Procedure for Determining Near-Surface Pollution Sensitivity

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Division of Ecological and Water Resources
County Geologic Atlas Program

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I. Background

This procedure document outlines modifications to the DNR's Near-Surface Pollution Sensitivity mapping approach and provides supporting documentation for the transmission rates that will be used in future mapping of Near-Surface Pollution Sensitivity. It incorporates a systematic approach for determining infiltration developed by the Minnesota Geological Survey (MGS) for the Scott County Geologic Atlas update (Tipping, 2006) that was based on previous work completed by Barr Engineering (Barr, 2005). Barr's approach used estimated transmission rates to evaluate the near-surface time of travel to interpret infiltration for resource management. The estimated transmission rates for the near-surface materials were taken from a Natural Resources Conservation Service (NRCS) online publication that estimated unsaturated hydraulic conductivities of soil hydrologic groups A, B, C, and D. Unfortunately, the NRCS documentation for the infiltration rates used in 2006 investigation is no longer available. DNR staff have adapted the approach for determining near surface pollution sensitivity for the Todd County Part B Geologic Atlas (Petersen, 2010), the Carlton County Part B Geologic Atlas (Berg, 2011), and the Benton County Part B Geologic Atlas (Rivord, 2012).

II. Determination of Transmission Rates using Matrix Textures

The sensitivity-to-pollution assessment for near-surface materials estimates the time it would take for water to travel from the land surface to a depth of 10 feet in unsaturated conditions. Soil and sediment texture are the primary inputs into the determination of transmission rates. Texture is a measure of the range of particle sizes from coarse materials such as gravel and sand to finer materials such as silt and clay. In general, coarse-grained materials have faster transmission rates than fine grained materials. In this approach, attributes of the hydrologic soil group and surficial geologic matrix texture are coupled to estimate the time of travel.

The hydrologic soil group, provided by the NRCS county soil survey, generally combines soils into one to four hydrologic groups based on the soils hydrologic properties. Soils are classified with a Hydrologic Soil Group description ranging from A to D, with A soils being primarily coarse grained and D soils being primarily fine grained. The surficial geologic matrix texture is assigned using specific matrix textural data provided in the MGS Part A atlas. Soils assigned dual hydrologic soil groups, A/D, B/D, C/D, are typically soils that are saturated yet can be drained. This model assumes unsaturated conditions to a depth of 10 feet, so dual hydrologic soil groups don't apply. Soils with dual hydrologic soil group designations are reclassified using the first letter of the dual hydrologic soil group.

A. Method to Derive Transmission Rate from Texture

This approach begins with saturated hydraulic conductivity (K_s) rates to derive transmission rates that can be used for time-of-travel calculations. Numerous investigators have determined K_s rates for a range of soil textures. A comprehensive dataset of saturated K_s values for fourteen USDA-NRCS soil texture classes (Rawls, 1998) agrees with investigations conducted by others (NRCS, 2007 and Ferguson & Debo, 1990). Table 1 illustrates ranges of K_s values determined by hydrologic soil groups for common geologic textures from three different sources. K_s varies within each hydrologic soil group depending on a number of factors including the soil's relative percentages of sand, silt, and clay, antecedent moisture conditions, the presence or absence of macropores and hydraulic head.

Table 1. Ranges of Saturated Hydraulic Conductivity (K_s)
for Hydrologic Soil Group and Geologic Texture

Hydrologic Soil Group	NRCS,2007 [in/hr]	Rawls, 1998 [in/hr]	Ferguson & Debo, 1990 [in/hr]	Geologic Textural Classification
A, A/D	>1.42	>5.3	>8.27	Gravel, Sandy Gravel, Silty Gravel
	1.42	5.3-4.8	8.27	Sand, Fine Sand, Silty Sand
B, B/D	1.42	2.6-2.3	2.41	Silt, Silty Fine Sand, Loamy Sand
	0.57	0.9-0.3	1.02	Sandy Loam, Peat*
C, C/D	0.57	0.3-0.2	0.27	Silt Loam, Loam
	0.06	0.14	0.17	Sandy Clay Loam
D	<0.06	0.17-0.04	0.09-0.02	Clay, Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay

** Assumes Hemic Peat*

Transmission, synonymous with infiltration in this document, is estimated using the Green and Ampt equation (Bouwer, 2002). The transmission rate or the hydraulic conductivity (K) of the wetted zone which has water and entrapped air in the pore spaces "… is less than K_s at saturation, about 0.5 K_s for sandy soils, and 0.25 K_s for clays and loams" (Bouwer 1978, Bouwer 1995, Bouwer 2002). The near-surface-sensitivity model developed herein assumes that soils are unsaturated to a depth of 10 feet so hydraulic conductivity values are lowered for this interval by using K (Bouwer, 2002). Additional saturated to unsaturated hydraulic conductivity references are found in ASTM D 5126 and Jammal and Assoc. (1989).

Table 2 is a modified version of *Table 2.4 Design Infiltration Rates* from the Minnesota Pollution Control Agency's Stormwater Manual (MPCA, 2005) that was used as a starting point. It breaks down hydrologic soil group rates by texture, allowing greater flexibility to the user and lists a range of saturated hydraulic conductivity values based on hydrologic soil group that are primarily from the *National Engineering Handbook* published by the NRCS (NRCS, 2007), but are supplemented with values from Rawls (Rawls, 1998). Included within the table are two columns, columns "I" and "II" that list the transmission rates to be used in this model. The transmission rates were determined by applying Bouwer's coefficients, listed in the column titled *% saturated K*, to the saturated K values. The saturated K values that were empirically corrected for unsaturated conditions that fall within published ranges of infiltration from a number of investigations. Comparison of the saturated rates listed in Table 1 to those used in Table 2 demonstrates that the rates used are generally consistent with respect to soil texture / hydrologic soil group.

Table 2. Transmission Rates through unsaturated materials for Hydrologic Soil Groups and Geologic Textures

Hydrologic Soil Group	Saturated K_s [in/hr]	% Ks	"I" Hydrologic Soil Group (0'-3') Transmission Rate [in/hr]	"II" Geologic Texture (3'-10') Transmission Rate [in/hr]	Geologic Textural Classification
A, A/D	2*	0.5	1	1	Gravel, Sandy Gravel, Silty Gravel
	1.42*	0.5		0.71	Sand, Fine Sand, Silty Sand
B, B/D	1*	0.5	0.50	0.50	Silt, Silty Fine Sand, Loamy Sand
	0.57*	0.5		0.28	Sandy Loam, Peat***
C, C/D	0.3**	0.25	0.075	0.075	Silt Loam, Loam
	0.14**	0.25		0.035	Sandy Clay Loam
D	≤0.06*	0.25	0.015	0.015	Clay, Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay

** Values derived from range of values published within NRCS, 2007*
*** Values derived from range of values published within Rawls, 1998*
**** Assumes Hemic Peat*

B. Method to Assign Texture to Mapped Surficial Geologic Units

Matrix texture is the less than 2mm fraction of a sediment sample that has been separated by standard sieve analysis. The matrix texture for most surficial geologic units and some Quaternary Stratigraphic units is usually shown in a Part A table characterizing the relative sand, silt, and clay percentages of the unit. If a surficial geologic unit is not shown in the table, then the matrix texture must be determined from the map unit description. Sometimes, the matrix texture data are not presented in the Part A report. These data may be available directly from the MGS by contacting the MGS geologist who created the plate. If matrix texture data are not available, the surficial geologic unit descriptions usually provide sufficient information to select the appropriate unit texture. If it is necessary to choose the transmission rate based on unit description, choose the fastest rate available within a unit descriptions range. For instance, if the unit description states the unit is loam to sandy loam, then the sandy loam rate of 0.28 inches/hour would apply. Note that geologic units are not homogenous and vary in texture both laterally and with depth. This approach assigns a uniform transmission rate for entire units.

Plotting matrix texture for geologic units described in the counties Part A Surficial Geology and/or Quaternary Stratigraphy plates on the USDA soil texture classification ternary diagram allows the user to assign objective and reproducible transmission rates to the units for which sieve results are available. For example, a surficial geologic unit is described in a Part A matrix texture table as having a composition of 55% sand, 30% silt, and 15% clay. When plotted on the soil texture triangle, Figure 1, this composition classifies the unit as a Sandy Loam. The geologic texture Sandy Loam is then selected from Table 2 to choose the appropriate transmission rate of 0.28 inches/hour for the geologic unit with this texture.

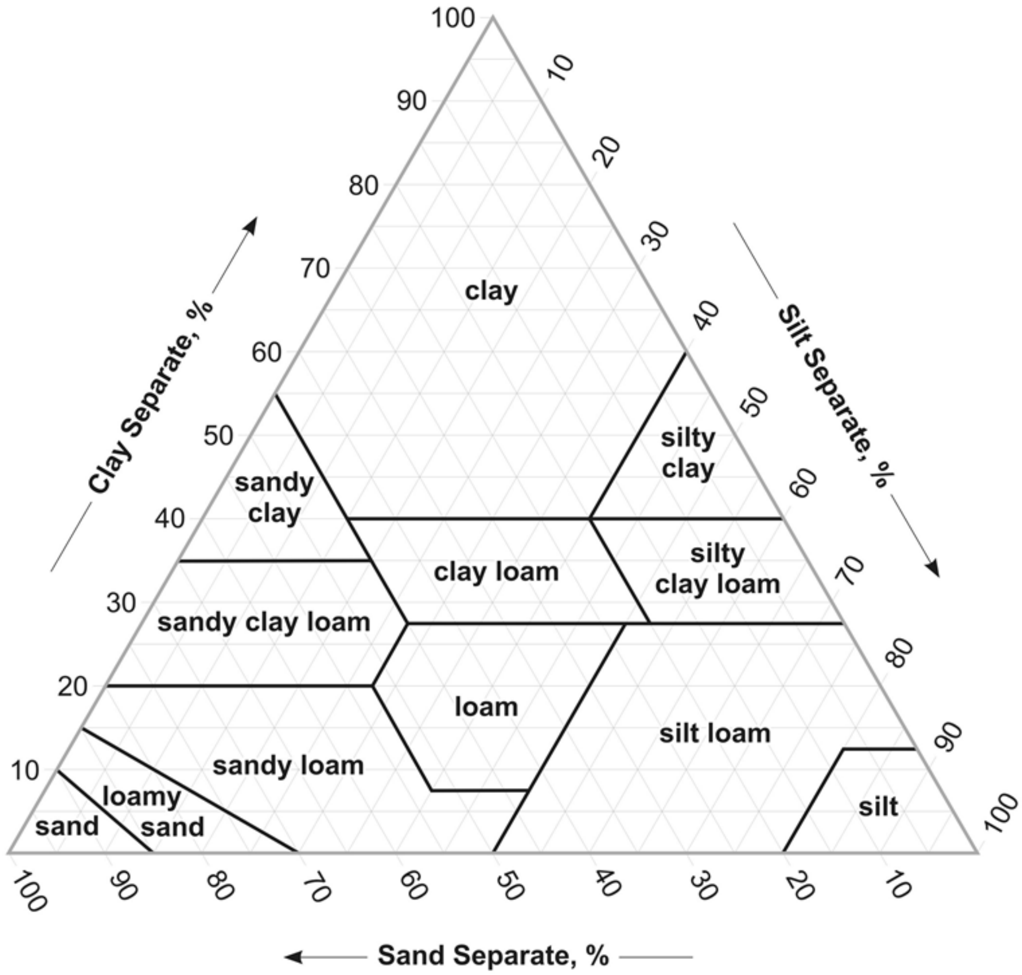

Figure 1. United States Department of Agriculture (USDA) Soil Textural Triangle

from: http://soils.usda.gov/education/resources/lessons/texture/textural_tri_hi.jpg

III. Applying Transmission Rates to Determine Sensitivity of Near-Surface Materials

The near-surface-materials sensitivity rating is determined using the transmission rates from Table 2 to calculate an estimated time of travel time of a containment that moves conservatively with water to a depth of 10 feet below land surface. The steps below offer the general approach used to create the maps.

1. GIS polygons from soil and surficial geologic units are brought together by the GIS union process. Soil polygons are a product of the Natural Resources Conservation Service (NRCS) and the surficial geologic polygons are a product of the MGS Part A (Geologic) mapping. The union process creates new polygons that have the attributes of both the soil and surficial geologic unit polygons. The soil polygons are obtained from the NRCS Soil Data Mart, available on-line at: http://soildatamart.nrcs.usda.gov/Default.aspx.
   The surficial geology polygons are obtained from the MGS and are available on-line at: http://www.mngs.umn.edu/county_atlas/countyatlas.htm.

2. The travel time for 0 to 3 feet below land surface is calculated using the transmission rates from the Hydrologic Soil Group (0-3 feet) column labeled “A” in Table 2.

3. The travel time for 3 feet to 10 feet below land surface is calculated using the transmission rates from the Geologic Texture (3-10 feet) column labeled “B” in Table 2. Determine the geologic unit texture from a Part A matrix texture table, a unit description from a Part A Surficial Geology plate, or from descriptions provided in a Part A Quaternary Stratigraphy plate. Geologic units with texture data should be classified using the soil textural triangle approach outlined above. If a unioned polygon is not populated with soil hydrologic group data, then use the surficial geologic unit texture for the entire 0-10 foot range.

Figure 2 illustrates the approach used to calculate the estimated time of travel for a polygon with both Hydrologic Soil Group and Geologic Texture inputs; and the approach used to calculated time of travel for a polygon for which there is no soil data available.

Figure 2. Example Time of Travel Calculations

Example A - The unioned polygon has attributes of both the Hydrologic Soil Group (HSG) and the surficial geologic texture. In this example, the polygon's HSG is A and the surficial geologic texture is Loamy Sand.	**0-3 ft. below ground surface**	**3-10 ft. below ground surface**	**Total Time of Travel (hours)**	**Sensitivity Category**
	36"/ soil transmission rate (in/hr)	84"/ surficial geologic transmission rate (in/hr)		
	36"/ 0.50"/hr	84"/ 0.5"/hr		
	72	168	240	Moderate, 170-430 hours

Example B - The unioned polygon has no hydrologic soil group attributes (e.g.- gravel pit), only surficial geologic texture attributes (Loamy Sand) are used for the travel time calculation.	**0-10 ft.**			
	120"/ surficial geologic transmission rate (in/hr)			
	120"/ 0.5"/hr			
	240		240	Moderate, 170-430 hours

1. The total travel time from 0 to 10 feet below land surface is the sum of the estimated travel times for 0-3 feet and 3-10 feet. The total travel time for each unioned polygon is then interpreted using the Near-Surface Pollution Sensitivity criteria outlined in Table 3.

Table 3. Near-Surface Pollution Sensitivity Criteria

Near-Surface Pollution Sensitivity	Time of Travel	Description
Very High	Very Fast	Overlay in karst areas or where fractured bedrock is within 10 feet of land surface
High	<170 hours	Hours to a week
Moderate	170.01 to 430 hours	A week to weeks
Low	430.01 to 1600 hours	Weeks to months
Very Low	1600.01 to 8000 hours	Months to a year

IV. Model Limitations

This model is heavily dependent on matrix texture of soils and the parent material and assumes that they are relatively homogenous within mapped units. This model does not explicitly take into account other variables such as hydraulic head, soil compaction, drain tiles, macropores, or other soil heterogeneities. Dense soils will decrease infiltration and an overlay of dense soils can be created where appropriate by querying the NRCS data. Some investigators have found a correlation between matrix texture and the likelihood of subsurface fracturing (Kim & Christy, 2006). In regions of the state where karstic or fractured bedrock lies within 10 feet of the land surface, a GIS overlay should be used to re-classify areas calculated as *high* into a category of *very high*.

The maps generated through this process are generalized interpretations of near-surface sensitivity. They are intended to be used for resource protection planning and to help focus the gathering of information for site-specific investigations.

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