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Vulnerability of Ground Water in the Tokio and Warwick Aquifers to Surface Contamination, Fort Totten Indian Reservation, North Dakota

Water-Resources Investigations Report 98-4152

U.S. Department of the Interior
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Bismarck, North Dakota
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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By Thomas B. Reed

Abstract

The vulnerability of ground water in the Tokio and Warwick aquifers to surface contamination was evaluated using existing hydrologic, climatic, geologic, topographic, and land-use/land-cover data and geographic information system procedures. The aquifers underlie parts of the Fort Totten Indian Reservation in northeastern North Dakota. The vulnerability was evaluated using vertical hydraulic leakance, depth to water, hydraulic conductivity, land use/land cover, land-surface slope, hydrologic sinks, and drainage basin areas. Data were discretized using a land-surface altitude grid divided into 50-foot-square cells. Vertical hydraulic leakance was determined by combining data from ring-permeameter and slug tests, land-use/land-cover data were obtained from data sets, and land-surface slope and hydrologic sinks were calculated from land-surface altitude data.

The vulnerability of ground water in the Tokio and Warwick aquifers to surface contamination is high in terms of land use/land cover and land-surface slope. The land surface of the Warwick aquifer also has numerous hydrologic sinks that result in areas of increased vulnerability of ground water to surface contamination.

Report Describes Vulnerability of Ground Water to Surface Contamination

The vulnerability of ground water to surface contamination depends on many factors.

To make informed decisions about ground-water protection, the Spirit Lake Sioux Nation needs information on the vulnerability of ground water to surface contamination from potential sources such as pesticides, gasoline spills, etc. Therefore, the U.S. Geological Survey, in cooperation with the Spirit Lake Sioux Nation, conducted a study to evaluate the vulnerability of ground water in the Tokio and Warwick aquifers, which underlie parts of the Fort Totten Indian Reservation in northeastern North Dakota (fig. 1.0-1), to surface contamination. Results will provide an improved understanding of the relation of various factors to vulnerability to contamination. Although contamination of ground water occurs in many ways, only transport by simple percolation, which excludes preferential flow paths such as cracks and holes, was considered in the study, and only those parts of the aquifers for which Bureau of Reclamation land-surface altitude and vertical hydraulic conductivity data are available were considered. This report describes the vulnerability of ground water in about half of the Tokio aquifer outcrop area and most of the Warwick aquifer on the Reservation.

The Tokio and Warwick aquifers are unconfined glacial aquifers. The Tokio aquifer, which is recognized surficially as about 30 square miles of collapsed outwash deposits, is composed of sand, gravel, till, and clay and averages about 32 feet thick (Randich, 1977). The extent of the Tokio aquifer as delineated by Paulson and Akin (1964) is shown in figure 1.0-1. The Warwick aquifer (fig. 1.0-1), which is recognized surficially as about 85 square miles of outwash, dune, and alluvial deposits located north of the Sheyenne River on the eastern end of the Reservation, is composed of sand and gravel and typically is 20 to 30 feet thick but thickens where the underlying bedrock is channelized (Reed, 1997). The aquifer is terminated on the south by the Sheyenne River Valley, which is incised about 60 feet lower than the outwash deposit. To the north and west, the aquifer generally is bordered by topographically higher end-moraine deposits, and, to the east, it is interrupted by deep coulees and ravines. Cretaceous Pierre Shale underlies the Warwick aquifer and is exposed in parts of the Sheyenne River Valley. The Pierre Shale was deeply incised by various glacial events and, therefore, provides a highly irregular basal surface for the overlying glacial deposits.

Existing hydrologic, climatic, geologic, topographic, and land-use/land-cover data were used to develop physical-factor data sets for the Tokio and Warwick aquifers. These data sets then were used to generate and compile spatially-distributed geographic information system (GIS) coverages (data bases) for selected factors. The vulnerability of ground water in the Tokio and Warwick aquifers to surface contamination was evaluated using the customized GIS coverages, ARC Macro Language (AML) programs within the GRID module of Arc/Info, and an index method in which specific physical factors that influence vulnerability are given an arbitrary numerical score called the contamination vulnerability rating. Analyses were done using a GRID raster data base, called a grid, for both aquifers. The grid was divided into 50-foot-square cells and had 1,313 rows and 2,715 columns. For this study, 15.4 square miles of the Tokio aquifer were examined, and 59.9 square miles of the Warwick aquifer were examined. Data were unavailable for the remaining area of each aquifer or the area was outside of the Reservation or covered by lakes, sloughs, and wetlands.

The vulnerability of ground water to surface contamination depends on many physical factors, including soil properties, hydraulic properties, climate, and land use, and on how a particular contaminant reacts chemically and biologically within the soil or aquifer material. Factors used in this study are vertical hydraulic leakance, depth to water, hydraulic conductivity, land use/land cover, land-surface slope, hydrologic sinks, and drainage basin areas. The coverages for factors used in this study are presented separately in terms of vulnerability, and then the coverage for vertical hydraulic leakance is presented in combination with coverages for land use/land cover, land-surface slope, and hydrologic sinks. The resultant combined coverages show areas of high vulnerability based on the two specified factors. For example, one resultant combined coverage shows the areas where vulnerability is high in terms of both vertical hydraulic leakance and hydrologic sinks.

Much uncertainty is associated with the methods used to evaluate vulnerability of ground water to surface contamination. The amount of data available, the spatial resolution of the mapping, the scale at which the study is conducted, and the scale used to show results are all parts of the uncertainty.

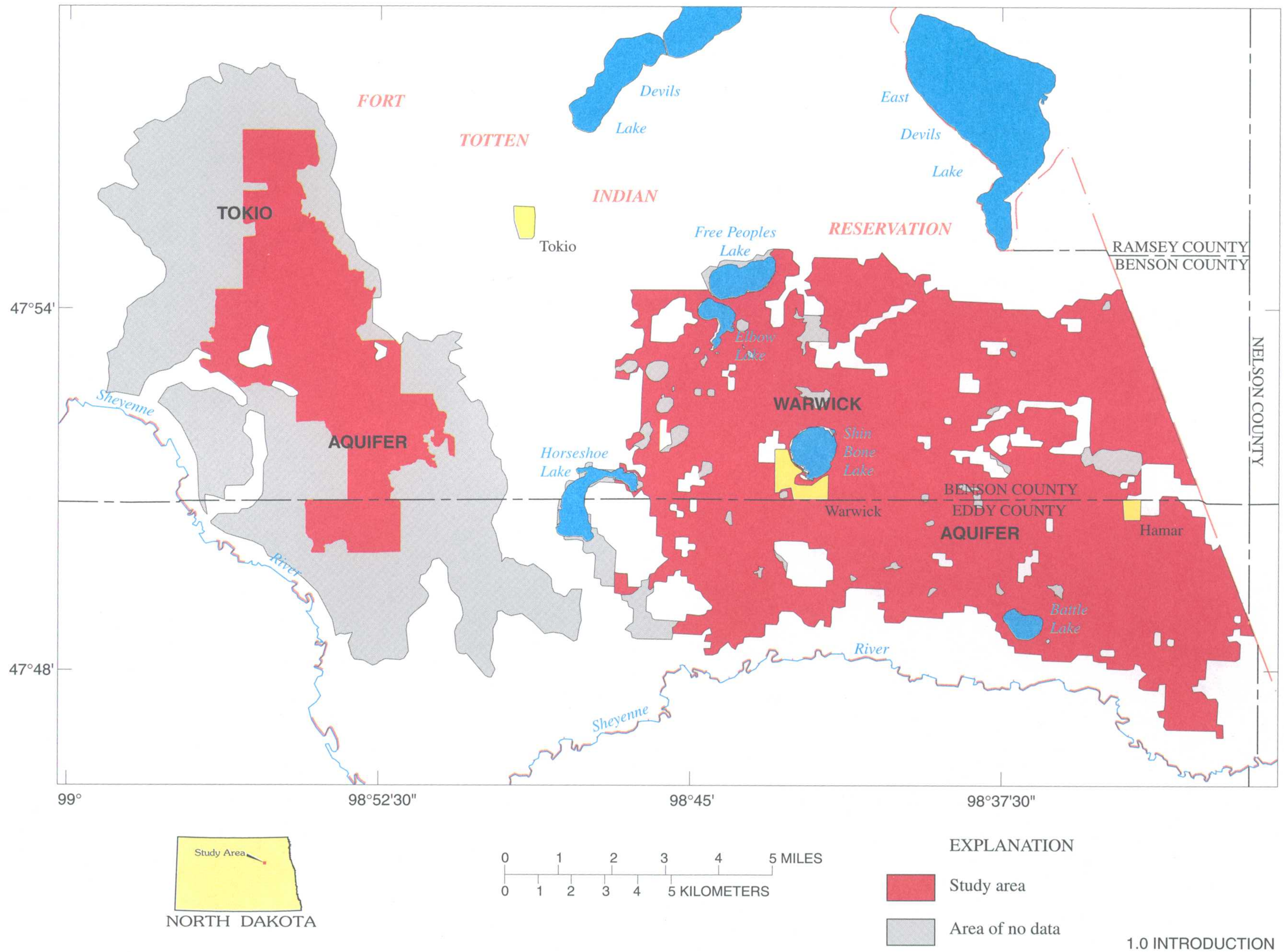


Figure 1.0-1 Location of study area.

Large Vertical Hydraulic Leakance Above an Aquifer Represents Increased Vulnerability of Ground Water to Surface Contamination

The southeast corner of the Warwick aquifer area has large vertical hydraulic leakance values.

Vertical hydraulic leakance provides a single, integrated value for the capacity of the entire sequence of earth materials that overlie the saturated zone to transmit water (with or without contaminants) from the land surface to the water table. Thus, leakance is a measure of the ease of fluid transmission, independent of the grid area chosen in the analysis, through the total vertical recharge path and a measure of the length of time the water and contaminants contained in the water spend in transit to the water table. This report considers vertical hydraulic leakance at saturated conditions within a saturated wetting front produced by a precipitation event but does not consider leakance at unsaturated conditions. Although vertical hydraulic leakance at saturated conditions is a reasonable index of relative vulnerability, leakance at unsaturated conditions may be more important in finer soils (W.M. Schuh, North Dakota State Water Commission, oral commun., 1997).

Vertical hydraulic leakance can be calculated using the equation

$$H = \frac{K_v}{L}$$

where

H is vertical hydraulic leakance, in day^{-1};

K_v is vertical hydraulic conductivity, in feet per day; and

L is the length of the vertical recharge path, in feet.

Knowledge of both the length of the vertical recharge path (the depth to water) and the hydraulic conductivity of the material between the land surface and the water table is needed to determine hydraulic leakance.

For this report, the vertical recharge path was divided into three layers to determine the equivalent vertical hydraulic leakance. Layer 1 consists of the top 6 inches of the soil profile, layer 2 consists of the soil profile below 6 inches, and layer 3 consists of the material between the bottom of the soil profile and the water table. Thus, the thickness of layer 1 is 6 inches, the thickness of layer 2 is the thickness of the soil profile minus 6 inches, and the thickness of layer 3 is the depth to water minus the thickness of the soil profile. The depth to water was calculated by subtracting water-level altitudes from land-surface altitudes. Water-level altitudes for the Tokio aquifer were derived from a multiple-regression method developed by O'Hara and Reed (1995) in which depth to water is related to land-surface altitude. Water-level altitudes for the Warwick aquifer were obtained from Reed (1997).

The vertical hydraulic conductivity of layer 1 was estimated from Bureau of Reclamation ring-permeameter data, the vertical hydraulic conductivity of layer 2 was estimated from Soil Conservation Service (now the Natural Resources Conservation Service) soil-map data, and the vertical hydraulic conductivity of layer 3 was estimated by multiplying the horizontal hydraulic conductivity estimated from Bureau of Reclamation slug-test data by the ratio of vertical to horizontal hydraulic conductivity. The vertical hydraulic conductivities for the three layers then were combined to determine the equivalent mean vertical hydraulic leakance using the following equation:

$$H_{eq} = \frac{1}{\frac{L_6}{K_6} + \frac{(L_{soil} - L_6)}{K_{soil}} + \frac{(L_{aq} - L_{soil})}{(K_{aq} r)}}$$

where

H_{eq} is the equivalent mean vertical hydraulic leakance of the material between the land surface and the water table, in day^{-1};

L_6 is the thickness of the top 6 inches of the soil profile, in feet;

L_{soil} is the thickness of the soil profile, in feet;

L_{aq} is the depth to water, in feet;

K_6 is the vertical hydraulic conductivity of the top 6 inches of the soil profile, in feet per day;

K_{soil} is the vertical hydraulic conductivity of the soil profile below 6 inches, in feet per day;

K_{aq} is the horizontal hydraulic conductivity of the material between the bottom of the soil profile and the water table, in feet per day; and

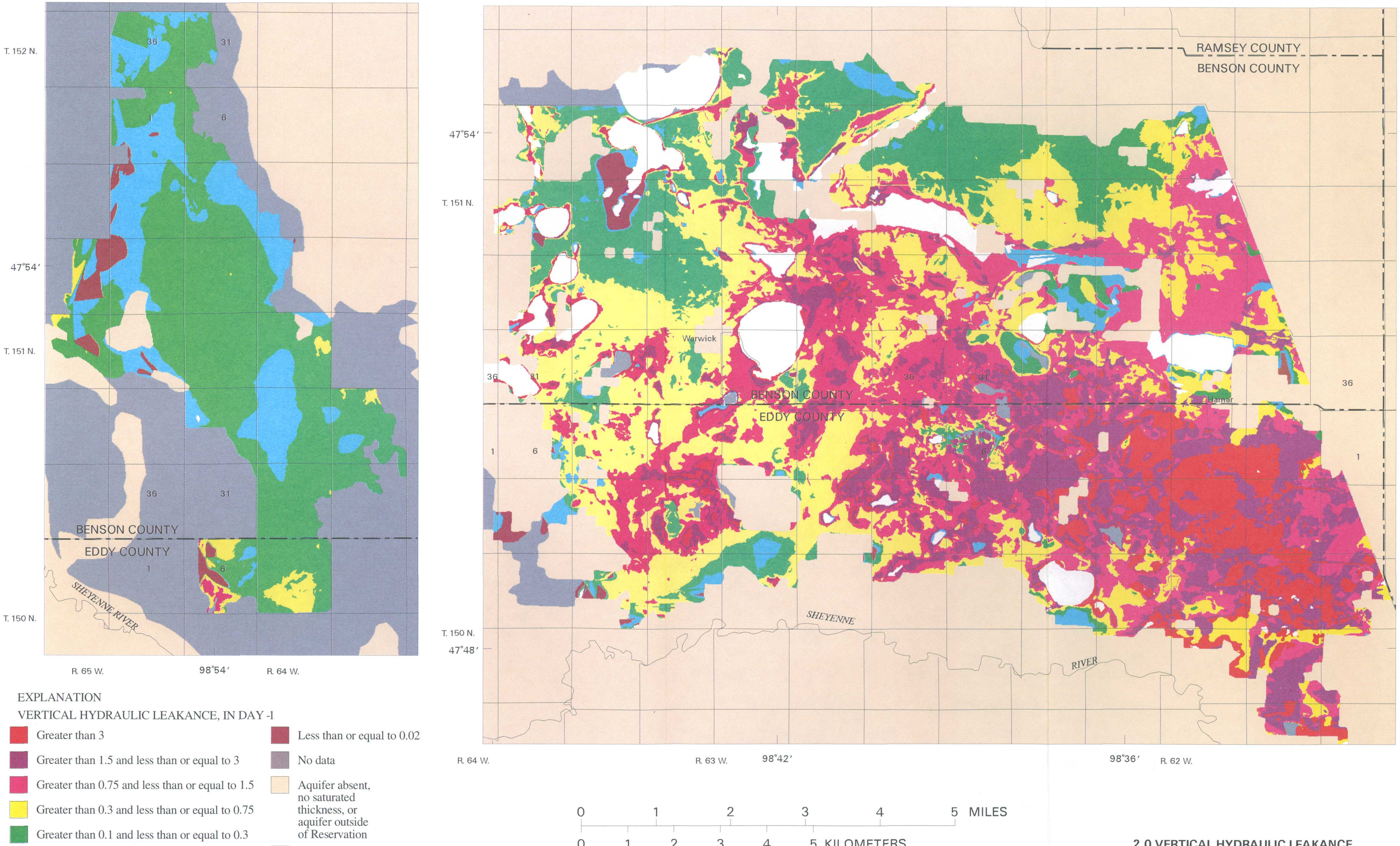
r is the ratio of vertical to horizontal hydraulic conductivity of the material between the bottom of the soil profile and the water table.

Bouwer (1978) reported a ratio of about 0.06 for sand and gravel layers of varying thicknesses and textures and a ratio of 0.05 to 0.5 for glacial-outwash aquifers in Wisconsin. For this study, a ratio of 0.1 was considered to be reasonable.

Contamination vulnerability ratings based on vertical hydraulic leakance are shown in the following table:

Vertical hydraulic leakance (day^{-1})	Contamination vulnerability rating
Less than or equal to 0.02	1
Greater than 0.02 and less than or equal to 0.1	2
Greater than 0.1 and less than or equal to 0.3	3
Greater than 0.3 and less than or equal to 0.75	4
Greater than 0.75 and less than or equal to 1.5	5
Greater than 1.5 and less than or equal to 3	6
Greater than 3	7

Vertical hydraulic leakance in the Tokio aquifer area (fig. 2.0-1) ranges from about 0.0007 to 2 day^{-1} and has a mean of about 0.15 day^{-1}. Vertical hydraulic leakance in the Warwick aquifer area (fig. 2.0-1) ranges from about 0.0002 to 7.6 day^{-1} and has a mean of about 1 day^{-1}. Based on vertical hydraulic leakance alone, the greatest contamination vulnerability is in the southeast corner of the Warwick aquifer area.



EXPLANATION

VERTICAL HYDRAULIC LEAKANCE, IN DAY -1

- Greater than 3
- Greater than 1.5 and less than or equal to 3
- Greater than 0.75 and less than or equal to 1.5
- Greater than 0.3 and less than or equal to 0.75
- Greater than 0.1 and less than or equal to 0.3
- Greater than 0.02 and less than or equal to 0.1
- Less than or equal to 0.02
- No data
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

Figure 2.0–1 Vertical hydraulic leakance.

Depth to Water was Used to Calculate Vertical Hydraulic Leakance for the Tokio and Warwick Aquifer Areas

Depth to water varies considerably across the Tokio and Warwick aquifer areas.

The depth to water in the Tokio aquifer (fig. 2.1-1) was estimated using a multiple-regression method developed by O'Hara and Reed (1995). Because too few water-level data were available for a specific time period, water-level altitudes for the Tokio aquifer were derived using the multiple-regression method. Water levels for 12 wells completed in the Tokio aquifer were measured at various times and used to relate depth to water to aquifer mean water-level altitude, land-surface altitude, and local mean water-level altitude, which is the mean for a rectangle of nine cells. This process yielded a multiple-regression equation that had a root-mean-squared error of 8.334 feet and an adjusted R-squared value of 0.7665. The multiple-regression equation was used with the land-surface altitude grid and the local mean water-level altitude grid to estimate the depth to water in the Tokio aquifer. The depth to water in the Tokio aquifer generally was greater than 30 feet except in areas along the western and southern margins.

The depth to water in the Warwick aquifer (fig. 2.1-1) was derived from ground-water level data for 54 observation wells measured by the U.S. Geological Survey in October 1992, land-surface altitude and surface-water level data obtained from U.S. Geological Survey topographic maps, and land-surface altitude data obtained from Bureau of Reclamation land-surface contours. The ground-water level data were hand contoured and interpolated into each grid cell, and the land-surface altitude data were used to establish upper limits for the October 1992 water-level altitudes (Reed, 1997). The October 1992 water-level altitudes then were subtracted from the land-surface altitudes to determine the depth to water in the Warwick aquifer. The depth to water was 10 feet or less in 70 percent of the aquifer and 5 feet or less in 41 percent of the aquifer (Reed, 1997).

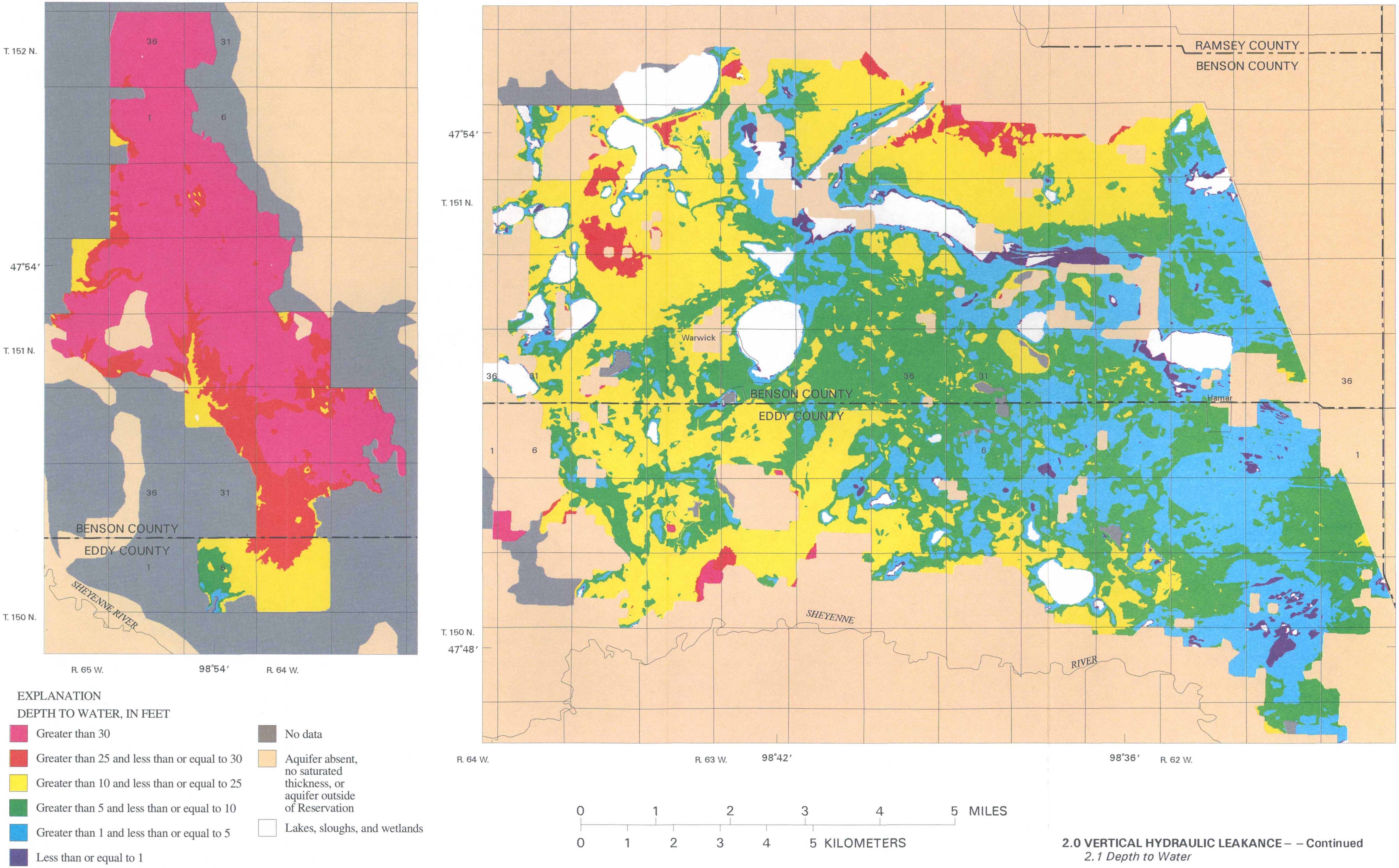


Figure 2.1–1 Depth to water.

Vertical Hydraulic Conductivity of Layer 1 was Used to Calculate Vertical Hydraulic Leakance for the Tokio and Warwick Aquifer Areas

Values were based on ring-permeameter data.

The vertical hydraulic conductivity of layer 1 (fig. 2.2-1) at saturated conditions was estimated from unpublished data for about 1,500 boreholes augered by the Bureau of Reclamation in the Tokio and Warwick aquifers. According to Arden Mathison (Bureau of Reclamation, oral commun., 1997), the top 6 inches of the soil profile was considered to be the least permeable part of the aquifer and, therefore, the most important part for the Bureau of Reclamation studies. Vertical hydraulic conductivity values for the top 6 inches of the soil profile at selected sites were determined by the Bureau of Reclamation using 18-inch ring permeameters. These values then were extrapolated to the other boreholes by using pedologic correlation (Reed, 1997). The vertical hydraulic conductivity data were combined with the spatial locations of the boreholes to produce a spatially-distributed grid of vertical hydraulic conductivity. The vertical hydraulic conductivity of layer 1 in the Tokio aquifer area ranges from essentially zero to 3.28 feet per day and has a mean of about 1 foot per day. The vertical hydraulic conductivity of layer 1 in the Warwick aquifer area ranges from essentially zero to 10.98 feet per day and has a mean of about 4 feet per day.

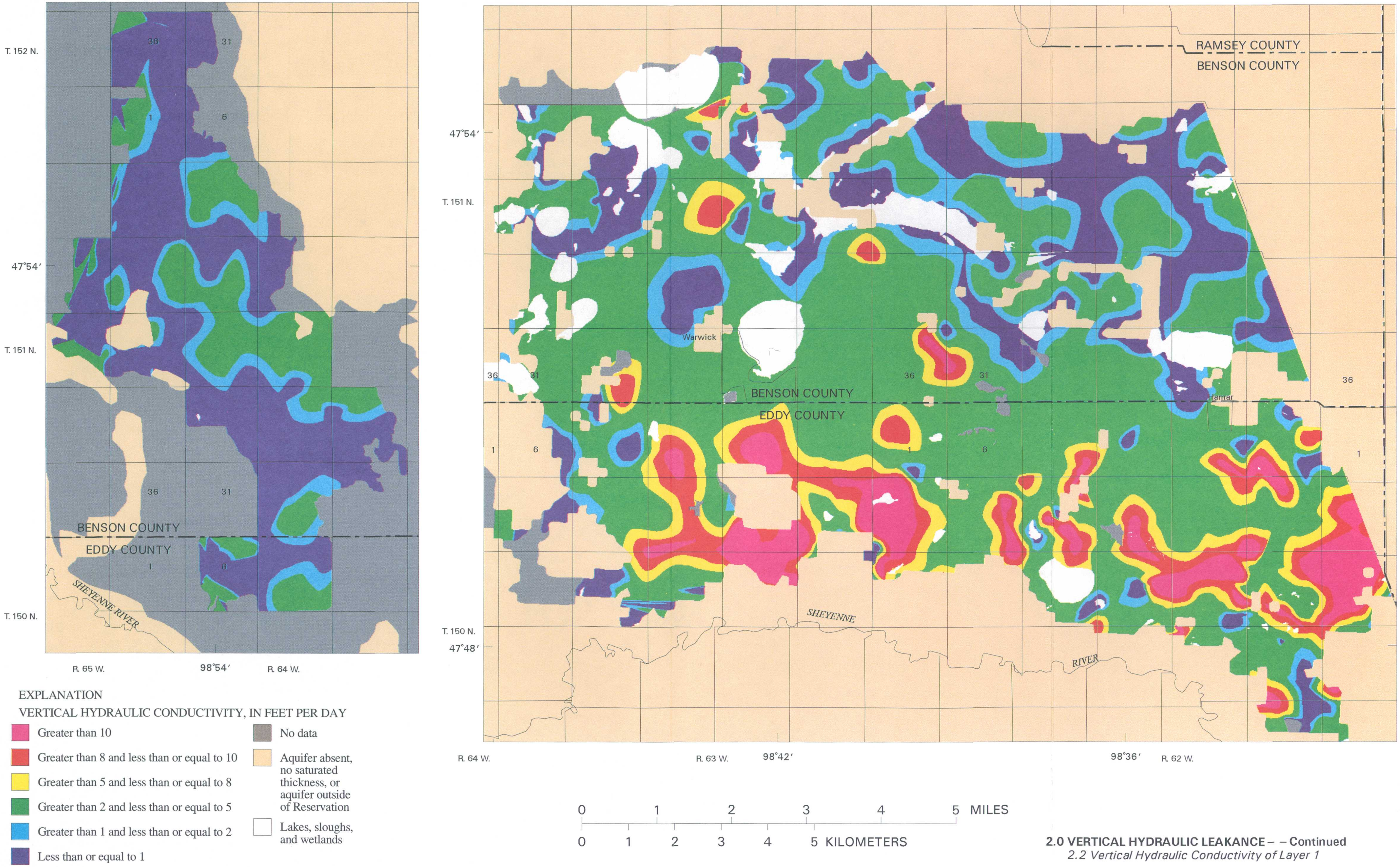
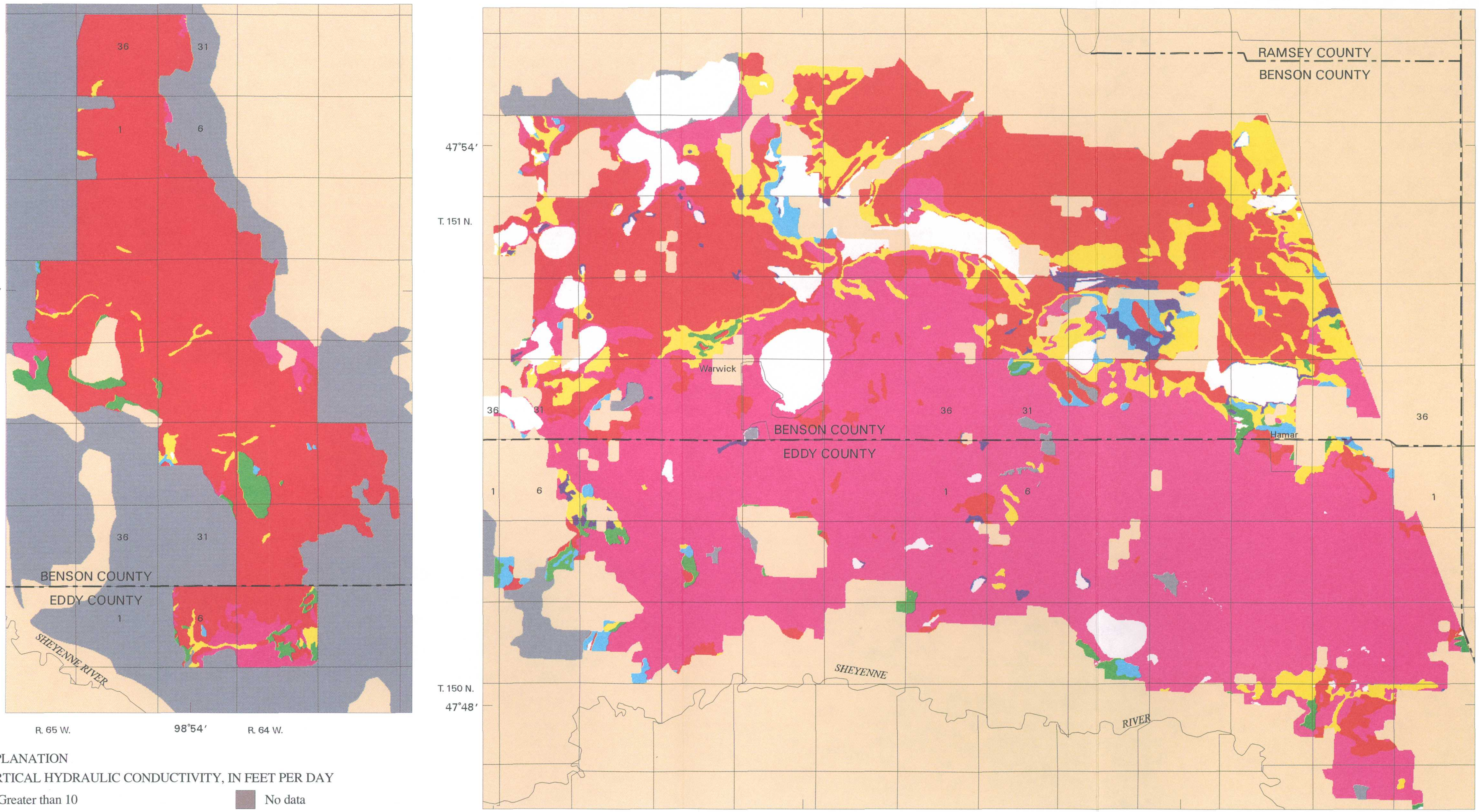


Figure 2.2–1 Vertical hydraulic conductivity of layer 1.

Vertical Hydraulic Conductivity of Layer 2 was Used to Calculate Vertical Hydraulic Leakance for the Tokio and Warwick Aquifer Areas

Values were based on soil-map data.

The vertical hydraulic conductivity of layer 2 (fig. 2.3-1) at saturated conditions was estimated from soil-map data given in Wright and Sweeney (1977) and Strum and others (1979). The soil maps, which delineate map units that represent specific soil profiles and slopes, generally were at a 1:24,000 scale and were hand digitized to create a GIS grid for this study. The total soil-profile thickness and area-weighted harmonic mean vertical hydraulic conductivity was calculated for each soil-map unit using the procedure developed by O'Hara (1994). The vertical hydraulic conductivity of layer 2 in the Tokio aquifer area ranges from 0.56 to 24.92 feet per day and has a mean of about 7.3 feet per day. The vertical hydraulic conductivity of layer 2 in the Warwick aquifer area ranges from 0.28 to 21.9 feet per day and has a mean of about 12 feet per day.



EXPLANATION

VERTICAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

- Greater than 10
- Greater than 5 and less than or equal to 10
- Greater than 3 and less than or equal to 5
- Greater than 2 and less than or equal to 3
- Greater than 0.5 and less than or equal to 2
- Less than or equal to 0.5
- No data
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

0 1 2 3 4 5 MILES

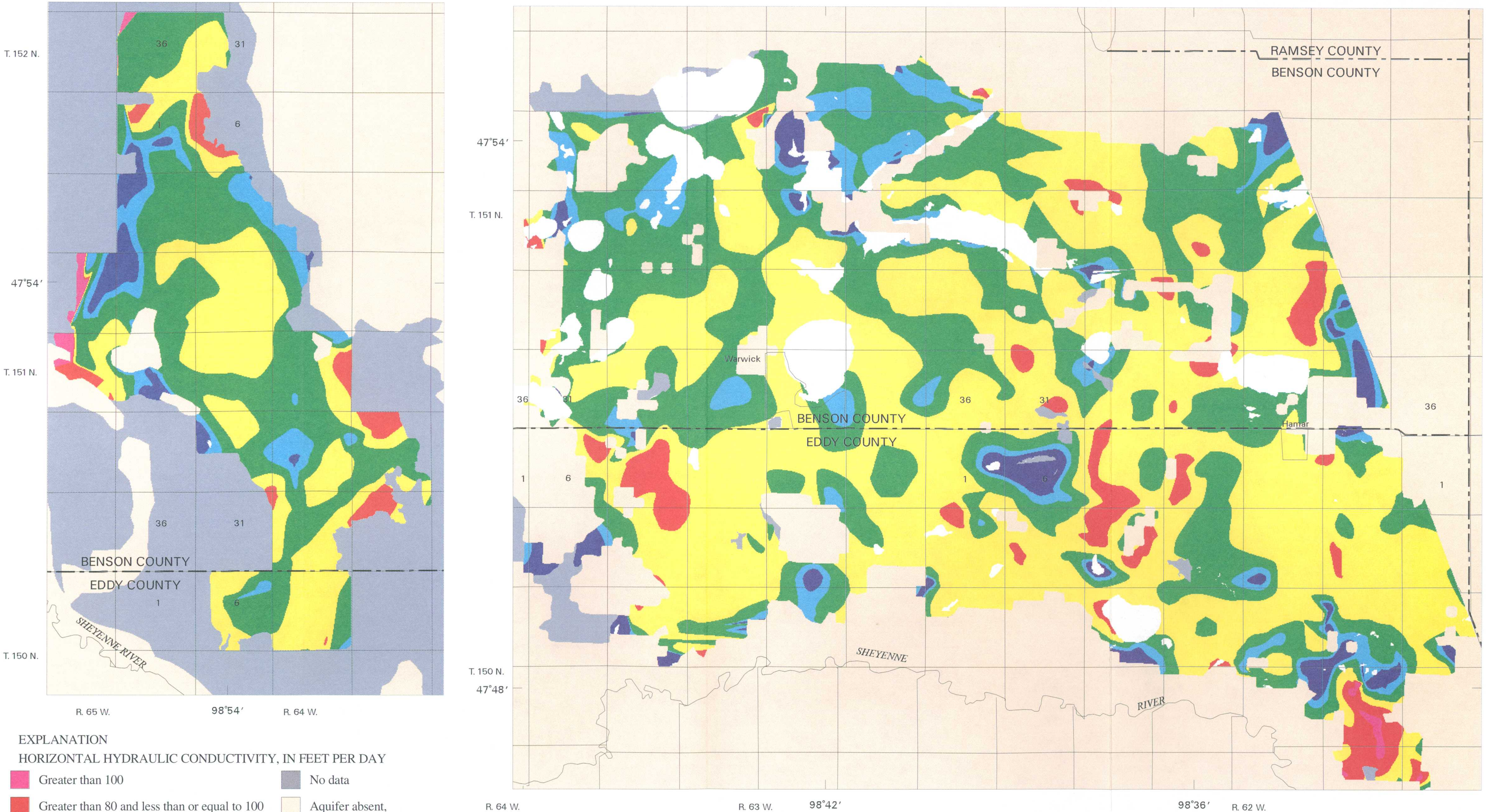
0 1 2 3 4 5 KILOMETERS

Figure 2.3–1 Vertical hydraulic conductivity of layer 2.

Horizontal Hydraulic Conductivity of Layer 3 was Used to Calculate Vertical Hydraulic Leakance for the Tokio and Warwick Aquifer Areas

Values were based on slug-test data.

The horizontal hydraulic conductivity of layer 3 (fig. 2.4-1) at saturated conditions was estimated from unpublished data for about 1,500 boreholes augered by the Bureau of Reclamation in the Tokio and Warwick aquifers. The boreholes were augered to a maximum depth of 30 feet or to the first occurrence of clay or till. Horizontal hydraulic conductivity values for selected sites were determined by slug tests and then were extrapolated to the other boreholes by using pedologic correlation (Reed, 1997). The horizontal hydraulic conductivity data were combined with the spatial locations of the boreholes to produce a spatially-distributed grid of horizontal hydraulic conductivity. The horizontal hydraulic conductivity of layer 3 in the Tokio aquifer area ranges from 0.637 to 106.1 feet per day and has a mean of about 45.8 feet per day. The horizontal hydraulic conductivity of layer 3 in the Warwick aquifer area ranges from 0.016 to 108.8 feet per day and has a mean of about 50 feet per day.



EXPLANATION

HORIZONTAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

- Greater than 100
- Greater than 80 and less than or equal to 100
- Greater than 50 and less than or equal to 80
- Greater than 20 and less than or equal to 50
- Greater than 10 and less than or equal to 20
- Less than or equal to 10
- No data
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

Figure 2.4–1 Horizontal hydraulic conductivity of layer 3.

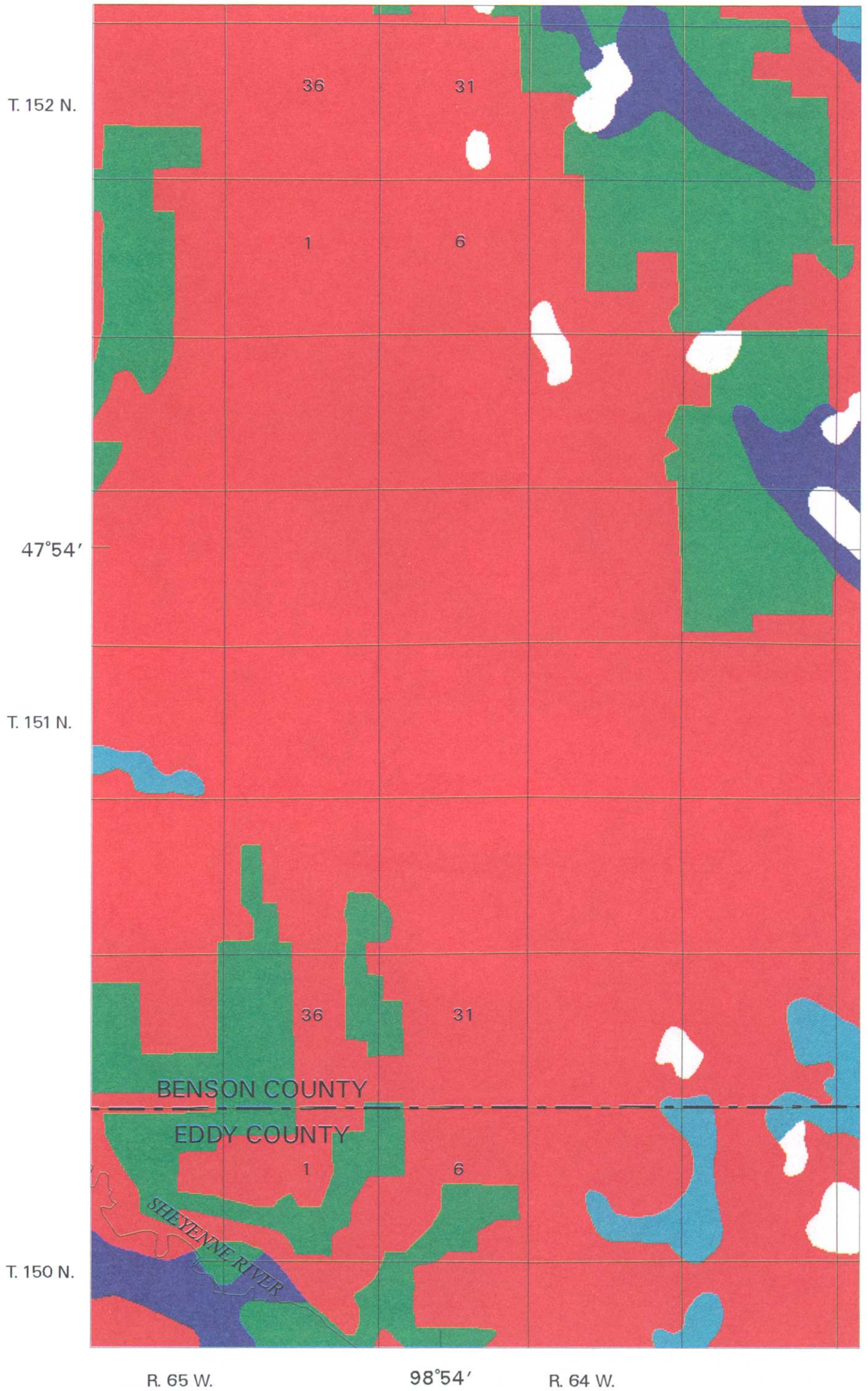
Land Use/Land Cover Affects Vulnerability of Ground Water to Surface Contamination

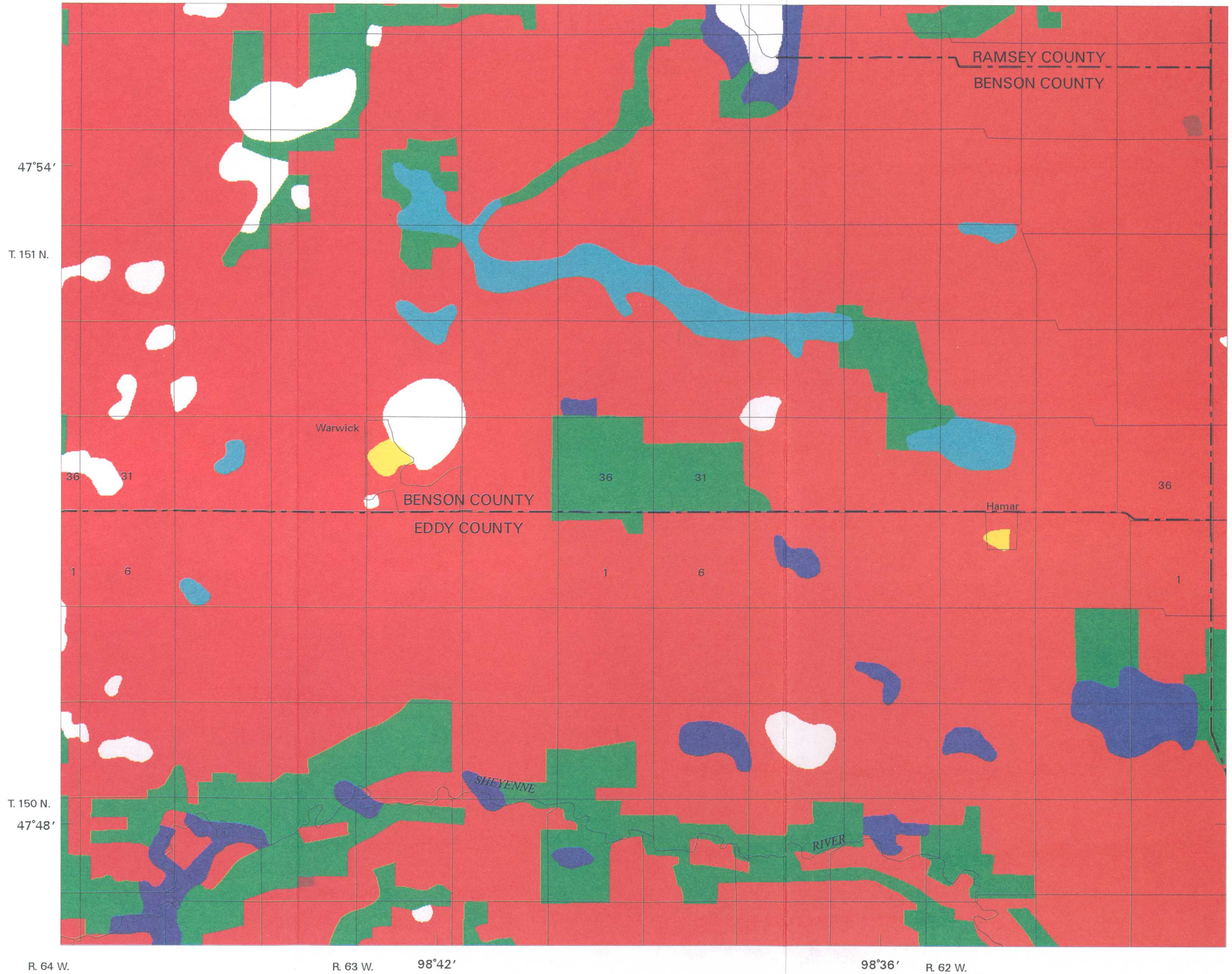
Cropland and pasture is the major type of land use/land cover in the Tokio and Warwick aquifer areas.

The type of land use/land cover affects the infiltration and/or generation of potential contaminants. Contamination vulnerability ratings were developed by Moreland and O'Hara (1994, sheet 1) on the basis of the effect of land use/land cover on runoff, the relative contamination risk from local human and natural activities, and the local hydrologic properties. Whenever possible, documented relations between contamination and land-use practices were used to modify the contamination vulnerability ratings. Rangeland was not included in the study by Moreland and O'Hara (1994) but, in this study, was assigned a contamination vulnerability rating of 5, midway between the rating for residential land and the rating for deciduous forest land. The contamination vulnerability rating for residential land, which has major sources of contamination such as septic tanks, sanitary sewers, and lawn fertilizers, probably is larger than that for rangeland. However, the contamination vulnerability rating for rangeland, which is used to graze livestock, with attendant animal waste, probably is larger than that for deciduous forest land. The contamination vulnerability ratings given by Moreland and O'Hara (1994, sheet 1, table 3) for the types of land use/land cover in the study area are given in the following table along with the contamination vulnerability rating for rangeland:

Type of land use/land cover	Contamination vulnerability rating
Cropland and pasture	10
Lakes	8
Residential land	6
Rangeland	5
Nonforested wetlands	5
Deciduous forest land	4

The coverage for land use/land cover was developed from Geographic Information Retrieval and Analysis System (GIRAS) data sets that generally are compiled at a scale of 1:250,000 (U.S. Geological Survey, 1987). The data sets are based on the land-use/land-cover classification system developed by Anderson and others (1976). The types of land use/land cover in the study area include cropland and pasture, lakes, residential land, rangeland, nonforested wetlands, and deciduous forest land. The areal distribution of the six types of land use/land cover is shown in figure 3.0-1. The predominate type of land use/land cover for both aquifer areas was cropland and pasture. The contamination vulnerability rating for the Tokio aquifer area ranges from 5 to 10, and the contamination vulnerability rating for the Warwick aquifer area ranges from 4 to 10.





EXPLANATION

- Cropland and pasture (contamination vulnerability rating is 10)
- Lakes (contamination vulnerability rating is 8)
- Residential land (contamination vulnerability rating is 6)
- Rangeland (contamination vulnerability rating is 5)
- Nonforested wetlands (contamination vulnerability rating is 5)
- Deciduous forest land (contamination vulnerability rating is 4)

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

3.0 LAND USE/LAND COVER

Figure 3.0–1 Land use/land cover.

Small Land-Surface Slopes Represent Areas of Increased Vulnerability of Ground Water to Surface Contamination

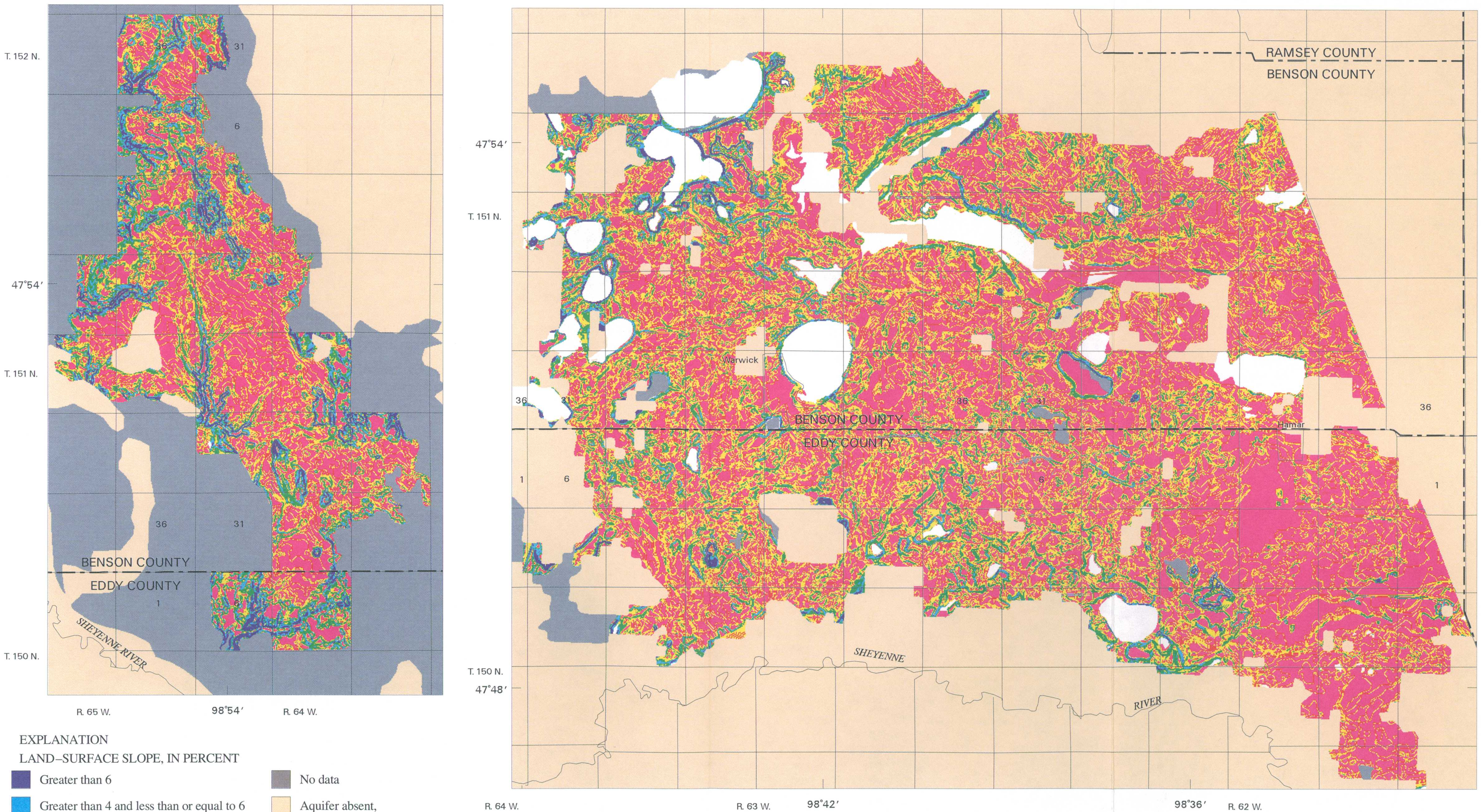
Most land-surface slopes are small in the Tokio and Warwick aquifer areas.

Land-surface slope affects the vulnerability of ground water to surface contamination. Areas that have small slopes have little runoff and large infiltration rates, and areas that have large slopes have much runoff and small infiltration rates. Therefore, areas that have small slopes should have larger contamination vulnerability ratings than areas that have large slopes.

To determine land-surface slope in the study area, a land-surface altitude grid was interpolated into 50-foot-square cells from 1-foot land-surface contours developed by the Bureau of Reclamation. The land-surface altitude grid then was used with GIS procedures to produce a land-surface slope grid. The land-surface slope produced by this process is shown in figure 4.0-1. The contamination vulnerability ratings given by O'Hara (1996, sheet 2) for land-surface slopes are given in the following table:

Land-surface slope (percent)	Contamination vulnerability rating
Less than or equal to 2	10
Greater than 2 and less than or equal to 6	9
Greater than 6 and less than or equal to 12	5
Greater than 12 and less than or equal to 18	3
Greater than 18	3

The land-surface slope for the Tokio aquifer area ranges from zero to about 30 percent and has a mean of about 2 percent. The land-surface slope for the Warwick aquifer area ranges from zero to about 58 percent and has a mean of about 1.1 percent. Because land overlying the Tokio and Warwick aquifers has a small (generally less than 2 percent) land-surface slope, the contamination vulnerability rating for most of the area is 10.



EXPLANATION

LAND–SURFACE SLOPE, IN PERCENT

- Greater than 6
- Greater than 4 and less than or equal to 6
- Greater than 2 and less than or equal to 4
- Greater than 1 and less than or equal to 2
- Greater than 0.5 and less than or equal to 1
- Less than or equal to 0.5
- No data
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

4.0 LAND – SURFACE SLOPE

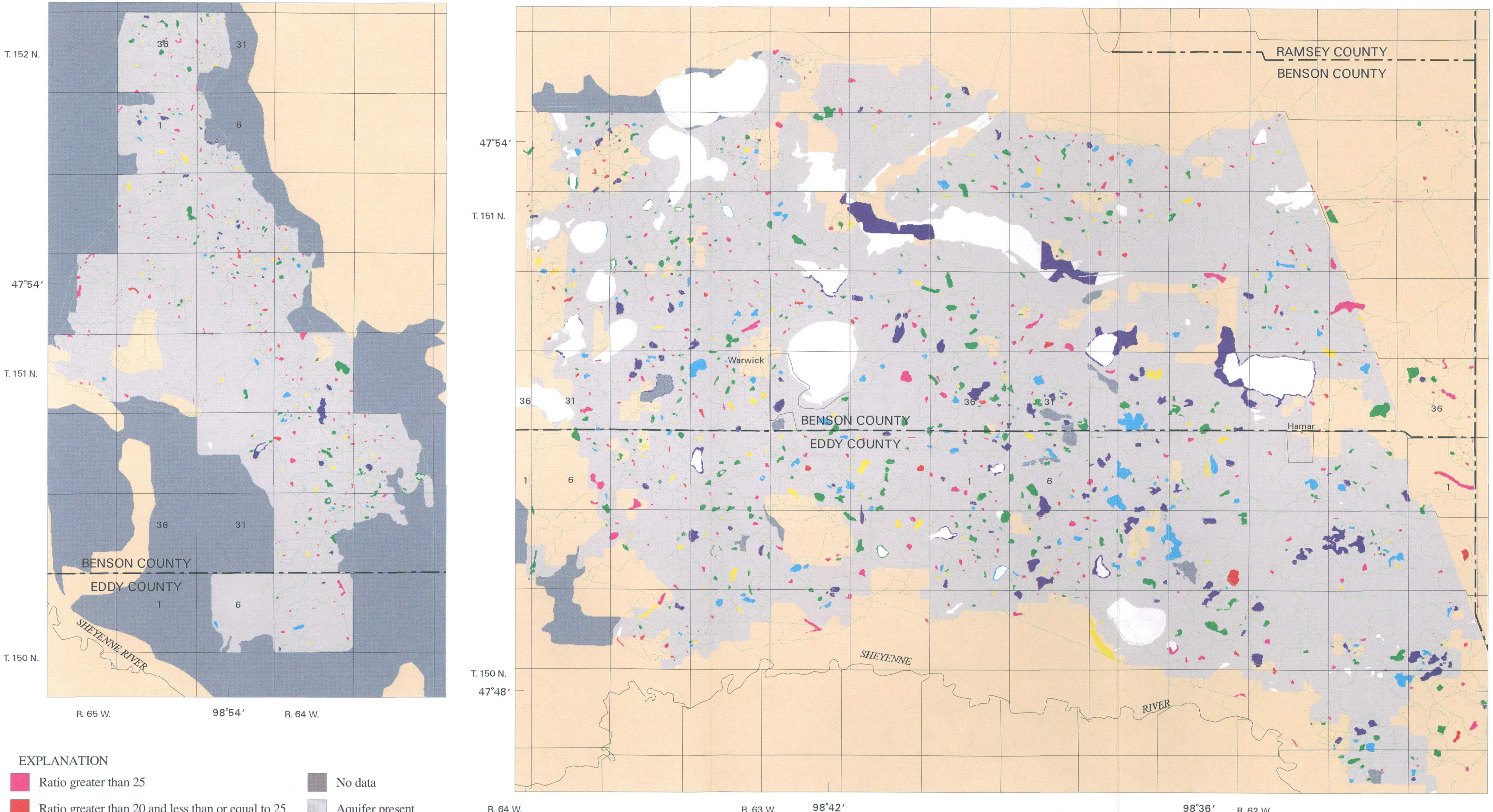
Figure 4.0–1 Land-surface slope.

Enclosed Hydrologic Sinks Represent Areas of Increased Vulnerability of Ground Water to Surface Contamination

Vulnerability also is affected by the area that contributes runoff to hydrologic sinks.

Runoff from precipitation naturally drains from higher to lower land-surface altitudes. In most areas of the world, surface erosion caused by runoff has created a network of streams through which water naturally flows downgradient to sea level, transporting part of the potential contaminants away from that area. In many glacial terrains such as the Warwick aquifer area, the network of streams has not developed. Therefore, the land surface has numerous closed drainage basins, and runoff drains into localized hydrologic sinks or depressions. Depending on the amount of precipitation and the depth of the drainage basin, surface-water runoff and potential contaminants that drain into the hydrologic sinks may be unable to leave through surface flow except during large precipitation events when sinks can fill and overflow. Therefore, hydrologic sinks on the land surface represent areas of increased vulnerability of ground water to surface contamination.

The vulnerability of ground water to surface contamination also is affected by the volume of surface-water runoff that drains into the hydrologic sinks. The larger the drainage basin area, the larger the volume of surface-water runoff and the larger the chance of potential contaminants outside of a hydrologic sink draining into the hydrologic sink and then infiltrating into the ground water. The increase in volume causes an increase in the movement of water downward to the water table; thus, potential contaminants within the drainage basin have a greater potential of being transported to the water table. The ratio of the drainage basin area to the corresponding hydrologic sink (fig. 5.0-1) is a relative measure of the vulnerability of ground water to surface contamination. A large ratio indicates more surface-water runoff per unit area of hydrologic sink, and less vulnerability to contamination, than a small ratio. The ratio for the Tokio aquifer area ranges from 2.67 to 3,217 and has a mean of about 28.9. The ratio for the Warwick aquifer area ranges from 1.85 to 675 and has a mean of about 14.3. Lakes in the Warwick aquifer area were not evaluated as hydrologic sinks because the connection between the aquifer and the lake can vary substantially among lakes.



EXPLANATION

- Ratio greater than 25
- Ratio greater than 20 and less than or equal to 25
- Ratio greater than 15 and less than or equal to 20
- Ratio greater than 7.5 and less than or equal to 15
- Ratio greater than 5 and less than or equal to 7.5
- Ratio less than or equal to 5
- No data
- Aquifer present on Reservation
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands
- Boundary of drainage basin area

0 1 2 3 4 5 MILES

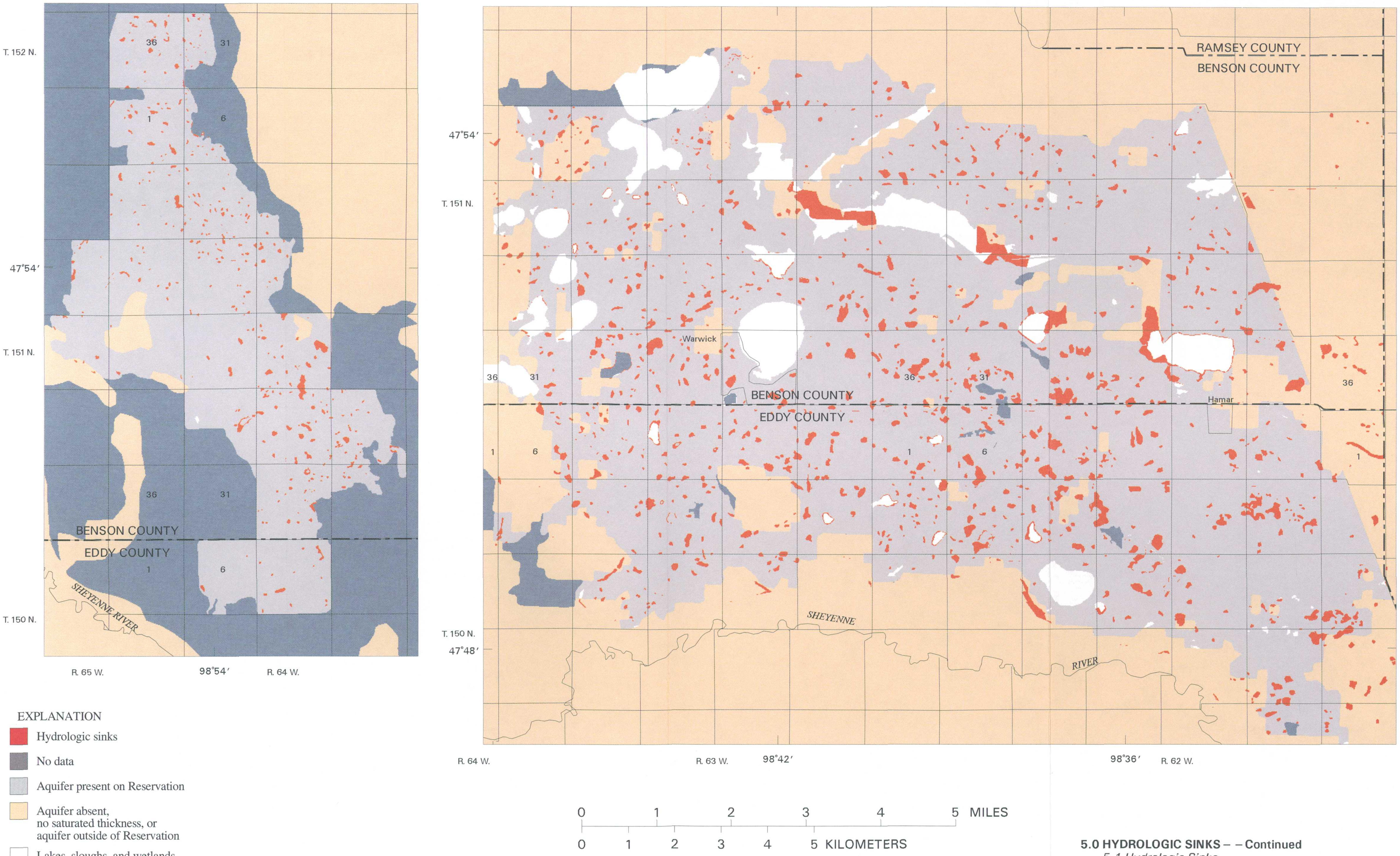
0 1 2 3 4 5 KILOMETERS

Figure 5.0–1 Ratio of drainage basin area to corresponding hydrologic sink.

Hydrologic Sinks were Determined Using Geographic Information System Procedures

Areas were defined based on land-surface altitude data.

GIS procedures were used with land-surface altitude data to locate hydrologic sinks. A land-surface altitude grid was interpolated into 50-foot-square cells from 1-foot land-surface contours developed by the Bureau of Reclamation. The land-surface altitude grid then was used with GIS procedures to produce a grid showing the flow direction of fluid applied at the surface of each cell. The flow direction was calculated for each cell by simulating the flow of surface-water runoff downslope until the land-surface slope was so small that the flow direction could no longer be calculated. The areas where flow direction could no longer be calculated are hydrologic sinks and are shown in figure 5.1-1. The hydrologic sinks for the Tokio aquifer area encompass 0.447 square mile, about 2.9 percent of the aquifer area examined in this study. The hydrologic sinks for the Warwick aquifer area encompass 4.228 square miles, about 7.1 percent of the aquifer area examined in this study.



EXPLANATION

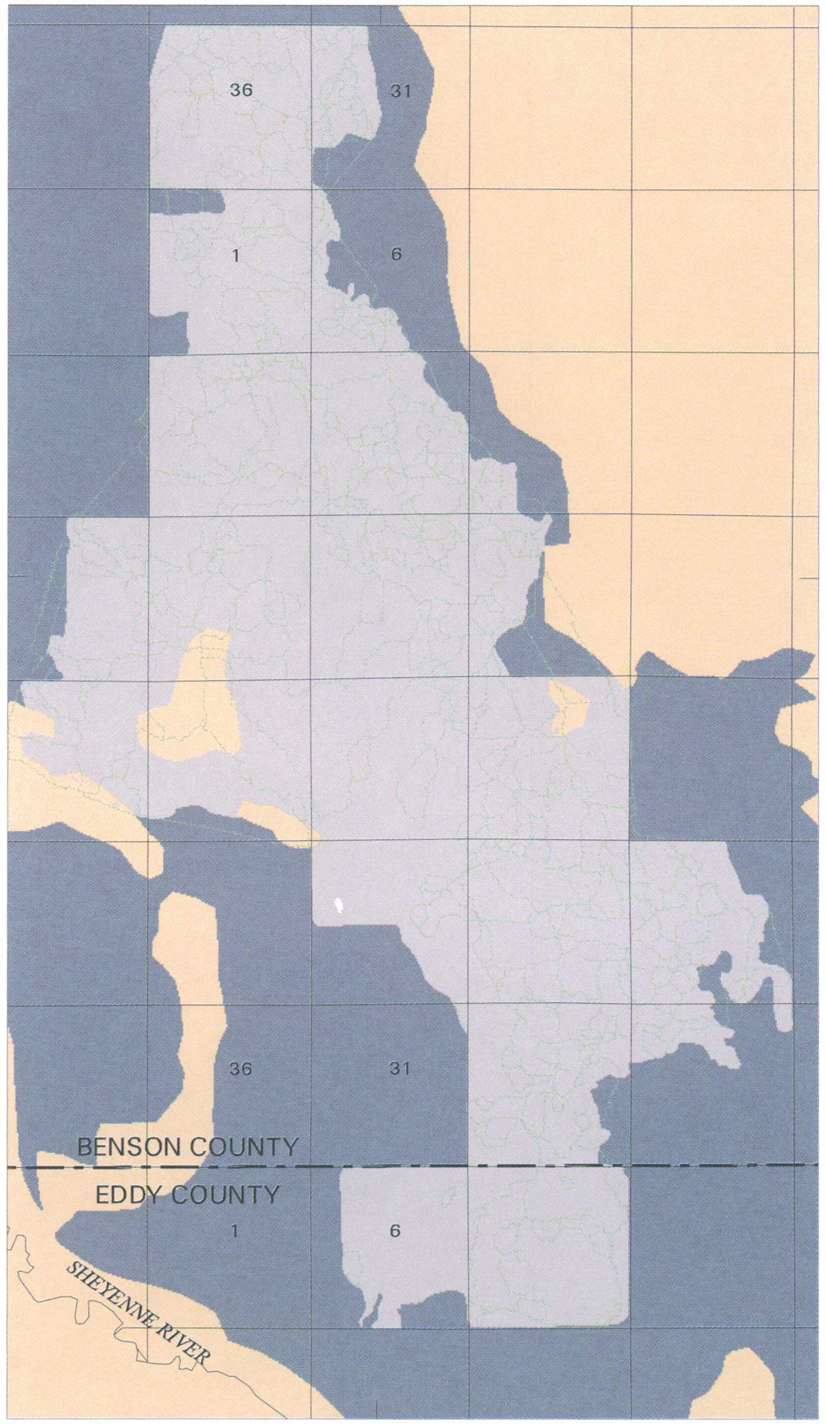
- Hydrologic sinks
- No data
- Aquifer present on Reservation
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

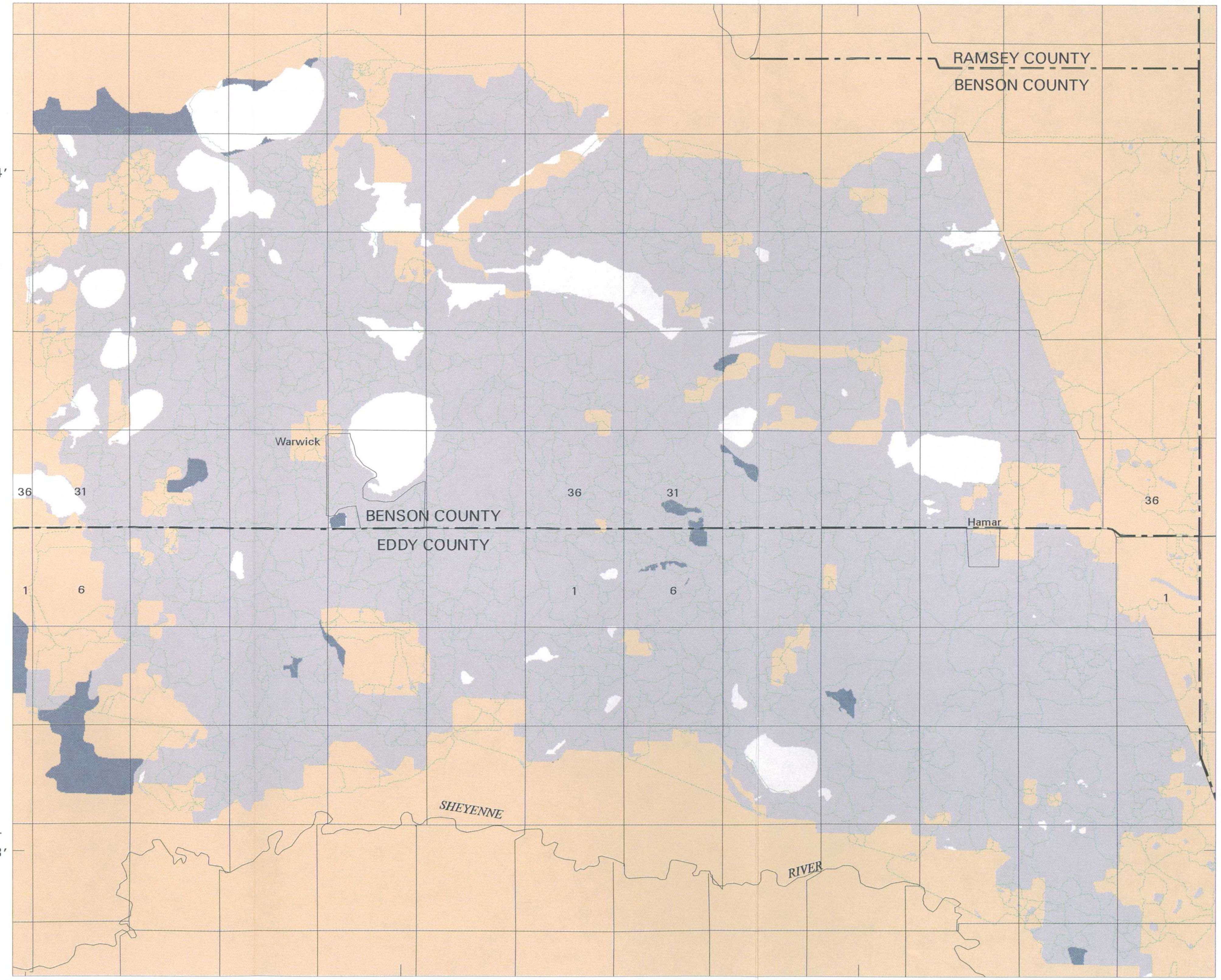
Figure 5.1–1 Hydrologic sinks.

Drainage Basin Areas were Determined Using Geographic Information System Procedures

Areas were defined based on land-surface altitude data.

GIS procedures were used with land-surface altitude data to locate hydrologic sinks. The hydrologic sinks then were used to delineate the drainage basin area associated with each hydrologic sink. Grid cells from which fluid would flow into a hydrologic sink represented the contributing drainage area and, thus, the drainage basin area for a hydrologic sink. The drainage basin areas corresponding to the hydrologic sinks are shown in figure 5.2-1. The Tokio aquifer is overlain by 393 drainage basins that are as large as 0.6 square mile in area and have a mean area of 0.035 square mile. The Warwick aquifer is overlain by 1,216 drainage basins that are as large as 3.6 square miles in area and have a mean area of 0.067 square mile.





EXPLANATION

- No data
- Aquifer present on Reservation
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands
- Boundary of drainage basin area

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

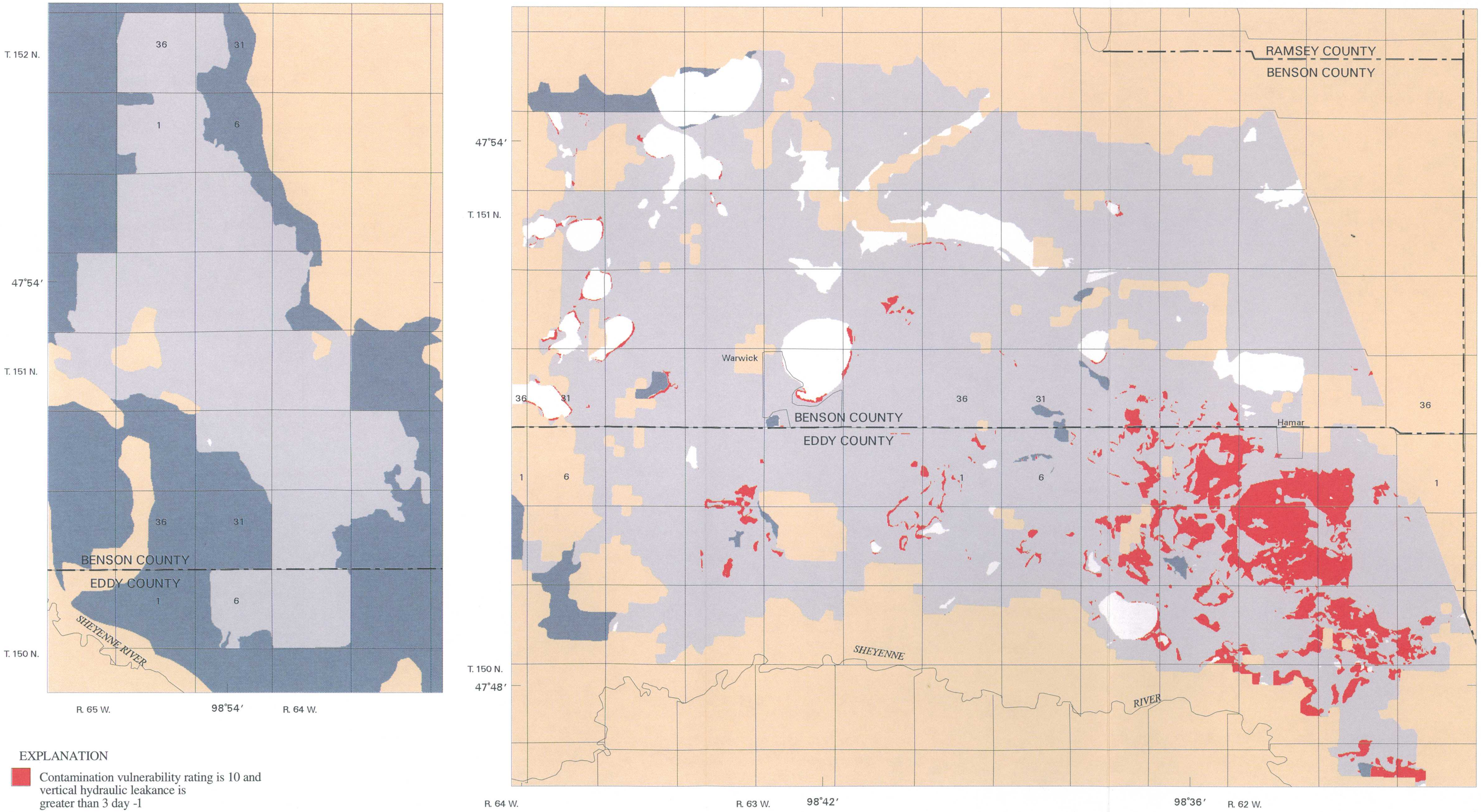
Figure 5.2–1 Drainage basin areas corresponding to hydrologic sinks.

6.0 MOST VULNERABLE AREAS BASED ON LAND USE/LAND COVER AND VERTICAL HYDRAULIC LEAKANCE

Land Use/Land Cover and Vertical Hydraulic Leakance are Important Factors in Evaluating the Vulnerability of Ground Water to Surface Contamination

Areas of high vulnerability were determined from land use/land cover and vertical hydraulic leakance.

Land use/land cover and vertical hydraulic leakance are important factors in evaluating the vulnerability of ground water to surface contamination. Therefore, a combination of these factors was considered in evaluating the vulnerability of ground water in the Tokio and Warwick aquifers to surface contamination. Areas in which the land-use/land-cover contamination vulnerability rating is 10 and the vertical hydraulic leakance is greater than 3 day^{-1} are shown in figure 6.0-1. Although most of the Tokio aquifer area has a land-use/land-cover contamination vulnerability rating of 10 (fig. 3.0-1), vertical hydraulic leakance for the aquifer area is less than or equal to 3 day^{-1} (fig. 2.0-1). Thus, the Tokio aquifer does not meet the combination of factors used in evaluating the vulnerability of ground water to surface contamination. The area of the Warwick aquifer that meets the combination of factors is 4.853 square miles. Because most of the study area is overlain by cropland and pasture and, thus, has a contamination vulnerability rating of 10, the areas delineated in figure 6.0-1 are about the same as those delineated separately for vertical hydraulic leakance (fig. 2.0-1).



EXPLANATION

- Contamination vulnerability rating is 10 and vertical hydraulic leakance is greater than 3 day -1
- No data
- Aquifer present on Reservation
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lake, sloughs, and wetlands

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

Figure 6.0–1 Land use/land cover and vertical hydraulic leakance.

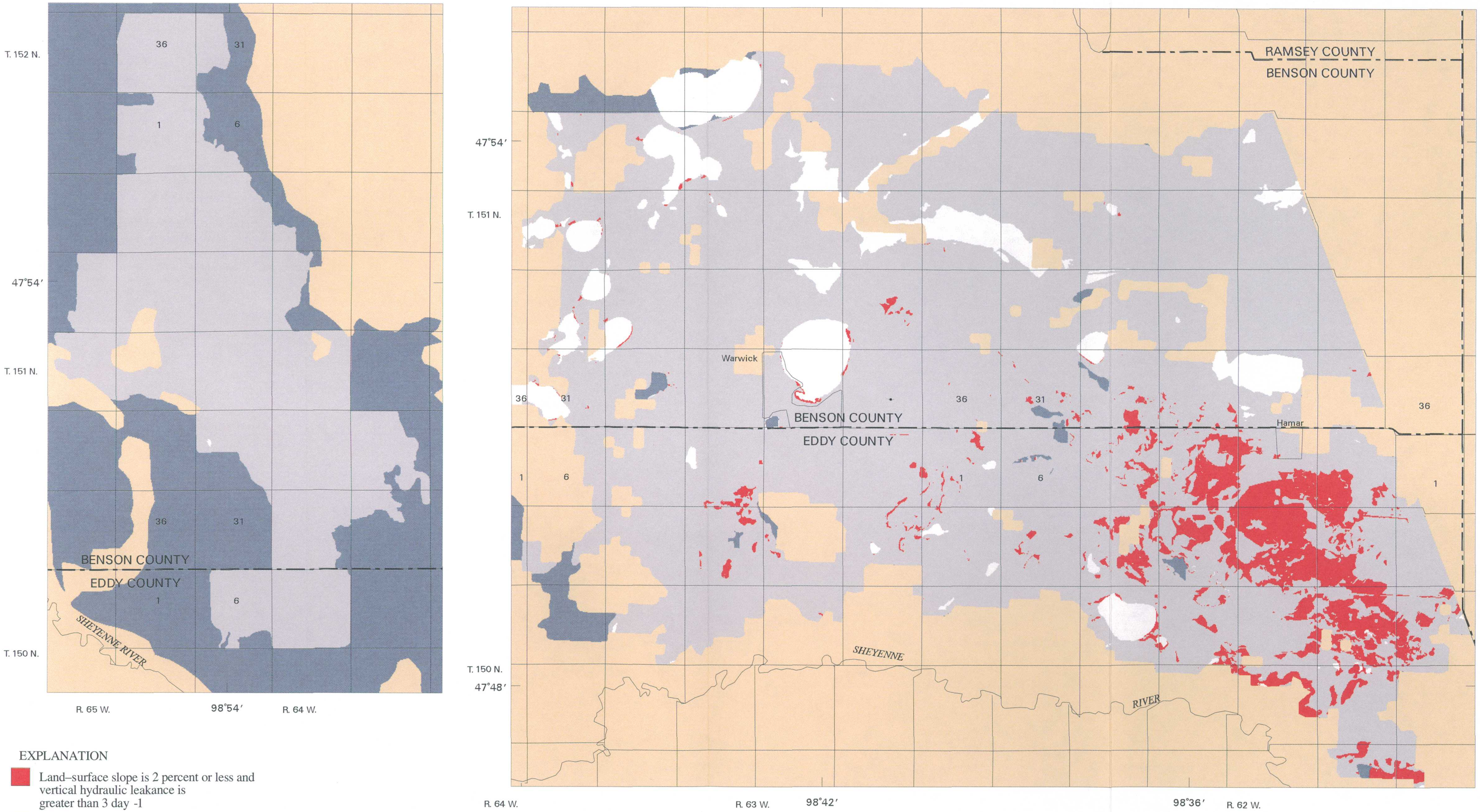
6.0 MOST VULNERABLE AREAS BASED ON LAND USE/LAND COVER AND VERTICAL HYDRAULIC LEAKANCE

7.0 MOST VULNERABLE AREAS BASED ON LAND-SURFACE SLOPE AND VERTICAL HYDRAULIC LEAKANCE

Land-Surface Slope and Vertical Hydraulic Leakance are Important Factors in Evaluating the Vulnerability of Ground Water to Surface Contamination

Areas of high vulnerability were determined from land-surface slope and vertical hydraulic leakance.

Land-surface slope and vertical hydraulic leakance are important factors in evaluating the vulnerability of ground water to surface contamination. Therefore, a combination of these factors was considered in evaluating the vulnerability of ground water in the Tokio and Warwick aquifers to surface contamination. Areas in which the land-surface slope is 2 percent or less and the vertical hydraulic leakance is greater than 3 day^{-1} are shown in figure 7.0-1. Although the Tokio aquifer area sometimes has a land-surface slope less than 2 percent (fig. 4.0-1), vertical hydraulic leakance for the aquifer area is less than or equal to 3 day^{-1} (fig. 2.0-1). Thus, the Tokio aquifer does not meet the combination of factors used in evaluating the vulnerability of ground water to surface water. The area of the Warwick aquifer that meets the combination of factors is 4.956 square miles. Because most of the study area has a small land-surface slope and, thus, a contamination vulnerability rating of 10, the areas delineated in figure 7.0-1 are about the same as those delineated separately for vertical hydraulic leakance (fig. 2.0-1).



EXPLANATION

- Land–surface slope is 2 percent or less and vertical hydraulic leakance is greater than 3 day -1
- No data
- Aquifer present on Reservation
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

7.0 MOST VULNERABLE AREAS BASED ON LAND – SURFACE SLOPE AND VERTICAL HYDRAULIC LEAKANCE

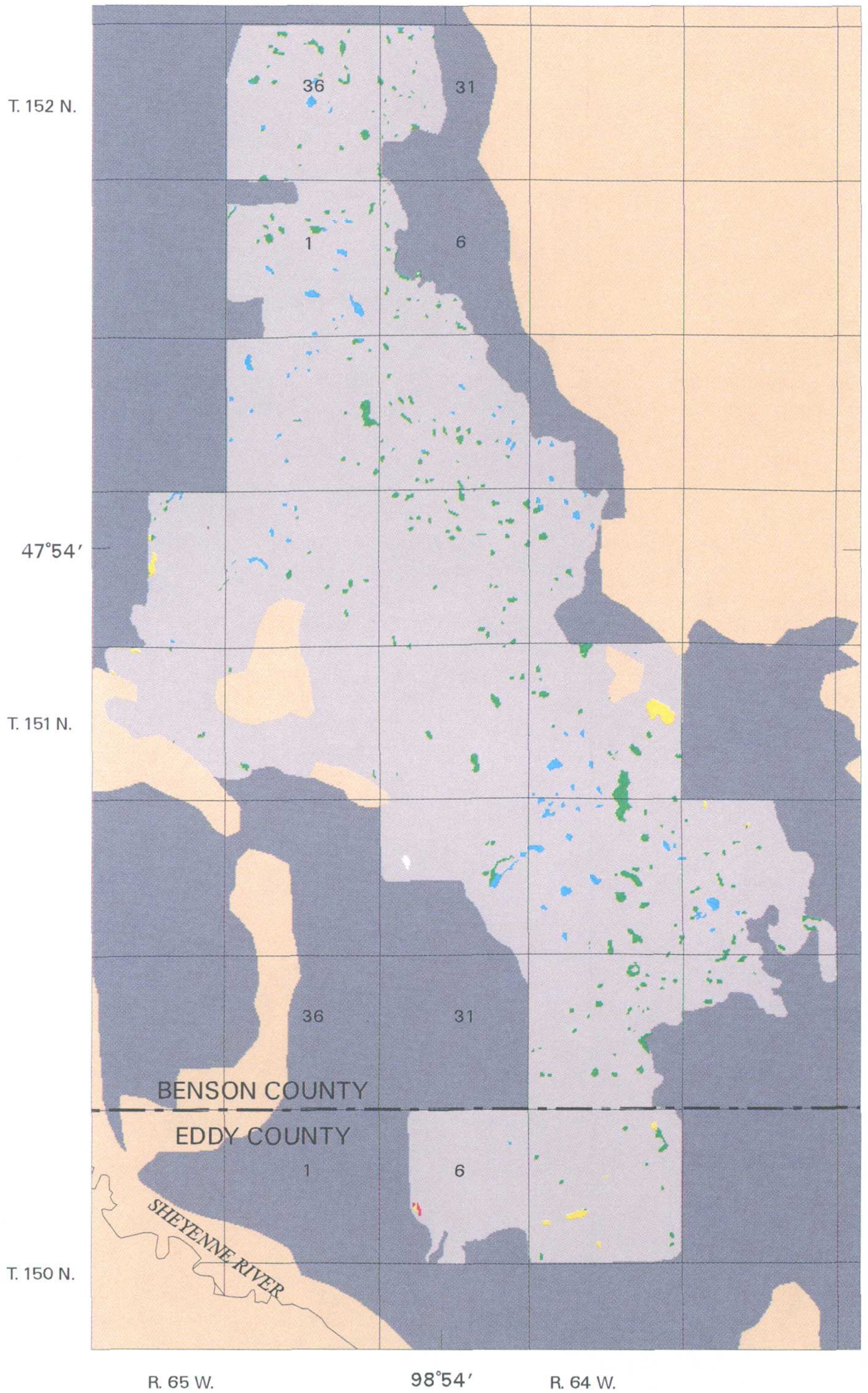
Figure 7.0–1 Land-surface slope and vertical hydraulic leakance.

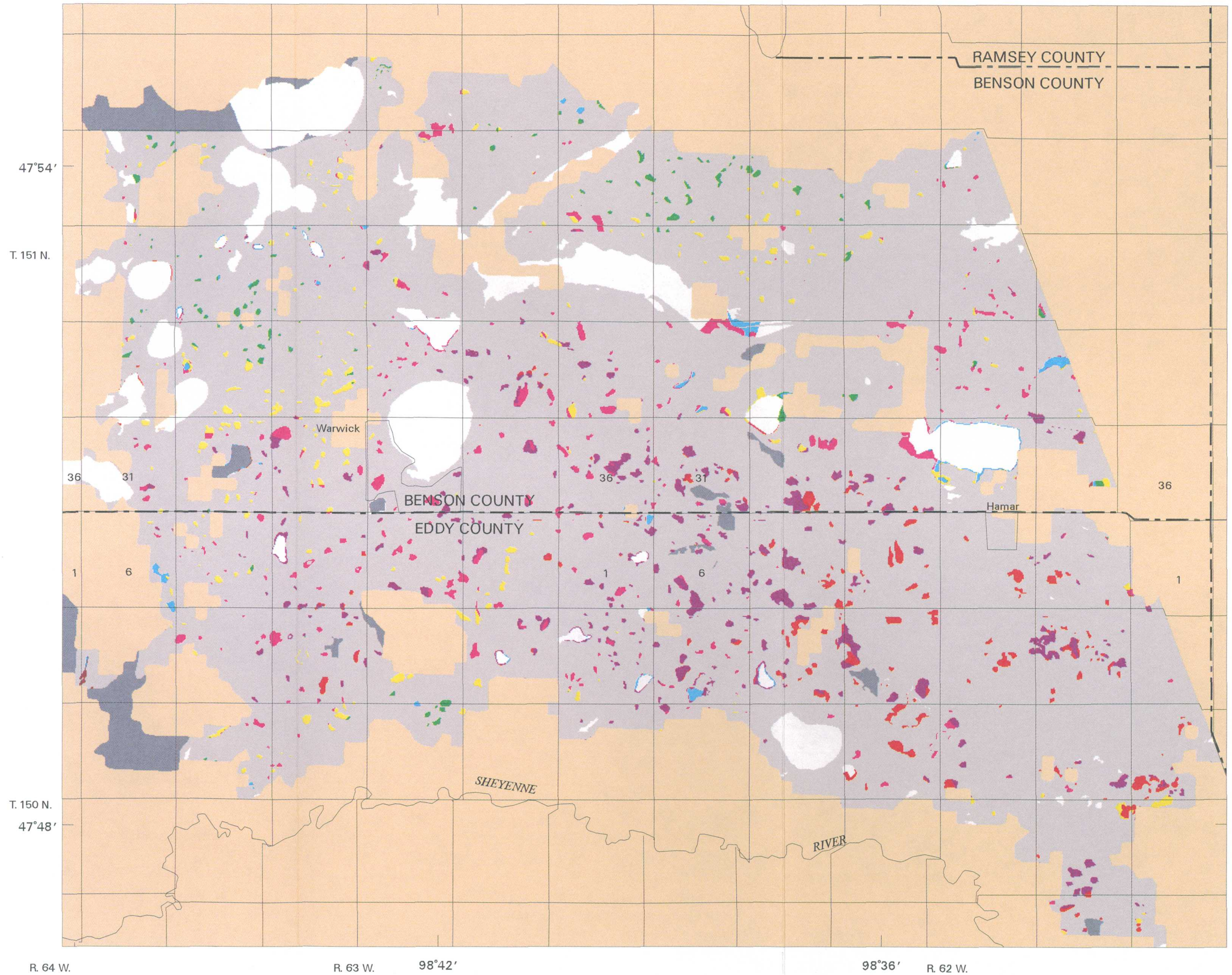
8.0 MOST VULNERABLE AREAS BASED ON HYDROLOGIC SINKS AND VERTICAL HYDRAULIC LEAKANCE

Hydrologic Sinks and Drainage Basin Areas and Vertical Hydraulic Leakance are Important Factors in Evaluating the Vulnerability of Ground Water to Surface Contamination

Areas of high vulnerability were determined from hydrologic sinks and vertical hydraulic leakance.

Hydrologic sinks and drainage basin areas and vertical hydraulic leakance are important factors in evaluating the vulnerability of ground water to surface contamination. However, when a combination of these factors was considered in evaluating the vulnerability of ground water in the Tokio and Warwick aquifers to surface contamination, very few areas had a ratio of drainage basin area to hydrologic sink greater than 25 (fig. 5.0-1) and a vertical hydraulic leakance greater than 3 day^{-1} (fig. 2.0-1). Therefore, a combination of hydrologic sinks (fig. 5.1-1) and vertical hydraulic leakance (fig. 2.0-1) was considered instead of the previously mentioned combination. The vertical hydraulic leakance of the hydrologic sinks in the Tokio aquifer (fig. 8.0-1) ranges from 0.002 to 1.352 day^{-1} and has a mean of about 0.2 day^{-1}. The vertical hydraulic leakance of the hydrologic sinks in the Warwick aquifer (fig. 8.0-1) ranges from 0.002 to 6 day^{-1} and has a mean of about 2 day^{-1}. The vertical hydraulic leakances are shown for the hydrologic sinks covering about 0.444 square mile of the Tokio aquifer and about 3.311 square miles of the Warwick aquifer.





EXPLANATION

VERTICAL HYDRAULIC LEAKANCE, IN DAY -1

- Greater than 3
- Greater than 1.5 and less than or equal to 3
- Greater than 0.75 and less than or equal to 1.5
- Greater than 0.3 and less than or equal to 0.75
- Greater than 0.1 and less than or equal to 0.3
- Greater than 0.02 and less than or equal to 0.1
- Less than or equal to 0.02
- No data
- Aquifer present on Reservation
- Aquifer absent, no saturated thickness, or aquifer outside of Reservation
- Lakes, sloughs, and wetlands

0 1 2 3 4 5 MILES

0 1 2 3 4 5 KILOMETERS

8.0 VERTICAL HYDRAULIC LEAKANCE OF HYDROLOGIC SINKS

Figure 8.0–1 Vertical hydraulic leakance of hydrologic sinks.

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