In cooperation with the San Antonio Water System

Vulnerability of Ground Water to Contamination, Edwards Aquifer Recharge Zone, Bexar County, Texas, 1998

Water-Resources Investigations Report 00–4149

U.S. Department of the Interior
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By Allan K. Clark

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From	Multiply by	To
	<u>English to Metric</u>	
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	<u>Metric to English</u>	
meters (m)	3.281	feet (ft)

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Abstract

The Edwards aquifer, one of the most productive carbonate-rock aquifers in the Nation, is composed of the Kainer and Person Formations of the Edwards Group plus the overlying Georgetown Formation. Most recharge to the Edwards aquifer results from the percolation of streamflow loss and the infiltration of precipitation through porous parts of the recharge zone. Residential and commercial development is increasing, particularly in Bexar County in south-central Texas, atop the densely fractured and steeply faulted recharge zone. The increasing development has increased the vulnerability of ground water to contamination by spillage or leakage of waste materials, particularly fluids associated with urban runoff and (or) septic-tank leachate. This report describes a method of assessing the vulnerability of ground water to contamination in the Edwards aquifer recharge zone. The method is based on ratings of five natural features of the area: (1) hydraulic properties of outcropping hydrogeologic units; (2) presence or absence of faults; (3) presence or absence of caves and (or) sinkholes; (4) slope of land surface; and (5) permeability of soil. The sum of the ratings for the five natural features was used to develop a map showing the recharge zone's vulnerability to ground-water contamination.

INTRODUCTION

The Edwards aquifer, composed of the Kainer and Person Formations of the Edwards Group (Rose, 1972) plus the overlying Georgetown Formation, is one of the most productive carbonate-rock aquifers in the Nation. The densely fractured, steeply faulted, diagenetically modified limestone aquifer (Buszka and others, 1990) is the sole source of public-water supply for San Antonio and is the major source of water for Bexar County, Texas (fig. 1). In addition to providing drinking water to more than 1 million people in south-central Texas and supporting the livelihoods of thousands of agricultural and industrial users, the Edwards aquifer sustains outflow from several springs. Two major springs (discharging at rates averaging more than 100 cubic feet per second [ft^3/s]) support recreational activities and businesses, provide surface water to several thousand downstream users, and ensure the survival of several federally protected plant and animal species.

Most recharge to the Edwards aquifer results from the percolation of streamflow losses and the infiltration of precipitation through porous parts of the outcropping recharge zone. A substantial increase in residential and commercial development has occurred atop the recharge zone during the 1980s to 1990s, particularly in Bexar County. According to Buszka (1987, p. 2), "Carbonate aquifers such as the Edwards are readily susceptible to ground-water contamination where the presence of pollutants coincides with the outcrop of the aquifer."

The increasing development upon the recharge zone could threaten the quality of the water entering the Edwards aquifer. Ground water could be contaminated by spills or leaks of waste materials, particularly fluids associated with runoff from rapidly developing urban areas and (or) leachate from septic tanks.

The hydrogeologic subdivisions of the Edwards aquifer are distinguished, in part, by different hydraulic properties, such as porosity and permeability. The more porous and (or) more permeable parts of the recharge zone are more vulnerable to contamination.

Many interpretative maps have been published that present spatial information on the geology, hydrology, soils, land use, karstic natures, and plant and animal habitats of the Edwards aquifer recharge zone. As stand-alone documents, these maps furnish important, but limited, information for water managers,

Figure 1. Location of study area.

environmental planners, and government regulators to make informed decisions regarding the vulnerability of ground water to contamination in the recharge zone. A comprehensive method was needed to assess the vulnerability (susceptibility) of the recharge zone to ground-water contamination as the result of the natural features of the system. Therefore, in 1997, the U.S. Geological Survey (USGS), in cooperation with the San Antonio Water System, began a study to develop such a method and to produce a vulnerability map.

Purpose and Scope

The purpose of this report is to present results of an assessment of the vulnerability of ground water to contamination in the Edwards aquifer recharge zone of Bexar County, Texas, as of 1998. Vulnerability to contamination as applied herein depends on the natural, or intrinsic, characteristics of the hydrogeologic environment—for example: porosity, permeability, and slope—all of which are independent of human activity in the area (National Research Council, 1993, p. 17). This report describes a method of evaluating the vulnerability of the ground-water system with respect to a combination of selected natural features and presents the results of that evaluation on a map.

Methods of Investigation

Available data for the Edwards aquifer recharge zone, including hydrogeologic literature, maps, and field records were assembled and, if pertinent, entered into a digital spatial database. Natural features of the recharge zone—including topographic slope, soil type, and geology—were mapped during 1995–97; aspects of the geologic mapping included the delineation of faults, caves, sinkholes, and collapsed features.

Aerial photographs were used to help identify geologic landmarks. Aerial photographs were obtained from the USGS Earth Resources Observation Systems (EROS) Data Center. The aerial photographs were taken in January 1995 at a scale of 1:40,000.

Digital spatial datasets obtained from various local, State, and Federal agencies were reviewed and spot-checked in the field. All field data were compiled and entered into the database for display and analysis using a geographic information system (GIS). All datasets used in this report have Federal Geographic Data Committee (FGDC)-compliant content-level metadata (Federal Geographic Data Committee, 1994). Content-level metadata contain information about the source documents or databases used to produce digital spatial datasets and information about the resultant dataset including data elements such as scale, projection, and author.

Three methods for assessing the vulnerability of ground water to contamination in the recharge zone were reviewed and modified for this study. The first method is the result of Title 30 of the Texas Administrative Code, which mandates that geologic assessments be performed and development plans approved before land plots within the Edwards aquifer recharge zone can be developed (John Mauser, Texas Natural Resource Conservation Commission, written commun., 1995). To aid managers, planners, developers, and regulators in complying with this regulatory requirement, the Texas Natural Resource Conservation Commission (TNRCC) has developed "Instructions to geologists for geologic assessments on the Edwards aquifer recharge/transition zones" (Texas Natural Resource Conservation Commission, 1995). The current (2000) geologic assessment system for the recharge zone rates specific hydrogeologic and anthropogenic factors in the study area to pinpoint areas that are of potential concern.

The second method is a procedure developed by Leopold and others (1971) to evaluate environmental impacts. The idea behind this method is to "evaluate the probable impact of the proposed action on the environment." (Leopold and others, 1971, p. 1). This is accomplished by designing a scheme for analyzing and assigning a numerical weighting of probable impacts.

The third method is called DRASTIC, which stands for depth to water, (net) recharge, aquifer media, soil media, topography (slope), impact of the vadose zone media, and conductivity (hydraulic) of the aquifer. DRASTIC was developed by the U.S. Environmental Protection Agency (EPA) to evaluate ground-water pollution potential of any hydrogeologic setting with existing data (Aller and others, 1987). "Pollution potential is a combination of hydrogeologic factors, anthropogenic influences, and sources of contamination in any given area," according to Aller and others (1987, p. 1).

The basis of all three methods is a numerical weighting, or rating, of each factor considered. The results of all the ratings considered are accumulated to provide a composite rating. This composite rating can then be produced into a new map (coverage) that reflects the total effect of all factors. After these methods were reviewed, a process for this study was adapted to evaluate the unique geologic and hydrologic characteristics of the Edwards aquifer recharge zone.

The process adapted for this study integrates the effects of five natural features: (1) hydrogeologic units, (2) faults, (3) caves and sinkholes, (4) slopes, and (5) soils. Data for selected natural features were obtained and entered into a digital database in vector type format for display and analysis using GIS technology. These vector datasets contained either points, lines, or polygons depending on the type of feature (for example, faults are a line dataset, and caves are a point dataset).

Table 1. Vulnerability ratings for natural features, Edwards aquifer recharge zone, Bexar County, Texas

Natural feature	Subdivision of feature	Rating
Hydrogeologic unit	Inliers of upper confining unit	5
	Georgetown Formation	15
	Person Formation:	
	Cyclic and marine members, undivided	25
	Leached and collapsed members, undivided	35
	Regional dense member	15
	Kainer Formation:	
	Grainstone member	35
	Kirschberg evaporite member	35
	Dolomitic member	25
	Basal nodular member	15
Fault	Fault present	35
	No fault present	0
Cave or sinkhole	Cave present	35
	Sinkhole and closed depressions present	20
	No cave or sinkhole present	0
Slope (with soil)	Greater than 18 percent	1
	Greater than 12 to 18 percent	3
	Greater than 6 to 12 percent	5
	Greater than 2 to 6 percent	9
	Less than or equal to 2 percent	10
Soil	No soil present	20
	Relatively permeable	15
	Less permeable	10

Databases were established for each feature, and vulnerability ratings were assigned (table 1). After all available data were entered into a feature-specific, digital database, the data were converted into a cell-based grid, or data layer. A cell size of 30 by 30 m was used, thus allowing the various layers to be stacked or merged together developing a cumulative rating (fig. 2). This cumulative rating was then used to compile plate 1. All maps used in the production of plate 1 were obtained and (or) digitized at a scale of 1:24,000, Universal Transverse Mercator projections. The base maps were in North American Datum of 1927 (NAD27).

Acknowledgments

Special thanks are extended to George Veni, consulting karst hydrologist in the San Antonio area, and to personnel of the San Antonio Water System (SAWS) for their assistance in field mapping. The author also expresses thanks to personnel of the TNRCC, Bexar County Appraisal District, Alamo Area Council of Governments (AACOG), Edwards Aquifer Authority (EAA), Bexar County Health Department, and Texas Parks and Wildlife Department, who assisted in the acquisition of data and databases. Thanks are also extended to all the property owners who granted permission to enter their property.

ASSESSMENT OF GROUND-WATER VULNERABILITY

This section briefly describes the five natural features that were included in the assessment. Digital databases were compiled from available data and (or) from data resulting from fieldwork to characterize each natural feature. Metadata were developed for all feature

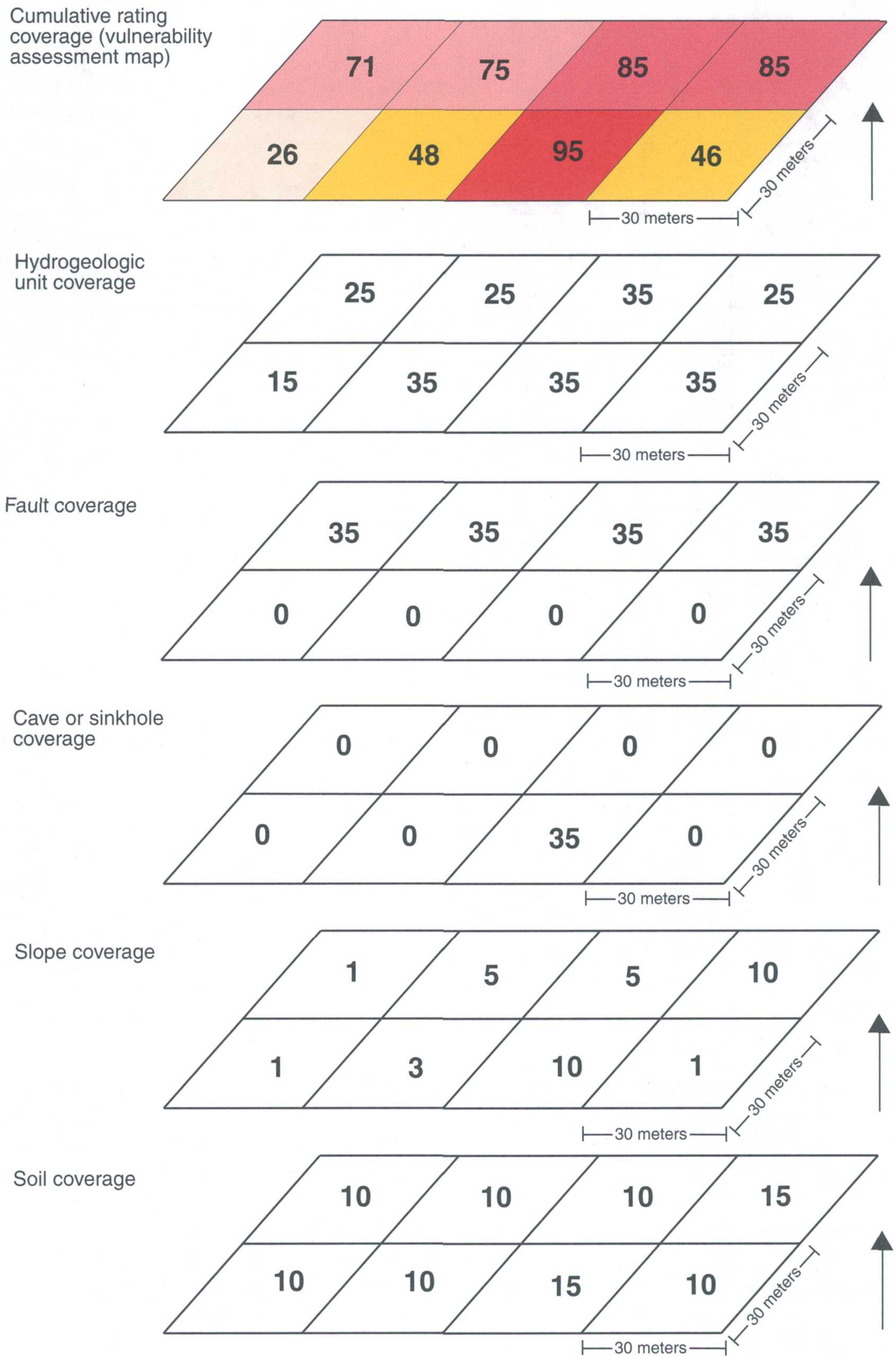

Figure 2. Diagram showing an example of the generation of the vulnerability assessment map.

Table 2. Summary of the lithologic and hydrologic properties of the hydrogeologic subdivisions of the Edwards aquifer recharge zone, Bexar County, Texas

[Hydrogeologic subdivisions modified from Maclay and Small (1976); groups, formations, and members modified from Rose (1972); lithology modified from Dunham (1962); and porosity type modified from Choquette and Pray (1970). CU, confining unit; AQ, aquifer]

Hydrogeologic subdivision			Group, formation, or member			Hydrologic function	Thickness (feet)	Lithology	Field identification	Cavern development	Porosity/ permeability type
Upper Cretaceous	Upper confining unit		Eagle Ford Group			CU	30–50	Brown, flaggy shale and argillaceous limestone	Thin flagstones; petroliferous	None	Low porosity/low permeability
			Buda Limestone			CU	40–50	Buff, light-gray, dense mudstone	Porcelaneous limestone with calcite-filled veins	Minor surface karst	Low porosity/low permeability
			Del Rio Clay			CU	40–50	Bluish-green to yellowish-brown clay	Fossiliferous; *Ilymatogyra arietina*	None	None/primary upper confining unit
Lower Cretaceous	I	Edwards aquifer	Georgetown Formation			Karst AQ; not karst CU	2–20	Reddish-brown, gray to light-tan, marly limestone	Marker fossil; *Waconella wacoensis*	None	Low porosity/low permeability
	II		Edwards Group	Person Formation	Cyclic and marine members, undivided	AQ	80–90	Mudstone to packstone; *miliolid* grainstone; chert	Thin graded cycles; massive beds to relatively thin beds; crossbeds	Many subsurface; might be associated with earlier karst development	Laterally extensive; both fabric and not fabric/ water-yielding
	III				Leached and collapsed members, undivided	AQ	70–90	Crystalline limestone; mudstone to grainstone; chert; collapsed breccia	Bioturbated iron-stained beds separated by massive limestone beds; stromatolitic limestone	Extensive lateral development; large rooms	Majority not fabric/one of the most permeable
	IV				Regional dense member	CU	20–24	Dense, argillaceous mudstone	Wispy iron-oxide stains	Very few; only vertical fracture enlargement	Not fabric/low permeability; vertical barrier
	V			Kainer Formation	Grainstone member	AQ	50–60	*Miliolid* grainstone; mudstone to wackestone; chert	White crossbedded grainstone	Few caves	Not fabric/recrystallization reduces permeability
	VI				Kirschberg evaporite member	AQ	50–60	Highly altered crystalline limestone; chalky mudstone; chert	Boxwork voids, with neospar and travertine frame	Probably extensive cave development	Majority fabric/one of the most permeable
	VII				Dolomitic member	AQ	110–130	Mudstone to grainstone; crystalline limestone; chert	Massively bedded light gray, *Toucasia* abundant	Caves related to structure or bedding planes	Mostly not fabric; some bedding-plane fabric/ water-yielding
	VIII				Basal nodular member	Karst AQ; not karst CU	50–60	Shaly, fossiliferous, nodular limestone; mudstone; *miliolid* grainstone	Massive, nodular and mottled, *Exogyra texana*	Large lateral caves at surface; a few caves near Cibolo Creek (see pl. 1)	Fabric; stratigraphically controlled/large conduit flow at surface; no permeability in subsurface
	Lower confining unit		Upper member of the Glen Rose Limestone			CU; evaporite beds AQ	350–500	Yellowish-tan, thinly bedded limestone and marl	Stair-step topography; alternating limestone and marl	Some surface cave development	Some water production at evaporite beds/relatively impermeable

coverages using appropriate documentation software. The sources of data and an explanation of the ratings assigned for each of the natural features are presented in the following sections.

Hydrogeologic Units

The geology and fault data were either mapped initially by the USGS (Stein and Ozuna, 1995) or field-checked by USGS personnel. The hydrogeologic units were digitized from 7.5-minute topographic maps. Table 2 contains descriptions of the porosity and permeability of the hydrogeologic subdivisions of the Edwards aquifer recharge zone. The hydrogeologic units were assigned ratings on the basis of their relative porosities and permeabilities (table 1). The more porous and permeable units, such as the Kirschberg evaporite member of the Kainer Formation, were assigned ratings as high as 35, while the less porous and permeable units, such as the Georgetown Formation, were assigned ratings as low as 15. Isolated outliers of the Edwards Group—for example, unsaturated hilltop remnants underlain by Glen Rose Limestone—were not rated and are presented as white areas on plate 1. Outcrops of the

Glen Rose Limestone also were not rated because their hydraulic association with the Edwards aquifer is unknown. However, some inliers of the upper confining unit (table 2) were assigned permeability ratings of 5 because of their apparent hydraulic connection to the Edwards aquifer. Where such outcrops surround or nearly surround permeable parts of the Edwards Group, the aquifer might be vulnerable to the migration of contaminated ground water.

Faults

The study area lies within the Balcones fault zone of south-central Texas (fig. 1). The fault zone is composed mostly of high-angle, "down-to-the-coast," en echelon structures that trend primarily southwestward to northeastward, and a smaller network of cross faults that trend southeastward to northwestward. The dominant system of southwestward-northeastward trending fault blocks tends to enhance northeastern flow and impede southeastern flow. Because faults generally increase opportunities for recharge and, therefore, increase the vulnerability of ground water to contamination, they were assigned the highest vulnerability rating of 35 (table 1).

Fault locations were digitized from USGS 7.5-minute topographic maps (Stein and Ozuna, 1995) into a vector dataset. Faults composing this dataset were assigned a vulnerability rating of 35. All other areas were rated zero. A rating of 35 was assigned to fault traces because these areas are considered to be more permeable, in general, than the areas without fractures.

Caves and Sinkholes

A cave is a naturally occurring subsurface chamber or series of chambers commonly formed by the dissolution of calcium carbonate by water, typically ground water. To qualify as a cave for this report, the chamber must be large enough to accept an average-size human. Sinkholes are closed, roughly circular depressions in areas of karst topography and subterranean drainage. Sinkholes are formed by the massive dissolution of carbonate minerals at or near land surface and (or) by the collapse of underlying caves. Sinkholes are commonly funnel-shaped, large-scale features with size measured in tens or hundreds of feet.

The potential locations of caves, sinkholes, and topographic depressions in the study area were obtained from government agencies, non-government organizations, and private citizens. Most caves and sinkholes were field-checked and located with a Global Positioning System (GPS) on 7.5-minute topographic maps. Some cave reports were verified by SAWS personnel. Other locations—such as those identified by caving organizations—were field-checked where possible. All relevant karst was mapped and digitized as point features. Caves were assigned a vulnerability rating of 35, and sinkholes (including all closed depressions) were assigned ratings of 20.

Slopes

The slope of land surface is a potential contributor to ground-water contamination because the slope can determine where and how long a contaminant remains on the land surface. The less the slope, the longer a contaminant might remain on the surface and, therefore, the more likely the contaminant could migrate into the subsurface.

Land-surface altitudes were derived from USGS 7.5-minute digital elevation models (DEMs). DEMs are datasets that contain location information in three dimensions for each cell, thus allowing percent slope calculations for each cell. Cell dimensions were 30 by 30 meters in the x and y direction. The z direction, representing the altitude of land surface at the center of each cell, also was measured in meters. After calculating the percent slope, a rating was assigned to each cell in the slope coverage. The rating system used is a modification of the DRASTIC rating for slope (Aller and others, 1987). Slopes greater than 18 percent were rated as 1; slopes greater than 12 and up to 18 percent were rated as 3; slopes greater than 6 and up to 12 percent were rated as 5; slopes greater than 2 and up to 6 percent were rated as 9; and slopes less than or equal to 2 percent were rated as 10.

Soils

Soils can reduce the potential for ground-water contamination by trapping contaminants within the soil matrix and (or) obstructing the migration of contaminants into the subsurface. The soils database was translated from a 1995 soil survey by the Natural Resources Conservation Service (NRCS) (1995). The digital data were gridded at a scale of 30 m (horizontal resolution), and vulnerability ratings were assigned on the basis of NRCS assessment of the relation between different soils and sewage-disposal field design by Taylor and others (1966, p. 74–81). Taylor and others (1966, p. 103) indicated that because of erosion, slopes of 30 percent or greater generally do not support a significant thickness of soil. DEMs were used to identify cells that had slopes of 30 percent or more. These cells were assigned a rating of 20, on the assumption that no soils were present. No other cell within the soil coverage was assigned a rating of 20. Cells with slopes of less than 30 percent were assigned ratings of 15 or 10, depending on the permeability of the soil type. Tarrant-Brackett and Crawford-Bexar soils are classified as being relatively permeable; therefore, these soils were assigned a vulnerability rating of 15. Austin-Tarrant and Louisville-Houston soils, classified as slightly less permeable, were assigned a rating of 10.

Soils are not a primary factor in the variability of the vulnerability because, where they are present, they tend to be uniform over the recharge zone. About 97 percent of the soils (mostly Austin-Tarrant and Louisville-Houston) were assigned a rating of 10.

GROUND-WATER VULNERABILITY MAP

The ground-water vulnerability map (pl. 1) shows the vulnerability ranking based on the cumulative ratings of all selected natural features. Possible cumulative ratings ranged from 16 to 135; actual ratings ranged from 20 to 130. The majority of the 350,577 total cells ranked between greater than 26 and 66 (see table below). The cells were divided into eight groups as follows:

Cell group cumulative rating	Number of cells	Cell group cumulative rating	Number of cells
>16 to 26	1,061	>56 to 66	48,539
>26 to 36	148,667	>66 to 76	7,301
>36 to 46	69,151	>76 to 86	2,121
>46 to 56	70,812	>86 to 135	2,925

In the last group of 2,925 cells, 2,919 had values of 96 or less. Because of the scale of the map, the 6 cells with values greater than 96 could not be distinguished and, therefore, were included as part of the greater-than-86 group.

The cumulative rating process developed for this study indicates a higher vulnerability rating for the southeastern part of the Edwards aquifer recharge zone in Bexar County. This higher rating is primarily a reflection of the hydrogeologic unit present at the surface, in this case the leached and collapsed member of the Person Formation. Slopes also have more of an influence in this part of the recharge zone because of the relatively flat topography.

Two areas (views 1 and 2, pl. 1) illustrate how different natural features can result in the same cumulative vulnerability rating being applied to different grid cells. Cells in view 1 that range from greater than 56 to 66 are the result of the cumulative effect of the hydrogeologic unit, slope, and soil. The group of cells, rated greater than 86, running diagonally through view 1 are the result of the cumulative effect of a fault plus the hydrogeologic unit, slope, and soil. The remaining cells in the view, rated greater than 26 to 46, result from the cumulative effect of the hydrogeologic unit, slope, and soil. View 2 shows the effect of a sinkhole on the cumulative rating process. The cell rated greater than 56 to 66 in the center of view 2 received a higher rating because of the cumulative effect of a sinkhole plus the hydrogeologic unit, slope, and soil. The remaining cells in view 2 have lower ratings because of the cumulative effect of the hydrogeologic unit, slope, and soil.

Plate 1 could be used by planners and regulators for planning purposes and as an aid in land-use decisions; however, the plate is not intended to be the sole source of information or be relied upon to evaluate development within the recharge zone of the Edwards aquifer in Bexar County. Photographic or digital enlargement of the plate might cause misinterpretation of the data. The depicted rating boundaries, interpretations, and analysis derived from the plate (or the source data) do not minimize the need for a detailed on-site study (Texas Natural Resource Conservation Commission, 1995.

SUMMARY

The Edwards aquifer, composed of the Kainer and Person Formations of the Edwards Group plus the overlying Georgetown Formation, is one of the most productive carbonate-rock aquifers in the Nation. Most recharge to the Edwards aquifer results from the percolation of streamflow loss and the infiltration of precipitation through porous parts of the recharge zone. The increasing development upon the recharge zone has increased the threat of ground-water contamination.

A method was developed to evaluate the vulnerability (susceptibility) of the Edwards aquifer recharge zone to ground-water contamination. The method was based on rating each of five individual natural features: (1) hydrogeologic units, (2) faults, (3) caves and (or) sinkholes, (4) slopes, and (5) soils. The ratings were based on the effect each feature might have on precipitation and (or) runoff entering the ground-water system. Spatial databases for each feature were merged to produce overall, or cumulative, vulnerability ratings, which were used to generate a ground-water vulnerability map.

Study results indicate that the southeastern part of the recharge zone in Bexar County is the most vulnerable to contamination. The resulting vulnerability map is intended for planning purposes; the map does not minimize the need for detailed on-site study to locate or evaluate development within the recharge zone of the Edwards aquifer in Bexar County.

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