Pollution Sensitivity of Near-Surface Materials

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Minnesota Hydrogeology Atlas Series HG-02

Report

Plate 1

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Pollution Sensitivity of Near-Surface Materials

Introduction

This atlas provides statewide near-surface pollution sensitivity information to help users manage and protect groundwater resources. The map described in this report is an interpretation for a large geographic area and is intended to be used to help focus the information gathering for site-specific investigations. This information can be considered in land-use programs, zoning, surface-water-infiltration planning, and other large-scale planning efforts where groundwater protection is a concern.

The atlas includes a report, a statewide map (Plate 1), and digital files. The report describes the data sources and methods used to create the map. The map on Plate 1 portrays the pollution sensitivity of the near-surface materials. The digital data include Plate 1 and the surficial geology compilation and are available for use in geographic information systems (GIS). The coverage is continuous statewide but can be used by any specific area defined by the user.

This is the second installment (HG-02) of the Minnesota Hydrogeology Atlas (MHA) series, which provides statewide groundwater information. It builds on the county sensitivity maps and data initially published for the County Geologic Atlas (CGA) series, it updates the previous coverage, and provides new information in areas without existing atlases. This effort is part of the CGA program of the Minnesota Department of Natural Resources (DNR), Ecological and Water Resources Division.

The sensitivity to pollution of near-surface materials is an estimate of the time it takes for water to infiltrate the land surface to a depth of 10 feet. It is intended to estimate the time of travel through the unsaturated zone to reach the water table, which for the purposes of this method, is assumed to be 10 feet below land surface everywhere.

Sensitivity interpretation is based on overlapping estimated time of travel ranges as seen in Figure 1. The method used to calculate the sensitivity in this series was updated in 2015; variances may be seen in county geologic atlases created prior to this time.

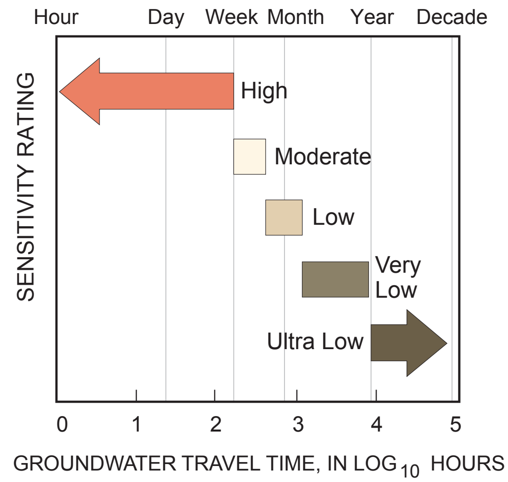

Figure 1. Geologic sensitivity rating for the near surface
Ratings are based on the vertical travel time range required for water to travel from the land surface to a depth of 10 feet.

A rating of high, moderate, low, very low, or ultra low is applied to units across the state, defined by vertical travel times ranging from hours to more than a year (Table 1).

Table 1. Geologic sensitivity rating descriptions of the near surface as defined by vertical travel time

Near-Surface Pollution Sensitivity	Time of Travel	Description
High	≤ 170 hours	Hours to a week
Moderate	>170–430 hours	A week to weeks
Low	>430–1600 hours	Weeks to months
Very Low	>1600–8000 hours	Months to a year
Ultra Low	>8000 hours	More than a year
Special Conditions: karst, bedrock at or near surface, peatlands, disturbed lands	Not applicable	See descriptions in Special Conditions

Methods

The migration of contaminants with or within water through geologic material is affected by factors such as biological degradation, oxidizing or reducing conditions, and contaminant density. This assessment requires the following generalizing assumptions: 1) flow paths from land surface to 10 feet below land surface are vertical, 2) transmission rates are related to sediment matrix texture, 3) contaminants move conservatively with water, and 4) units are homogeneous. The limitations of making these assumptions are discussed in the Model limitations section of this report. The total travel time is estimated in a two-layer approach using two primary inputs of matrix texture values: the soil layer (0–3 feet) and the underlying geologic materials (3–10 feet). Matrix texture is defined as relative amounts of sand, silt, and clay. It is used as a proxy for estimating the transmission rate, as coarse-grained materials have transmission rates greater than fine-grained materials because of the larger and more connected pore spaces between the grains.

More information on the methodology and data sources is available in *Methods to Estimate Near-Surface Pollution Sensitivity GW-03* (DNR, 2016).

Map Development

Continuous statewide coverage for soils and surficial geology has limitations. While larger-scale datasets are available, their accuracy and date of creation may limit their applicability in this model.

Soil

The transmission rate through the top 3 feet of the soil profile is estimated by using the Hydrologic Soil Group (HSG) from the Natural Resources Conservation Service (NRCS). The hydraulic conductivity variability within each HSG depends on a number of factors including the method used in rate determination; relative percentages of sand, silt, and clay; antecedent moisture conditions; the presence or absence of macropores; and hydraulic head.

The soil dataset used for statewide coverage was SSURGO, where county data were collected individually at a scale range of 1:12,000 to 1:63,360 (NRCS, 2016). The majority of Minnesota has SSURGO coverage; however, portions of Pine, Lake, Cook, and St. Louis counties do not. In these areas, STATSGO2 soils data at a scale of 1:250,000 were used (Figure 2). Tabular data for both sets of soil data were used to assign HSG to soil units.

Figure 2. Soil data used to create statewide coverage

Surficial geology

The transmission rate from a depth of 3–10 feet is estimated using the matrix texture of unconsolidated geologic units, commonly glacial sediments. Field samples from surficial units were assumed to be laterally and vertically homogenous and were used to assign the dominant texture for 3–10 feet by the Minnesota Geological Survey (MGS) (Appendix A). This approach allows objective and reproducible transmission rates to be assigned to surficial geology units.

In order to create statewide coverage, maps where combined in order of date of creation and map scale. Newer or larger-scale maps were used, where possible, before older or smaller-scale maps. No maps with scales larger than 1:100,000 were used. Figure 3 shows the distribution of surficial geology maps used and the scale of those maps. Detailed information is available in Appendix B: Geographic Information System Analysis.

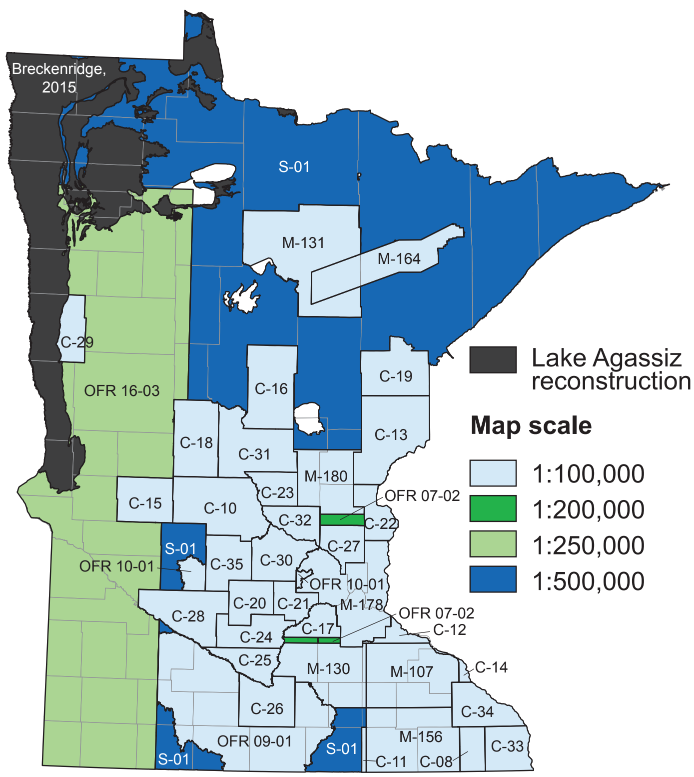

Figure 3. Surficial geology map coverage and scales used to create statewide surficial geology map
Labels indicate the map used (Appendix B).

Eolian sand and loess covered areas

Eolian deposits such as loess and (dune) sands are created through wind erosion of materials, and are deposited along the wind's travel path. This deposition creates widespread, well sorted, and commonly porous blankets of material. *Eolian or dune sand* consists of predominantly sand with some secondary grain sizes of fine sand or silt. *Loess* consists predominantly of silt with some secondary grain sizes of fine sand or clay. The deposition of eolian sediment does not include compaction and these materials are commonly invaded by a vegetative mat. This allows for large macropores to develop and become cemented within the deposit.

In Minnesota, the eolian sands occur near glaciolacustrine and glaciofluvial sediments, where the wind carried near-shore or alluvial sediments a distance from the source. This process results in blankets of sedimentary structures such as dunes or ripple marks above surrounding glacial deposits. Surface loess deposits in Minnesota are mapped as the Peoria Loess (Johnson and others, 2016). Peoria Loess was deposited in the Late Wisconsinan and has high silt content. For the purposes of this map, the textures related to Peoria Loess were applied to all undifferentiated loess units mapped in Minnesota. Loess occurs in the southeast and southwest (Figure 4). Field work related to the geologic and hydrologic properties of loess resulted in documented hydraulic conductivities for the Peoria Loess (Mason, 1995). These values are used in determining the transmission rate and pollution sensitivity of loess units in Minnesota.

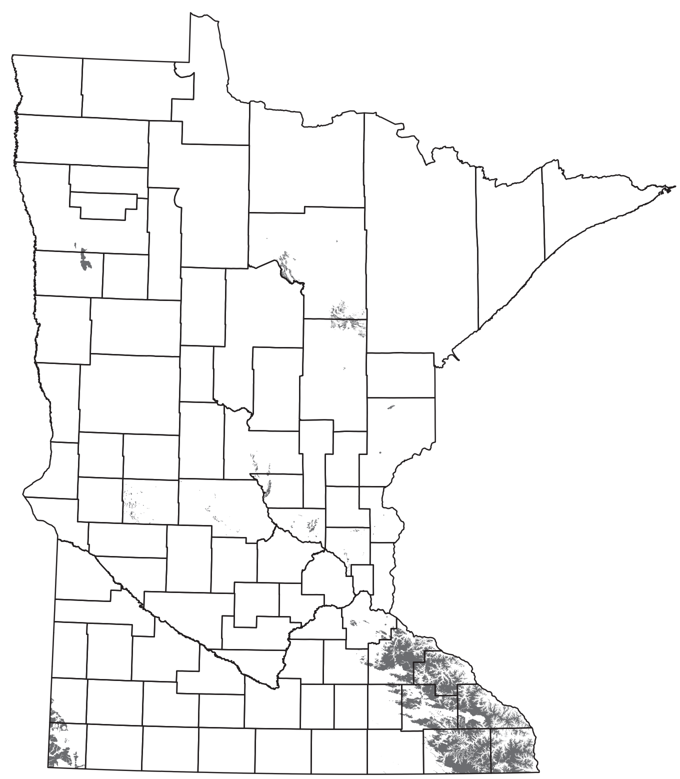

Figure 4. Eolian sand and loess coverage

Derived from surficial geology maps, thickness ranges from 5–15 meters.

Glacial lake sediments

Glaciolacustrine sediments were derived from glacial lake deposits composed of fine-grained material suspended in lakes. Although these occur throughout Minnesota, the northwestern areas are known internationally for their thick sequence of sediments (primarily clay) deposited by glacial Lake Agassiz during the Late Wisconsinan (Figure 5). Lake Agassiz occupied large areas of the central great plains of North America, reaching a maximum area over 100,000 square miles, and thicknesses upwards of 125 feet of fine-grained material.

Glaciolacustrine sediments from large glacial lakes Agassiz and Duluth produce unique conditions for groundwater flow and sensitivity analysis. Isotopic data from palaeoclimate research have revealed pore-water ages in excess of 10,000 years in Lake Agassiz sediments (Birks and others, 2000, Birks and others, 2007, Remenda and others, 1994). This very long residence time and ultra-low permeability of fine-grained materials creates conditions unique from other glacial lakes in the state.

The extent of these glacial lake sediments is delineated through a review of the region's glacial history and surficial geology maps of the northwest Minnesota (Breckenridge, 2015), the Carlton CGA map (Boerboom, 2009), and the lithostratigraphic parameters outlined in Johnson and others (2016).

Figure 5. Estimated extent of thick glacial lake sediments of glacial lakes Agassiz and Duluth

Estimating Transmission Rates Using Textures

Transmission rates are estimated by converting representative textures from published saturated hydraulic conductivity rates to unsaturated rates. These rates are then used to develop soil and surficial geology maps in a geographic information system (GIS), creating a two-layer model. The estimated transmission rates used in this model changed over time as new data became available. In 2015 the MGS created a statewide textural database of shallow geologic materials and the DNR defined two additional specific transmission rates for surficial geologic units: thick, glacial lake clays and loess (Table 2). For the first layer of this model the Hydrologic Soil Group from individual soil units is used to determine the transmission rate for that soil unit. For the second layer the DNR uses the dominant textures of surficial geology units to assign transmission rates.

Table 2: Relationships between classification and unsaturated transmission rates [in/hr]

Hydrologic Soil Group (0–3 feet)		Surficial Geology Texture (3–10 feet)	
Group	Transmission rate	Classification	Transmission rate
A, A/D	1.0	gravel, sandy gravel, silty gravel	1.0
		sand, silty sand	0.71
B, B/D	0.50	silt, loamy sand, units with eolian sand designation	0.50
		sandy loam, peat*	0.28
--	--	loess (Peoria)**	0.218
C, C/D	0.075	silt loam, loam	0.075
		sandy clay loam	0.035
D	0.015	clay, clay loam, silty clay loam, sandy clay, silty clay	0.015
--	--	Glacial lake sediments of lakes Agassiz and Duluth***	0.000011

*Assumes Hemic Peat

**Values derived from range of values published within Mason, 1995 and written communication, 2015

***Values derived from range of values published within Remenda and others, 1994

Applying Transmission Rates to Determine Sensitivity

The sensitivity rating of near-surface material is determined using the transmission rates (Table 2) to calculate an estimated travel time for a contaminant that moves conservatively with water to a depth of 10 feet below land surface. The general approach used to create the maps is as follows:

1. GIS polygons from soil and surficial geologic units are converted to rasters with 30-meter cells, with their transmission rates as the cell value.
2. Conditional statements are used to calculate travel time given the availability of soil and surficial geology data at a specific location where soil and surficial geology raster cells are coincident.

Soil		Surficial Geology		Travel Time
36 inches ÷ transmission rate	+	84 inches ÷ transmission rate	=	To reach depth of 10 feet (120 inches)

Exception to the two-layer model

The two-layer model was applied to large portions of the state, however, special conditions override this approach for regions where the unique geological environments dominate: karst within 50 feet of the land surface, bedrock at or near surface, north-central peatlands, and large areas of disturbed land. These are explained in the Special Conditions section of this report.

Model limitations

The maps generated through the previously described processes are generalized interpretations of near-surface sensitivity. The following factors are important for local interpretations but are not considered in this statewide model:

- This model assumes that the matrix texture of surficial geology units is homogenous within mapped units.
- Samples collected and analyzed by MGS assume lateral homogeneity for a texture class from a sample site.
- This model does not take into account hydraulic head, compaction, drain tiles, macropores, or other heterogeneities.
- Field testing of site-specific data is unavailable.
- When two or more surficial geology maps are available, the newest or largest map scale is used instead of older or smaller map scales. While this procedure ensures statewide coverage, abrupt changes in modeled values at source map borders are unavoidable.
- The two-layer model extends to a depth of 10 feet below the land surface, because it is assumed that the average water table is at that depth, allowing consistent ratings. The water table in many areas is actually shallower or deeper.
- Map making procedures have changed over time. Newer maps provide overlays of certain surficial units, e.g., loess, peat, etc. MGS has not mapped peat, but rather uses other sources for peat location, such as the NRCS. When NRCS delineation of peat is used in soil maps and in surficial geology maps, the peat thickness in the two-layer model would be estimated as 10 feet thick. Wherever peat is provided as an overlay, it was not used as the surficial geology unit.
- This model assumes layer thicknesses of 3 feet for soil and 7 feet for surficial geology. Soil development depends on many factors and therefore 3 feet of soil may not be representative in all locations.

Results

The resulting map for pollution sensitivity of the near-surface materials shows varying sensitivity within 10 feet of the land surface (Figure 6 and Plate 1). Generally, areas of coarse-grained material are modeled as higher sensitivity to pollution compared to areas of fine-grained material. Exceptions exist where special conditions occur.

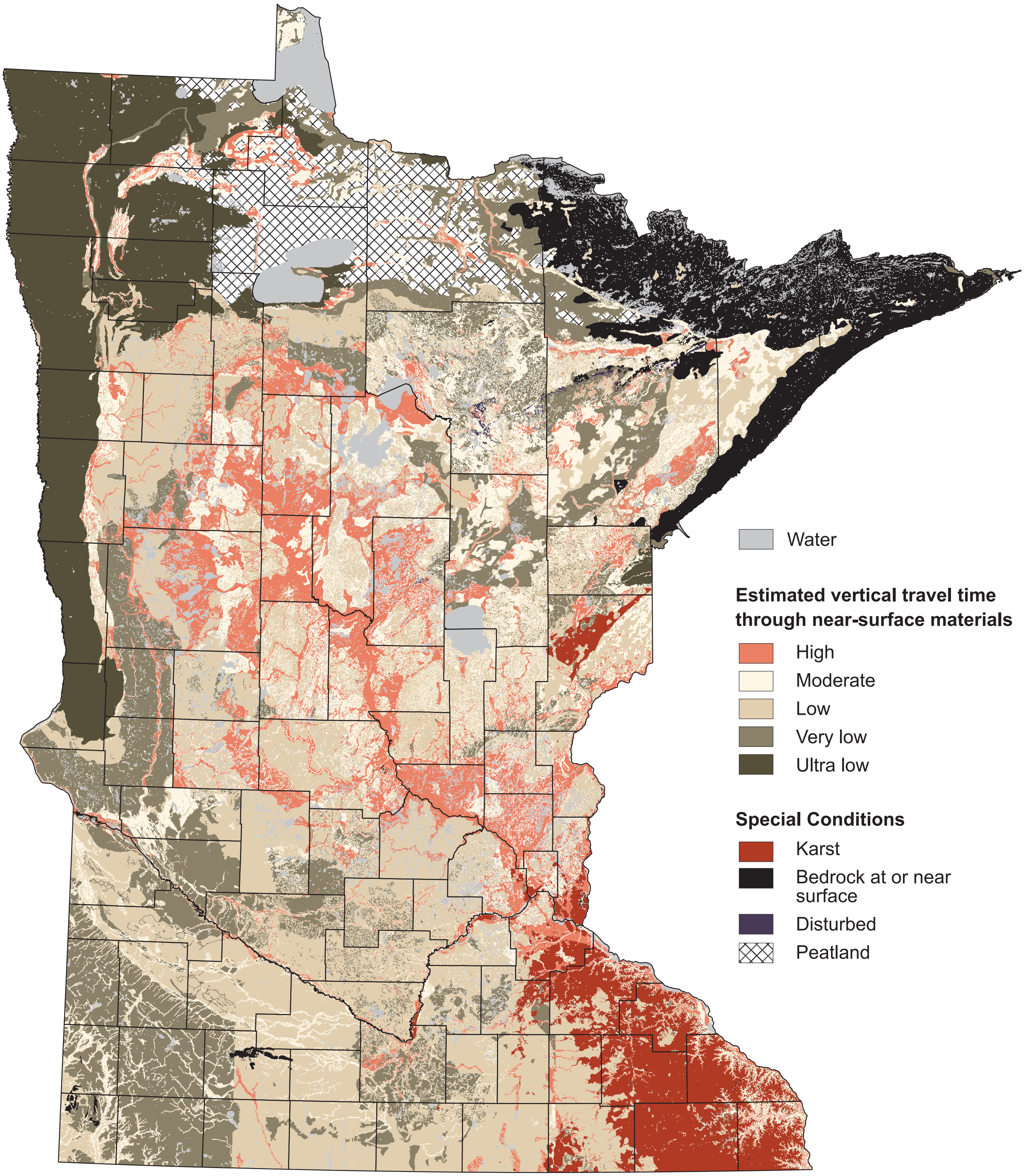

Figure 6. Pollution sensitivity of the near-surface materials (see Plate 1)

Special Conditions

There are areas within Minnesota where the two-layer model of the near surface does not provide an accurate estimation of the pollution sensitivity. These areas occur where certain combinations of geological conditions dominate the landscape and transmission rates cannot be assigned without further study.

Karst landscapes

Field-verified karst features such as sinkholes are direct evidence that karst processes are active both on the surface and in the subsurface. However, karst activity may still be present even where not visible at the surface. In Minnesota surface karst features occur primarily where 50 feet or less of unconsolidated sediment overlies Paleozoic carbonate bedrock, St. Peter Sandstone, or Hinckley Sandstone.

Karst allows a direct, very rapid exchange between surface water and groundwater, and significantly increases groundwater contamination risk from surface pollutants. Karst areas in the statewide map were delineated using *Minnesota Regions Prone to Surface Karst Feature Development, GW-01* (Adams and others, 2016).

To reflect karst as the dominant condition, the karst coverage was used in place of the near-surface pollution sensitivity values, even though some areas may have soil or shallow geologic materials extending to 10 feet below the land surface (Figure 7). In these cases the karst conditions are assumed to play a larger role in the near-surface pollution sensitivity, superseding the two-layer model.

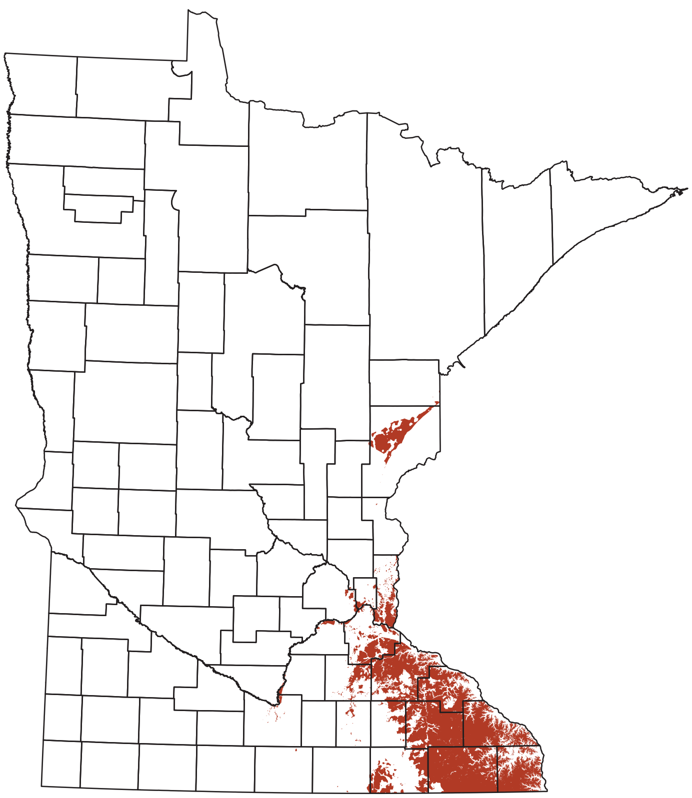

Figure 7. Regions prone to surface karst feature development

Bedrock at or near surface

Bedrock is solid rock that underlays the soil and unconsolidated surficial materials throughout Minnesota. In areas where bedrock is at or near the surface, it can be delineated on surficial geology maps as either the specific bedrock unit or as undifferentiated bedrock. Transmission rates through bedrock are not well documented and are subject to macro features such as voids and fractures that alter the local hydraulic conductivity of a rock.

This reasoning, as well as the variation in bedrock units across the state, results in a special condition for areas in which the two-layer model for the pollution sensitivity of the near-surface materials cannot be accurately applied. These areas were delineated from the surficial geology maps (Figure 8).

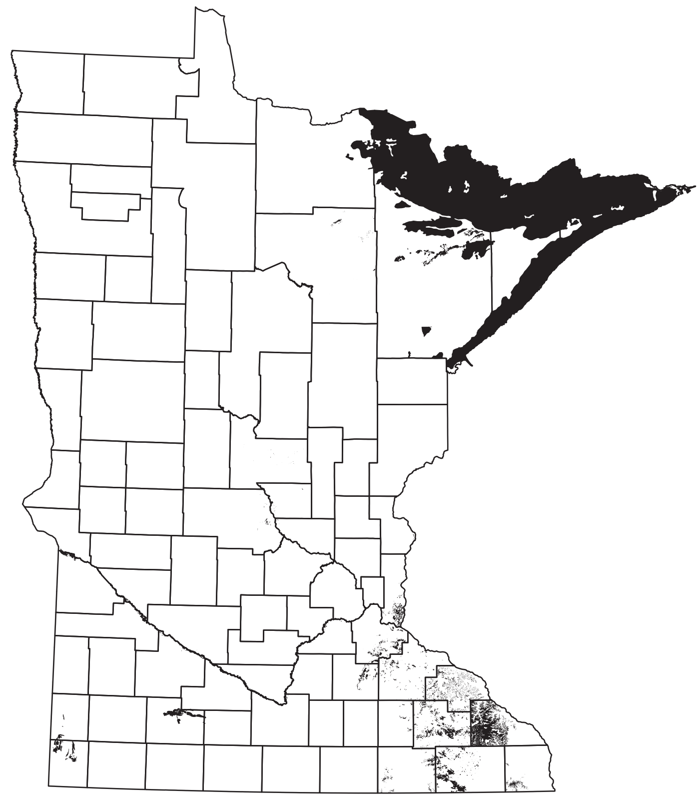

Figure 8. Bedrock at or near surface

Thick peatlands in north-central Minnesota

The peatlands of north-central Minnesota present a situation different from the traditional peat bodies and wetlands that occur throughout the rest of the state (Figure 9). These peatlands are known for their thick sequence of organic material with continuous saturation.

Most of the north-central peatlands overlay Lake Agassiz sediments in the west and bedrock at or near surface in the east. However, the unique characteristics of the peatlands require that they be treated as a special condition. Unlike the thinner peat bodies of central and southern Minnesota, the north-central peatlands range in thickness from 6 feet up to 175 feet, recharging the regional groundwater flow system (Siegel, 1981; Siegel and Glaser; 1987, Reeve and others, 2001).

One of the stipulations for the model for pollution sensitivity of near-surface materials is *unsaturated* vertical movement to a depth of 10 feet. The north-central peatlands are characteristically rarely unsaturated, making this portion of the state unsuitable for the two-layer near-surface model used to make the statewide map. These units were parsed out of the Ecological Classification System of Minnesota (DNR, 1999).

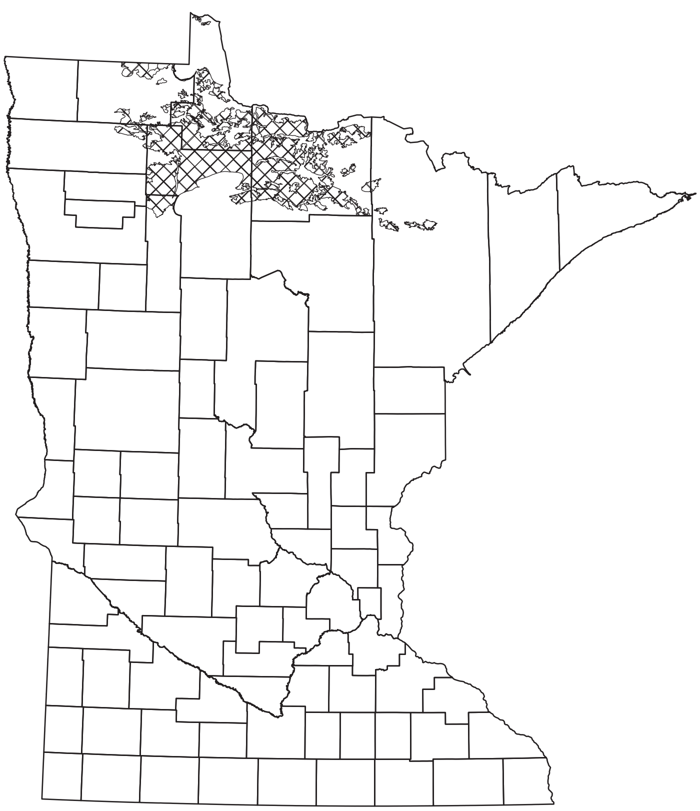

Figure 9. North-central peatlands

Disturbed lands

The MGS defines disturbed lands as the surface that is generally and variably disturbed by mining or other large scale human activity. They may contain a wide variety of materials including dump mounds and rock tailings basins, together with small areas of undisturbed surface material and bedrock outcrops. This does not include lands disturbed by urbanization. These areas are mapped as undifferentiated (too small to discern at the map scale) which makes them unsuitable for pollution sensitivity characterization. These units, which are primarily located in the Iron Range, are delineated from MGS surficial geology maps and labeled accordingly (Figure 10).

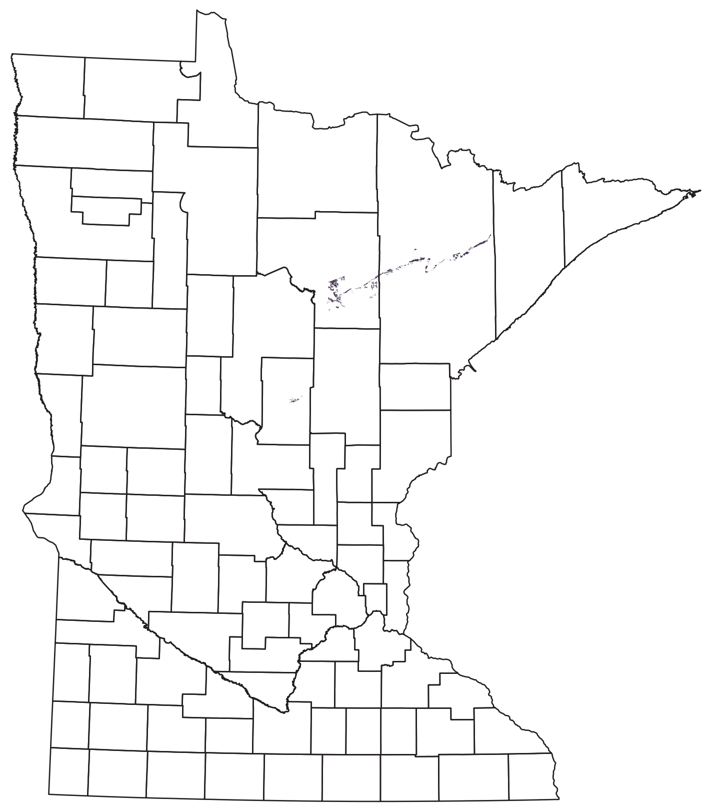

Figure 10. Disturbed lands

Summary

To map the pollution sensitivity of near-surface materials, a two-layer model was developed. The model correlates the properties of materials in the two layers with the travel time of water through 10 feet of geologic material. The travel time of water is proportional to the sensitivity to pollution, where high travel times result in high pollution sensitivity. The sensitivity varies throughout the state, based on estimated transmission rates of the soil and surficial geology layers. The near-surface pollution sensitivity map generally shows that coarse-grained materials such as sand result in high pollution sensitivity, whereas fine-grained materials tend to have lower pollution sensitivity. In some geological environments the two-layer sensitivity model breaks down and special conditions are applied: karst within 50 feet of the land surface, bedrock conditions at or near land surface, north-central peatlands, and large areas of disturbed land. Geologic variability and other factors make collecting additional information essential to further refine pollution sensitivity information for local or regional applications.

This model is meant to supplement previous work done by the County Geologic Atlas program as well as provide valuable information for areas not yet mapped. This statewide perspective serves as a base for protection, planning, modeling, and investigations. It should be used in conjunction with more detailed geologic and hydrogeologic information when conducting site-specific investigations.

References

Adams, R., Barry, J., Green, J., 2016, Minnesota regions prone to surface karst feature development: Minnesota Department of Natural Resources, Ecological and Water Resources Division, Series GW-01, http://files.dnr.state.mn.us/waters/groundwater_section/mapping/gw/gw01_report.pdf.

Birks, S.J., Remenda, V.H., Edwards, T.W.D., 2000, Clay aquitards as isotopic archives of Holocene palaeoclimate in the Northern Great Plains: sensitivity analysis: Hydrogeological Processes, 2000, issue 14, p. 1523–1536.

Birks, S.J., Edwards, T.W.D., Remenda, V.H., 2007, Isotopic evolution of Glacial Lake Agassiz: New insights from cellulose and porewater isotopic archives: Palaeogeography, Palaeoclimatology, Palaeoecology, 2007, issue 246, p. 8–22.

Boerboom, Terrence J., (2009). C-19 Geologic atlas of Carlton County, Minnesota [Part A]. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://purl.umn.edu/58760.

Breckenridge, A., 2015, The Tintah-Campbell gap and implications for glacial Lake Agassiz drainage during the Younger Dryas cold interval: Quaternary Science Reviews, 2015, v.117, p. 124–134.

DNR, 1999, Ecological Land Type Associations of Minnesota: Minnesota Department of Natural Resources, accessed April 2016 through GeoSpatial Commons at https://gisdata.mn.gov/dataset/geos-land-type-associations.

Johnson, M.D., Adams, R.S., Gowan, A.S., Harris, K.L., Hobbs, H.C., Jennings, C.E., Knaeble, A.R., Lusardi, B.A., Meyer, G.N., 2016, RI-68 Quaternary lithostratigraphic units of Minnesota: Minnesota Geological Survey, Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/177675.

Mason, J.A., 1995, Effects of glacial-interglacial climate change on mass wasting, southeastern Minnesota: University of Wisconsin-Madison, Ph.D. dissertation, 692 p.

Reeve, A.S., Warzocha, J., Glaser, P.H., Siegel, D.I., 2001, Regional ground-water flow modeling of the Glacial Lake Agassiz peatlands, Minnesota: Journal of Hydrology, 2001, issue 243, p. 91–100.

Remenda, V.H., Cherry, J.A., Edwards, T.W.D., 1994, Isotopic composition of old ground water from Lake Agassiz *in* Implication for late Pleistocene climate: Science, December 23 1994, v. 266, issue 5193, p. 1975–1978.

Siegel, D.I., 1981, Hydrogeologic setting of the Glacial Lake Agassiz Peatlands, Northern Minnesota: USGS Water-Resources Investigations 81–24.

Siegel, D.I., Glaser, P.H., 1987, Groundwater flow in a bog-fen complex, Lost River Peatlands, Northern Minnesota: Journal of Ecology, 1987, v. 75, no. 3, p. 743–754.

NRCS, 2016, Web Soil Survey: Natural Resources Conservation Service, United States Department of Agriculture, accessed April 2016 at http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Glossary

geology—The science dealing with the origin, history, materials, and structure of the earth, together with the forces and process operating to produce change within and on the earth.

glacial—Of, relating to, or derived from a glacier.

grain size, particle size—The diameter of individual grains in sediment. Grains range in size from clay, silt, sand, pebble, cobble and boulder.

groundwater—The water contained in pore spaces between rock and soil particles, or bedrock fractures.

Holocene—The geologic epoch that began 11,700 years ago and continues to the present.

hydraulic conductivity—The volume of fluid that flows through a unit area of porous medium for a unit hydraulic gradient normal to that area. Typically measured in gallons per day through a cross section of one square foot (gpd/ft2).

hydrogeology—The study of the interrelationships of geologic materials with water, especially groundwater.

karst—a terrain with distinctive landforms and hydrology created primarily from the dissolution of soluble rocks. It is characterized by sinkholes, caves, springs, and underground drainage dominated by rapid conduit flow.

Paleozoic—The geologic era from approximately 542 to 251 million years ago. Southeast Minnesota was once covered in seas that deposited sediment that make up the sedimentary bedrock.

pollution sensitivity—The general potential for groundwater to be contaminated owing to the hydrogeologic properties of the material hosting or overlying it.

Pleistocene—The geologic epoch that began 2.58 million years ago and ended 11,700 years ago, during which there were numerous ice sheet advances in the Northern & Southern Hemisphere.

Quaternary—The geologic period that began 2.58 million years ago and continues today. The Quaternary Period comprises the Pleistocene and Holocene epochs.

till—An unsorted deposit with a matrix of silt, clay and sand and clasts ranging from pebble- to boulder-sized, deposited directly by ice.

travel time—The time required for water or a contaminant to move from a source at the land surface to an aquifer or other target.

Appendix A: Minnesota Geological Survey 1:100,000 Geological Mapping Database

The following method is for the creation of the MGS 1:100,000 Geological Mapping Database, which is used by the DNR to estimate transmission rates of surficial geology units.

To support regional and statewide applications, Minnesota Geological Survey (MGS) has initiated a geological mapping database to compile county and quadrangle-resolution mapping − nominally 1:100,000 – beginning with surficial geology maps. These maps may be regarded as soil parent material maps, and are appropriate for applications that call for inference of near-surface materials such as sediment in the second and third meter, having obtained information on the uppermost meter from soil mapping. Reconciliation of adjacent maps to produce a seamless mapping database has been initiated on a pilot basis, and is expected to be a multi-year process. Current focus is on parsing of legends, to facilitate queries using broadly accepted, well-defined terminology, and thus to facilitate inference of properties – beginning with sediment texture. For the longer term, it is anticipated that thickness will progressively be more indicated, while increasing specification of properties will gradually be accompanied by indications of heterogeneity and uncertainty.

Predicted texture of sediments underlying areas mapped as surficial geology polygons in the Minnesota Geological Survey 1:100,000 geological mapping database has been updated relative to information on the original published maps using information needed to support the best readily achievable inference of texture as categorized by US Department of Agriculture terminology.

The database currently is based on 41 previously published maps, including county geologic atlas and regional hydrogeologic assessment surficial geology plates, as well as maps published by MGS as miscellaneous maps and open file maps. Where county or quadrangle-scale mapping is unavailable, the database is based on 1:500,000 mapping.

The following procedure was used to infer a categorization of sediment texture more specific than was provided by the original map authors. The MGS sediment sample and analysis database – part of the MGS Quaternary Data Index (QDI) – was queried for analyses within 3 m depth for each unit of each map. To exclude outliers, values of <10% or >90% sand were excluded in areas mapped as till, and remaining data were inspected so outliers could be excluded on the basis of available information and judgment.

Resulting data for each map unit on each map were plotted on a ternary plot of percent sand, silt, and clay. If the plot showed a clear data cluster not straddling categories, a single texture classification was assigned based on USDA terminology. For cases of a cluster straddling categories, the accompanying table of average texture was used to make a class assignment. For data that was not well-clustered, a texture classification was assigned based on other factors, such as author notes, other mapping sources, or published map-unit description.

The sediment texture categorizations of the maps were then merged into a state-wide map coverage so that discrepancies between adjacent maps could be evaluated and addressed. In some cases, textural classifications were revised after adjacent maps were further considered.

A code was assigned to indicate the method used to assign the texture classification: Method 1 was based on robust textural data, author notes, interpretation, map legend; Method 2 was based on more limited textural data or range, NRCS histosols layer, interpretation, and map legend; and Method 3 was based on little to no textural data, and interpretation based on regional geology and map legend.

It is noted that sediments across Minnesota were in most cases deposited by glacial processes, resulting in considerable heterogeneity. Assignment of a single textural classification to any map unit thus is a generalized reginal approximation. Furthermore, availability of data is sparse over broad areas.

The intention is regularly augment the database as new mapping is completed, as additional data are compiled, and as methods are refined.

Appendix B: Geographic Information System Analysis

The file geodatabase contains the statewide raster of the pollution sensitivity of near-surface materials. The soil maps used were SSURGO except for portions of Pine, Cook, Lake, and St. Louis counties. The surficial geology maps used to create the statewide raster and other information can be found in the table below.

Surficial geology maps used for statewide compilation, divided by county

County	Map	Scale	Soil Used
Aitkin	S-01	1:500,000	SSURGO
Anoka	C-27	1:100,000	SSURGO
Becker	OFR 16-03	1:250,000	SSURGO
Beltrami	S-01	1:500,000	SSURGO
	OFR 16-03	1:250,000	
Benton	C-23	1:100,000	SSURGO
Big Stone	OFR 16-03	1:250,000	SSURGO
Blue Earth	C-26	1:100,000	SSURGO
Brown	OFR 09-01	1:100,000	SSURGO
Carlton	C-19	1:100,000	SSURGO
Carver	C-21	1:100,000	SSURGO
Cass	S-01	1:500,000	SSURGO
Chippewa	OFR 16-03	1:250,000	SSURGO
Chisago	C-22	1:100,000	SSURGO
Clay	C-29	1:100,000	SSURGO
Clearwater	S-01	1:500,000	SSURGO
	OFR 16-03	1:250,000	
Cook	S-01	1:500,000	STATSGO2
Cottonwood	OFR 09-01	1:100,000	SSURGO
	S-01	1:500,000	
	OFR 16-03	1:250,000	
Crow Wing	C-16	1:100,000	SSURGO
Dakota	M-178	1:100,000	SSURGO
Dodge	M-107	1:100,000	SSURGO
	M-130	1:100,000	
	M-156	1:100,000	
	S-01	1:500,000	
Douglas	OFR 16-03	1:250,000	SSURGO
Faribault	OFR 09-01	1:100,000	SSURGO
Fillmore	C-08	1:100,000	SSURGO
	M-156	1:100,000	
Freeborn	OFR 09-01	1:100,000	SSURGO
	S-01	1:500,000	
Goodhue	C-12	1:100,000	SSURGO
	M-107	1:100,000	
	M-130	1:100,000	
Grant	OFR 16-03	1:250,000	SSURGO
Hennepin	M-178	1:100,000	SSURGO
	OFR 10-01	1:100,000	
Houston	C-33	1:100,000	SSURGO
Hubbard	S-01	1:500,000	SSURGO
	OFR 16-03	1:250,000	
Isanti	M-180	1:100,000	SSURGO
	OFR 07-02	1:200,000	
Itasca	M-131	1:100,000	SSURGO
	M-164	1:100,000	
Jackson	OFR 09-01	1:100,000	SSURGO
	S-01	1:500,000	
	OFR 16-03	1:250,000	
Kanabec	M-180	1:100,000	SSURGO
	S-01	1:500,000	
Kandiyohi	OFR 10-01	1:100,000	SSURGO
	S-01	1:500,000	
Kittson	S-01	1:500,000	SSURGO
Koochiching	S-01	1:500,000	SSURGO
Lac qui Parle	OFR 16-03	1:250,000	SSURGO
Lake	S-01	1:500,000	STATSGO2
Lake of the Woods	S-01	1:500,000	SSURGO
	S-01	1:500,000	
Le Sueur	M-130	1:100,000	SSURGO
	OFR 07-02	1:200,000	
	OFR 07-02	1:200,000	
Lincoln	OFR 16-03	1:250,000	SSURGO
Lyon	OFR 16-03	1:250,000	SSURGO
Mahnomen	OFR 16-03	1:250,000	SSURGO
Marshall	S-01	1:500,000	SSURGO
Martin	OFR 09-01	1:100,000	SSURGO
	S-01	1:500,000	
McLeod	C-20	1:100,000	SSURGO
Meeker	C-35	1:100,000	SSURGO
Mille Lacs	M-180	1:100,000	SSURGO
	S-01	1:500,000	
Morrison	C-31	1:100,000	SSURGO
Mower	C-11	1:100,000	SSURGO
	M-156	1:100,000	
Murray	OFR 16-03	1:250,000	SSURGO
Nicollet	C-25	1:100,000	SSURGO
Nobles	OFR 16-03	1:250,000	SSURGO
Norman	OFR 16-03	1:250,000	SSURGO
Olmsted	M-107	1:100,000	SSURGO
	M-156	1:100,000	
Otter Tail	OFR 16-03	1:250,000	SSURGO

Pennington	S-01	1:500,000	SSURGO
	OFR 16-03	1:250,000	
Pine	C-13	1:100,000	Both SSURGO and STATSGO2
Pipestone	OFR 16-03	1:250,000	SSURGO
Polk	S-01	1:500,000	SSURGO
	OFR 16-03	1:250,000	
Pope	C-15	1:100,000	SSURGO
Ramsey	M-178	1:100,000	SSURGO
Red Lake	OFR 16-03	1:250,000	SSURGO
Redwood	OFR 09-01	1:100,000	SSURGO
	S-01	1:500,000	
	OFR 16-03	1:250,000	
Renville	C-28	1:100,000	SSURGO
Rice	M-130	1:100,000	SSURGO
	OFR 07-02	1:200,000	
	OFR 07-02	1:200,000	
Rock	OFR 16-03	1:250,000	SSURGO
Roseau	S-01	1:500,000	SSURGO
Scott	C-17	1:100,000	SSURGO
Sherburne	C-32	1:100,000	SSURGO
Sibley	C-24	1:100,000	SSURGO
St. Louis	M-164	1:100,000	SSURGO
	S-01	1:500,000	
	C-19	1:100,000	
	S-01	1:500,000	
Stearns	C-10	1:100,000	SSURGO
Steele	M-130	1:100,000	SSURGO
	OFR 09-01	1:100,000	
	S-01	1:500,000	
Stevens	OFR 16-03	1:250,000	SSURGO
Swift	OFR 16-03	1:250,000	SSURGO
Todd	C-18	1:100,000	SSURGO
Traverse	OFR 16-03	1:250,000	SSURGO
Wabasha	C-14	1:100,000	SSURGO
	M-107	1:100,000	
Wadena	S-01	1:500,000	SSURGO
	OFR 16-03	1:250,000	
Waseca	M-130	1:100,000	SSURGO
Waseca	OFR 09-01	1:100,000	SSURGO
Washington	M-178	1:100,000	SSURGO
Watonwan	OFR 09-01	1:100,000	SSURGO
Wilkin	OFR 16-03	1:250,000	SSURGO
Winona	C-34	1:100,000	SSURGO
Wright	C-30	1:100,000	SSURGO
Yellow Medicine	OFR 16-03	1:250,000	SSURGO

All maps were kept at their original scale and applied a standardized description system through field attributes.

The only exceptions to the two-layer model where this data can be used were identified in the Special Conditions section: karst, bedrock at or near surface, northern peatlands, and areas of disturbed lands. Sensitivity ratings are determined by time of travel, and this relationship is seen in Table 1. Conditional statements were used to override the two-layer model when special conditions occur in an area.

Appendix C: Technical Reference

Map

Maps were compiled and generated in a geographic information system (GIS). Digital data products are available from the Department of Natural Resources (DNR), Ecological and Water Resources Division.

The map was prepared from DNR and other publicly available information. Every reasonable effort has been made to ensure the accuracy of the factual data on which the report and map interpretations were based. However, the DNR does not warrant the accuracy, completeness, or any implied uses of these data. Users may wish to verify critical information. Sources include both the references here and information on file in the offices of the Minnesota Geological Survey and the DNR. Every effort has been made to ensure the interpretations conform to sound geologic and cartographic principles. These maps should not be used to establish legal title, boundaries, locations of improvements, or other site specific decisions.

Project data was compiled at a scale of 1:500,000. Universal Transverse Mercator projection, zone 15N, North American Datum of 1983. North American Vertical Datum of 1988. GIS and cartography by Roberta Adams and Holly Johnson. Edited by Ruth MacDonald.

Conversion Factors

1 foot = 0.3048 meters

1 inch per hour = 7.06 x 10^{-6} meters per second

Recommended Citation

Adams, R., 2016, Pollution sensitivity of near-surface materials: St. Paul, Minnesota Department of Natural Resources, Minnesota Hydrogeology Atlas Series HG-02, report and plate, accessible at <http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-ns.html>.

Link to Supporting Atlases

County Geologic Atlas Series
http://www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html

Acknowledgements

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The DNR Information Center

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Ecological and Water Resources Division
500 Lafayette Road
St. Paul, MN 55155-4025
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http://www.mndnr.gov/waters

This information is available in alternative format on request.

STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
ECOLOGICAL AND WATER RESOURCES DIVISION

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Pollution Sensitivity of Near-Surface Materials

By Roberta Adams

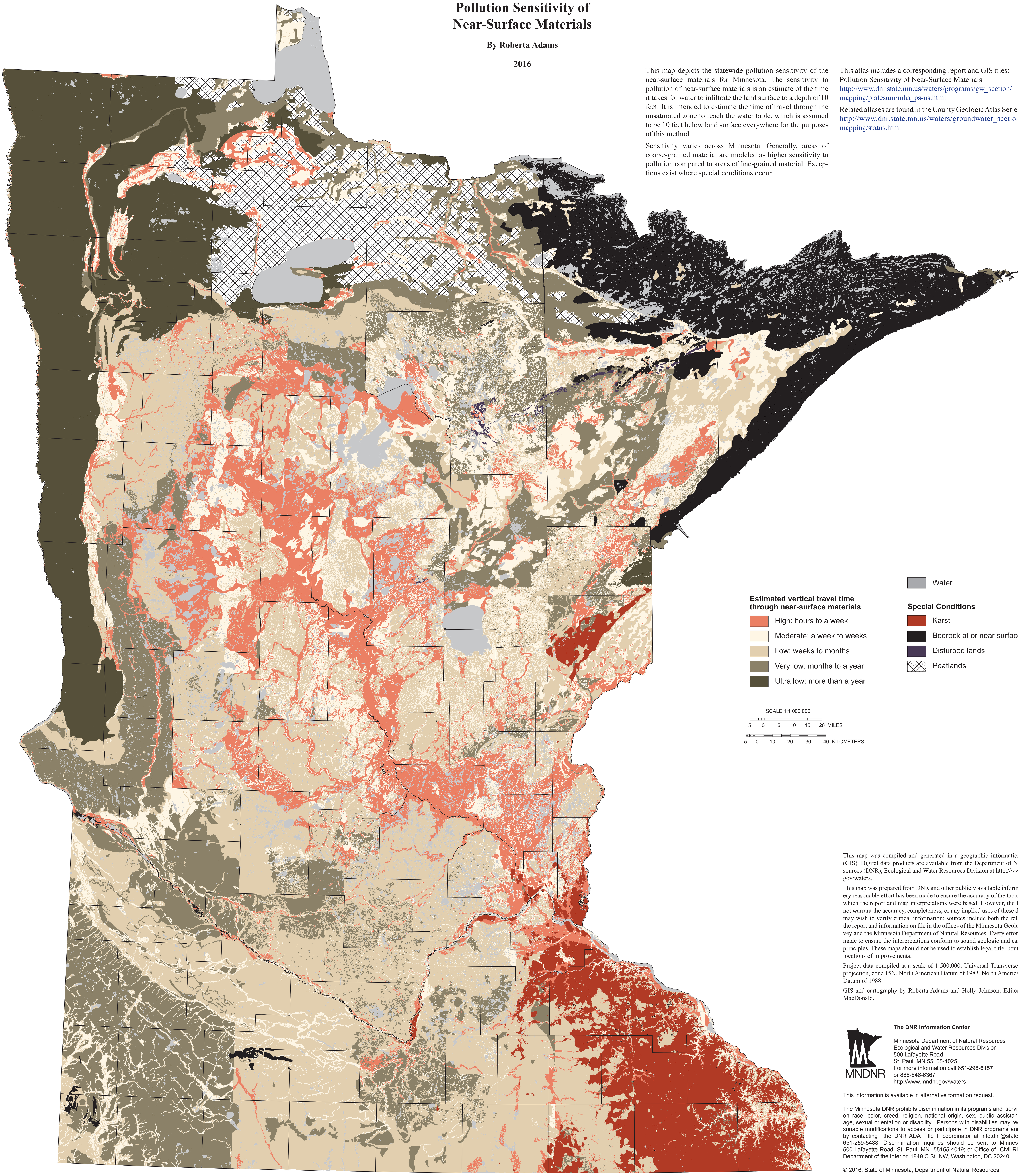
2016

This map depicts the statewide pollution sensitivity of the near-surface materials for Minnesota. The sensitivity to pollution of near-surface materials is an estimate of the time it takes for water to infiltrate the land surface to a depth of 10 feet. It is intended to estimate the time of travel through the unsaturated zone to reach the water table, which is assumed to be 10 feet below land surface everywhere for the purposes of this method.

Sensitivity varies across Minnesota. Generally, areas of coarse-grained material are modeled as higher sensitivity to pollution compared to areas of fine-grained material. Exceptions exist where special conditions occur.

This atlas includes a corresponding report and GIS files: Pollution Sensitivity of Near-Surface Materials
http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/mha_ps-ns.html

Related atlases are found in the County Geologic Atlas Series: http://www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html



This map was compiled and generated in a geographic information system (GIS). Digital data products are available from the Department of Natural Resources (DNR), Ecological and Water Resources Division at http://www.mndnr.gov/waters.

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GIS and cartography by Roberta Adams and Holly Johnson. Edited by Ruth MacDonald.

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