sensitivity; outwash and other coarse-grained sediments have the highest. The Grantsburg and Superior lobe tills were assigned Moderate ratings, except where subsurface information indicated a predominantly clayey texture, in which case the ratings were changed to Low. Sandstone, with intergranular flow similar to that of sand and gravel deposits, was rated Very High. Carbonate bedrock, typified by flow paths along interconnected, solution-enlarged fractures and cavities, was also rated Very High. In the southern part of the county, lateral discharge to the Mississippi River produces unconfined, or water-table, conditions in bedrock aquifers overlain by shale confining units. In these areas, the map shows the sensitivity of the bedrock formation above the Prairie du Chien Group that contains the water table. Both bedrock and glacial confining units were taken into account for ratings in these areas.

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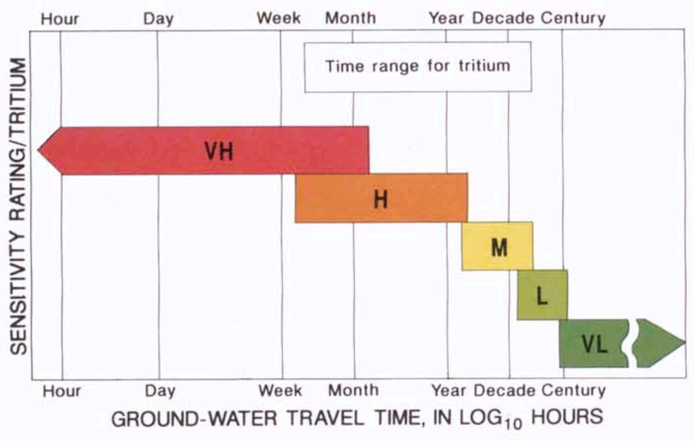

Figure 2. ***Geologic sensitivity ratings are based on the time required for surface water to travel vertically to an aquifer. The longer the travel time, the less sensitive is an aquifer to pollution. The presence of tritium, a radioactive isotope of hydrogen that was introduced in the atmosphere with the advent of nuclear testing in the early 1950s, can indicate the relative age of ground water. Modified from Minn. Dept. of Natural Resources, Div. of Waters (1991).***

Matrix for Rating the Sensitivity of the Water-Table System in Ramsey County

Geologic Materials at the Water Table	Confining Units in the Unsaturated Zone—Thickness and Permeability			
	Where the unsaturated zone is less than 20 feet thick	Where the unsaturated zone is more than 20 feet thick		
		No confining units of moderate or low permeability	One or more confining units of moderate permeability more than 20 ft thick	One or more confining units of low permeability more than 10 ft thick
Sandstone, carbonate bedrock	VH	H	M	L
Sand and gravel, organic deposits	VH	H	M	L
Sandy loam till, lake silt, colluvium	M	M	M	L
Loamy to clay-loam till, clay till, lake clay, shale	L	L	L	L

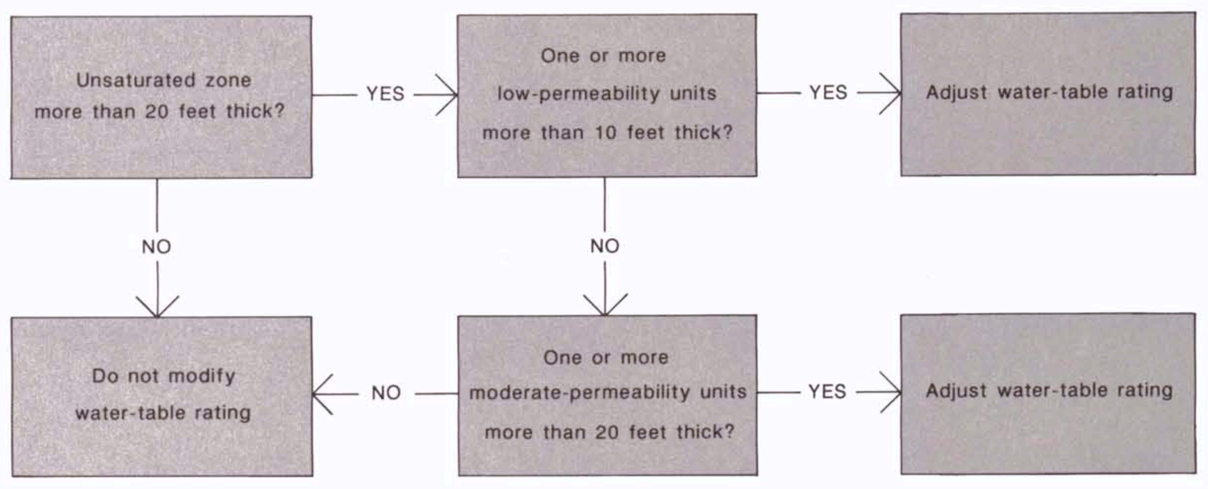

Figure 1. ***Sensitivity ratings for geologic materials at the water table are adjusted depending on the presence and thickness of low- or moderate-permeability units in the unsaturated zone. Modified from Minn. Dept. of Natural Resources, Div. of Waters (1991).***

INTRODUCTION

As specified by the 1989 Minnesota Groundwater Protection Act, a sensitive ground-water area is "a geographic area defined by natural features where there is a significant risk of groundwater degradation from activities conducted at or near the land surface." Sensitivity maps serve as planning tools for evaluating the threat certain activities and land uses present to ground-water quality. Plate 8 assesses the water-table system, the uppermost ground-water resource. Plate 9 examines the Prairie du Chien–Jordan bedrock aquifer, the most heavily used source of ground water in the county.

GEOLOGIC SENSITIVITY

Geologic sensitivity is the degree of protection provided by geologic materials overlying an aquifer. It is based on the vertical travel time required for a water-borne contaminant released at or near the land surface to enter the ground water. Travel time, which reflects the ability of geologic materials to impede the vertical movement of contamination, is controlled by the permeability, thickness, and lithology of the geologic materials through which the contaminants move. The sensitivity of an aquifer is inversely proportional to the time of travel. Longer travel times represent a greater degree of geologic protection and reduced sensitivity to ground-water pollution. Shorter travel times represent an increased sensitivity and a lessened ability to protect ground water from vertical contaminant movement. However, high sensitivity does not mean that water quality has or will be degraded, and low sensitivity does not guarantee that ground water is or will remain pristine.

POROSITY AND PERMEABILITY (Piegat, 1989)

The porosity and permeability of a geologic material determine its ability to store and transmit water. Porosity is the amount of void space (pores) available to store water. Permeability is a measure of the relative ease with which a material can transmit water. Porosity and permeability influence the entry and spread of contamination toward and through an aquifer.

No geologic material is absolutely solid. Ground water is stored in and moves through an intricate network of pores. Pore space can occupy as much as 30 percent or as little as a tiny fraction of one percent of the total volume of a geologic material. The number and size of pores, as well as the connections among them, control the ease with which water passes through a material. In unconsolidated materials, pores are related to the grain size, the degree of sorting of grain sizes, how closely grains are packed, and the amount of original pore space filled with secondary minerals. Materials that consist of large grains, grains with little variation in size, loosely packed grains, and pores that remain open have a higher porosity than materials with grains that are small, poorly sorted, and tightly packed, and where pores are filled with solid material. Fractures, which also provide space for ground water, can produce significant secondary porosity if they are relatively large, numerous, and interconnected.

PREPARATION OF THE SENSITIVITY MAPS FOR RAMSEY COUNTY

The sensitivity maps (Plate 8 and 9) are interpretations of information derived from other maps in the atlas, from U.S. Geological Survey 7.5-minute topographic maps, and from the data bases described on Plate 1. The geologic materials mapped in the county (Plates 2 and 3) were classified according to their hydrogeologic properties and rated as shown in the matrices. The sensitivity of ground water to pollution can be appraised on the ability of geologic materials (1) to absorb and hold contaminants, (2) to transform contaminants into benign substances, (3) to dilute contaminants to levels below a set standard, or (4) to control the rate that contaminated water flows to or through aquifers. The fourth category served as the rating basis for sensitivity mapping of Ramsey County: the estimated travel time for water-soluble, geologically inert contaminants released at the land surface to enter either the water-table system or the Prairie du Chien–Jordan aquifer.

Several methods have been devised for estimating the sensitivity of ground-water systems to pollution. The criteria developed by the Minnesota Department of Natural Resources, Division of Waters, were used to compile the maps for Ramsey County. In some cases, the geology of Ramsey County necessitated a deviation from their procedures.

Because of the wide variety of contaminants and contaminant behavior, no sensitivity rating scheme can address all types of pollution. Therefore, certain simplifying assumptions were adopted for map preparation. The maps are not contaminant-specific. Contaminants are assumed to be inert and to have the same behavior as water. All pollution is assumed to originate at or near the land surface, and not, for example, from an underground storage tank. Pollutant-attenuation processes (adsorption, cation exchange, biological decay), which may arise as a contaminant flows through soil and geologic materials, are not addressed. Contamination is presumed to flow vertically downward; lateral movement is ignored. The maps also ignore changes in sensitivity caused by human activities, such as abandoned water wells, large ground-water withdrawals, construction excavations, and the improper use and disposal of hazardous substances.

Preparing a map at any scale requires generalization of the information portrayed. In these maps, boundaries between map units do not portray absolute differences in ground-water sensitivity. The map units themselves are not finite; each portrays the predominant rating within its boundary. A common mistake is to enlarge, sometimes greatly, an existing map. Enlarging these maps will distort the complexity and sensitivity of particular sites. Projects that need greater detail than presented here require site-specific investigation to predict the behavior of contaminants as they move from the land surface to ground-water systems.

SENSITIVITY RATINGS

The geologic materials (Plates 2 and 3) were classified according to their estimated permeability and assigned a sensitivity rating. Ratings were adjusted according to the depth to the water table, the thickness of overlying Quaternary deposits, and the number and effectiveness of confining units. Each rating reflects a broad range of travel time. Sensitivity ratings are general classifications that accommodate the complex nature and rate of contaminant movement through geologic materials. Very High sensitivity indicates that contamination will result before detection and/or remedial action are possible. High sensitivity indicates that pollution will probably occur unless detection and treatment take place immediately. Moderate sensitivity indicates that enough time is probably available for the investigation and remediation of a recently developed contamination site. Low sensitivity indicates that a long-contaminated site can be investigated, and possibly corrected, before ground-water pollution develops. In the case of a Very Low rating, where the geology is an extremely effective barrier to contaminant flow, any existing contamination probably entered the ground water via a human-caused pathway, such as a improperly sealed abandoned well. Regardless of the degree of geologic protection, no area of the county is completely isolated from pollution.

RESIDENCE TIME OF GROUND WATER

The sensitivity of ground water to pollution is best understood in relation to the age of the ground water. The age of the water, also called its residence time, is the approximate time from when a drop of water infiltrates the land surface to when it is discharged or pumped from an aquifer. Radiometric dating using isotopes of carbon and hydrogen can determine the residence time of ground water in an aquifer (Alexander and Alexander, 1989). Shorter residence times indicate water that has recently entered the ground and may be associated with higher sensitivity. Longer residence times may represent both a greater travel time and an increased level of geologic protection.

Both residence time and information on water quality can be used to verify the accuracy of the sensitivity maps. Tritium is a radioactive isotope of hydrogen that occurs naturally in the atmosphere. Water that entered the ground prior to atmospheric testing of nuclear weapons in the early 1950s contains little or no tritium. Higher amounts of tritium are found in water that infiltrated the ground since 1953, the year tritium concentrations sharply increased. As a result, tritium analyses of water samples can be used to determine the relative age of ground water (Fig. 2). Tritium concentrations are classified as either recent water (post-1953), vintage water (pre-1953), or mixed water (some of both).

Four wells, pumping from the Prairie du Chien–Jordan, were sampled for tritium concentrations. In addition, the Minnesota Department of Health, in July 1991, performed tritium residence-time analyses on water samples from seven municipal wells pumping from the Jordan Sandstone. In areas evaluated as having Low sensitivity, one well had recent water, five had mixed water, and two had vintage water. In areas rated Moderate, the two wells had vintage water. In the area of High sensitivity, the one sample had—as was expected—recent water. The lack of agreement between residence times and sensitivity ratings may be due to map limitations, such as the exclusion of both lateral ground-water flow and the effects of pumping wells.

USES FOR THE SENSITIVITY MAPS

In Ramsey County, water enters the ground-water system most rapidly through areas rated Very High and High. Water entering through less sensitive areas reaches deeper aquifers at a slower rate and in smaller amounts. Short-term protection of ground-water quality can be accomplished by controlling contaminant sources in sensitive areas. However, because ground water travels laterally for considerable distances, and because much of the ground water in Ramsey County originates outside its boundaries, a regional effort is required to provide long-term aquifer protection.

Various land-use activities have an immense negative impact on ground-water resources. Once ground water is contaminated, it is expensive and difficult to clean up. In the past, there were few resources for incorporating ground-water information into local planning policies. A sensitivity assessment enables planners to include ground-water concerns into land-use decisions and to direct regulations and fiscal resources to areas most threatened by contamination.

In Ramsey County, current and future projects incorporating the sensitivity assessment may include, but are not limited to, ground-water protection planning, evaluation of well-head protection areas, evaluation of future development sites and proposed zoning ordinances, solid and hazardous waste management and facility siting, inventorying of abandoned wells, and public education about ground-water protection.