Methodologies for Determining Groundwater Vulnerability in Saline County, Missouri

Prepared for the Missouri Department of Natural Resources
Division of Environmental Quality
Public Drinking Water Program

December 23, 1998

Submitted by Chris Barnett
Center for Agricultural, Resource and Environmental Systems
Department of Agricultural Economics
University of Missouri-Columbia
List of Tables

Table 1. DRASTIC Components and Weights ................................................................. 9

List of Figures

Figure 1. Saline County Regional Groundwater Sources .............................................. 2
Figure 2. Saline County Soil Permeabilities ................................................................. 3
Figure 3. Saline County Hydrologic Groups ................................................................. 4
Figure 4. Geologic Map of Saline County .................................................................. 5
Figure 5. Saline County Geologic Permeability Descriptions ..................................... 5
Figure 6. Saline County Structural Contour Map ......................................................... 7
Figure 7. Pennsylvanian Cover in Saline County ......................................................... 8
Figure 8. Depth to Water .......................................................................................... 10
Figure 9. Net Recharge ............................................................................................ 10
Figure 10. Aquifer Media ......................................................................................... 11
Figure 11. Soil Media ............................................................................................... 11
Figure 12. Topography .............................................................................................. 12
Figure 13. Impact of Vadose Zone ........................................................................... 12
Figure 14. Hydraulic Conductivity ........................................................................... 13
Figure 15. DRASTIC Scores ................................................................................... 14
Figure 16. Pesticide DRASTIC Scores ................................................................... 14
Figure 17. Grouped DRASTIC Scores ..................................................................... 15
This report addresses task 21 from the FY1998 Vulnerability Assessment project which was to 
*Develop a methodology for determining vulnerability areas based on 1:24,000-scale soil and 
geology data for a pilot county.* Include a report and maps. Saline County was chosen as the 
area of analysis for this task. This was based on the availability of both soil and geologic data 
for a large area in digital format.

Three methods were employed to determine vulnerability areas. These were vulnerability based 
on permeability, vulnerability based on recharge potential, and vulnerability based on DRASTIC, 
a groundwater pollution potential evaluation system developed by the U.S. EPA.

**BACKGROUND**

Saline County is located in central Missouri. One of the larger counties in Missouri, Saline 
County has a transitional landscape including extensive river bottoms, rich deep loess hills and a 
portion of the wooded Ozark border. Saline's 23,000 residents have traditionally relied on an 
economy based on agriculture and its related industries. While Saline's rich soils and good 
climate continue to make agriculture a primary industry, other activities, such as tourism and 
industry, are becoming established within the county. New agricultural practices and an increase 
in concentrated animal feeding operations are also changing the traditional agricultural industry. 
Additionally, the slow decline in population experienced since the turn of the century has 
stopped and, in recent years, the population has been increasing.

Saline County lies in the Mineralized Groundwater Province of Missouri, an area of the state 
where naturally occurring dissolved solids creates poor-quality bedrock groundwater. Several 
spings in the county produce highly mineralized (or saline) water, providing the county its 
name. The county’s southern border approximates the mineralized-water fresh-water boundary 
in bedrock water sources in Missouri. Because of this mineralization, much of the ground water 
withdrawal for public drinking water in Saline County is from the broad alluvial regions along 
the Missouri River. Three general groundwater sources supply public water in Saline County – 
the Missouri River alluvium, Teteau Flats and the bedrock sources. Bedrock water sources 
include the Springfield Aquifer (Burlington – Keokuk Limestones) and the Ozark Aquifer 
(numerous geologic formations, most significantly the Potosi, Gasconade and Roubidoux). 
These areas are illustrated in Figure 1.

There are four active primary public drinking water systems in Saline County, all relying on 
ground water. These are Marshall, Slater, Countryside Palace and Breaktime C-Store & 
Restaurant. Marshall serves a population of 12,800 directly, and provides water to an additional 
2,585 people through multiple secondary systems (systems that purchase water rather than 
develop their own water sources). Slater directly serves 2,186 people, with an additional 1,062 
in secondary systems. Breaktime and Countryside Palace are both transient systems, serving a 
total of about 550 people. Secondary systems supplied by Saline County wells include Gilliam, 
Malta Bend, Saline Co. PWS#1, Saline Co. PWS#2, and Saline Co. PWS#3. One 
additional secondary system, Lafayette Co. Cons. PWS#1, supplies water to much of western 
Saline County, including the towns of Sweet Springs, Mount Leonard and Blackburn. Lafayette
Co. Cons. PWSD #1 purchases water from the surface water supplies of Concordia and Higginsville.

Marshall and Slater depend on the alluvial aquifers along the Missouri River for water supply. These aquifers can dependably supply large amounts of fresh water needed by these systems. The wells for Slater are located in the floodplain very near the Missouri River. Average well depths are about 65 feet. Marshall’s wells are located three to four miles from the river on an alluvial terrace (Teteseau Flats). This terrace, elevated 60 to 70 feet above the floodplain, contains slightly coarser sands and gravels than the bottomlands near the river. Marshall’s well depths range from 120 to 148 feet. The two transient systems rely on bedrock groundwater sources. Both are located in the area of Marshall Junction in the south-central region of the county. Well depth information was not available for these systems, but based on known depths of other wells in the area, the depths are likely in excess of 150 feet.

**Figure 1. Saline County Regional Groundwater Sources.**

**VULNERABILITY BASED ON PERMEABILITY**

The simplest method to determine vulnerability is to examine potential for contaminants to move from the surface into the groundwater based on soil and geologic characteristics. Using this
method, vulnerability is based on soil and geologic permeabilities. Soil information was taken from the 1:24,000-scale Soil Survey of Saline County. Geology was developed from a 1969 master’s thesis entitled “Geology and Groundwater Resources of Saline Co., Missouri”. As part of this thesis, a geologic map of Saline County was prepared on 1:24,000 and 1:62,500-scale maps, depending on map availability. All data was traced over 62,500 maps or photo-reduced 1:24,000 to produce a final 1:62,500-scale map.

Investigations into vulnerability based on soil characteristics were focused on two attributes provided with the digital soil survey, permeability and hydrologic group. The soil permeability, measured as the number of inches per hour that water moves downward through the saturated soil, is a rating of the ability of the soil to transmit water. This can be used to indicate the possibility of a water-born contaminant moving through the near-surface material. Permeability ratings in the soil survey are provided as a range for each soil layer within a soil map unit. Because the GIS handles data applied to whole map units, an average permeability was developed for each soil type. This was calculated by assigning the median value of each permeability range to each layer, then deriving a weighted average for all layers in the map unit based on layer thickness. The resulting data range was from .03 to 13 inches per hour. Figure 2 shows the resulting data layer.

![Saline County Soil Permeabilities](image-url)

Figure 2. Saline County Soil Permeabilities.
Soils with moderate and moderately slow permeabilities comprise about 92% of Saline County. Rapid or moderately rapid soils are found in less than one percent of the county. Generally, moderate permeability soils are found over the bedrock water source areas of Saline County, moderate to slow permeabilities in Teteseau Flats, and a wide variety of permeabilities are found in the Missouri River alluvium.

Hydrologic soil groups are groupings of soils based on their inherent capacity to permit infiltration independent of slope or land cover. Soils are assigned to one of four categories, A through D. Hydrologic group A soils have a high infiltration rate, while D soils have a very slow infiltration rate. This can be used as a second indicator of ground water vulnerability based on soil survey data. As Figure 3 shows, a high correlation between hydrologic groups and soil permeability exists in Saline County. Moderate infiltration rates (groups B and C) are dominant over much of the bedrock water source areas. Moderate to slow infiltration rates are found in the Teteseau Flats, while mixed infiltration rates continue to appear in the Missouri River alluvium.

Vulnerability determination using available geologic information was limited. While the available geologic map was fairly detailed (Figure 4), lack of certain supporting information restricted the use of this layer for the analysis. In the thesis, the author describes the water-
Geology

Recent Alluvium
Nebraskan - Kansan Drift
Desmoinesian Undifferentiated
Burlington - Keokuk Formation
Chouteau Group (Limestones & Shales)
Callaway Cooper Facies
Kimmswick Formation
St. Peter Sandstone

Groundwater Regions

Figure 4. Geologic Map of Saline County.

Geologic Permeability

High
Low
Very Low
Not Rated

Figure 5. Saline County Geologic Permeability Descriptions.
yielding characteristics of each geologic formation. The alluvial areas were not rated, with the exception of the Kansan-Nebraskan formations of the Teteseau Flats. He places nearly all formations depicted on the map into the ‘low to nearly impermeable if not jointed’ category (Figure 5). In particular, the Pennsylvanian (Desmoinsian Undifferentiated) is described as having a very low permeability. Lower formations, those below the St. Peter Sandstone were not mapped, but were generally described as having greater water bearing characteristics.

Because information on the amount of fracturing, solution channels or other characteristics affecting permeability are not quantified within the thesis, development of infiltration or permeability maps, such as was done with the soil data, is limited. While Figure 5 shows generally low permeability ratings, certain areas within the county may have moderate or high ratings depending on localized fracturing or solution channels. Dissolution activity is particularly evident in the area around Arrow Rock, where a number of sinks and springs are found. An important water bearing area, the Missouri River alluvium, is not even described within the thesis. Because of these considerations, combining the soil data with geologic data to create a final vulnerability map produces an inadequate interpretation of vulnerability.

VULNERABILITY BASED ON RECHARGE POTENTIAL

The second approach looks at the potential for aquifer recharge in Saline County and attempts to determine recharge areas. Vulnerability is based on the potential for surface activity to influence groundwater. Two aquifer systems are considered in this analysis, the alluvial aquifers (Missouri River Alluvium and the Teteseau Flats) and the Springfield aquifer, the bedrock aquifer nearest the surface in Saline County.

Recharge to the alluvial aquifers is from many sources, including direct precipitation, the Missouri River, numerous streams flowing down from higher elevations, and recharge from bedrock aquifers. However, since this analysis is restricted to influence of surface activities on groundwater quality, the characteristics of the first few feet of the alluvium have the most significant influence on vulnerability. The vulnerability map would look something like the permeability map (Figure 2) for the alluvial areas.

Burlington-Keokuk Limestones comprise the Springfield aquifer, which lies between Pennsylvanian deposits above and Chouteau Group deposits below. In general, the near impermeability of the Pennsylvanian layer restricts water movement, reducing meteoric recharge. The Pennsylvanian layer in Saline County ranges from 0 to 240 feet in thickness and is the leading edge of the Western Interior Plains confining system. This confining system overlays the Springfield aquifer, which receives most of its recharge from precipitation in exposed areas. Therefore, this aquifer is most vulnerable to surface activities where the Pennsylvanian is non-existent or where it is thin and fractured. The geologic map of Saline County (Figure 4) shows significant areas of the Burlington-Keokuk Limestones associated with the Springfield aquifer. Most importantly, these areas coincide with structural highs, or anticlines, which serve as underground watersheds. Water infiltrating to bedrock depth is directed along bedding plains away from these highs toward other parts of the aquifer, shown by
the arrows in Figure 6. Recharge is most significant on the Cow Creek anticline, which is free of any Pennsylvanian cover. Recharge at the Blue Lick anticline is greater in the southeast part of the county, but is greatly reduced as the Burlington-Keokuk drops below the thicker Pennsylvanian layers in the western portion of the county. The Fish Creek anticline has Pennsylvanian cover, but due to its reduced thickness and some exposure of the Burlington-Keokuk, meteoric recharge still occurs.

Because presence and thickness of the Pennsylvanian has such an influence on recharge to the Springfield aquifer, an attempt was made to predict its thickness. The structural map shows the top of the Chouteau, or the bottom of the Springfield aquifer. The Springfield aquifer has an average thickness of about 200 feet. Given this, areas more than 250 feet above the Chouteau should have about 50 feet of Pennsylvanian cover, providing increased restriction to water movement. The GIS was used to find areas where the surface elevation, based on USGS 1:24,000 DLG hypsography, was more than 250 above the surface of the Chouteau.

Figure 7 shows the predicted areas of Pennsylvanian cover greater than 50 feet. The yellow areas are where the model predicts thick Pennsylvanian cover. The red outline shows the limits of Pennsylvanian from the geology layer of Saline County. The analysis results seem to show a high correlation with the geologic layer. The apparent predictive failure of the model in the
northwestern portion of the county is due to the mapping of alluvial deposits over the Pennsylvanian within the geology layer. Only along the southwestern edge of the eastern section of Pennsylvanian cover does the model predict incorrectly. This is likely due to the generalization of the structural data as well as the 200-foot assumption for the thickness of the Springfield aquifer.

The map in Figure 7 can be used as a vulnerability map for the Springfield aquifer in Saline County. Surface activities in the white areas may have the greatest impact on the aquifer, as there is complete exposure of the Burlington-Keokuk. Areas in red hatch with no yellow are have a moderate vulnerability, as there is only a thin layer of protective Pennsylvanian. Areas in yellow (including overlaying red hatch) have a low vulnerability to surface activities due to the protective Pennsylvanian. Areas in blue are structurally below the Burlington-Keokuk.

A second, deeper aquifer, the Ozark Plateaus aquifer system, is also present in Saline County. However, research on this aquifer system indicates that most recharge occurs outside Saline County in areas where the bedrock layers comprising the aquifer system are more exposed. The Springfield and Ozark aquifers are separated by a thin confining layer, generally less than 100 feet thick, which does allow transmission of small quantities of water. Because of this,
vulnerability of the Ozark aquifers to surface activities in Saline County does exist, but the risk should be described as low for the entire county.

Actual use of these aquifer systems, for public or domestic systems, is limited in Saline County. The Springfield aquifer provides limited quantities of water, generally used for domestic supplies. This aquifer has both fresh and saline water regions in Saline County. The deeper Ozark aquifers do provide higher quantities of water, which could supply public systems, but salinity factors make water quality poor to fair at best. Many water systems, both domestic and public, have connected to the public water districts that rely on alluvial or surface water sources. This trend will likely continue in the near future.

VULNERABILITY BASED ON DRASTIC

DRASTIC is a groundwater pollution potential evaluation system developed by the U.S. EPA. This system was developed as a standardized tool to measure relative groundwater vulnerability to pollution. The objective of the system is to determine general vulnerability. The system was not designed for site-specific evaluation.

DRASTIC is an acronym referring to the components required by the system (see Table 1). These factors are accumulated to calculate a DRASTIC score. Each factor is weighted for it’s relative importance. Two weighting systems have been developed – normal DRASTIC and pesticide DRASTIC. The latter was developed to focus on vulnerability to usage of agricultural chemicals.

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
<th>Pesticide Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>D – Depth to Water</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>R – (Net) Recharge</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>A – Aquifer Media</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>S – Soil Media</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>T – Topography (Slope)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>I – Impact of the Vadose Zone Media</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>C – Conductivity (Hydraulic) of the Aquifer</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

A layer for each of the seven components was developed. These were based on the best available information. Guidance for layer development and execution of the DRASTIC system was obtained from the EPA publication entitled “DRASTIC: A Standardized System for Evaluation Ground Water Pollution Potential Using Hydrogeologic Settings.

The following figures show the seven data sets developed for the DRASTIC system. Each figure includes the points assigned to the various regions of the county.
Figure 8. Depth to Water – Based on static water data within the Vulnerability Assessment Geographic Information System (VAGIS). Ratings are assigned to different areas based on depth to the aquifer used for drinking water. For the alluvial areas, a depth rating of 8 was assigned to all alluvial areas, 3 to the Teteseau Flats, and 1 to the non-alluvial areas. Depth to water for the non-alluvial areas of Saline County was estimated for the deeper Ozark aquifers.

Figure 9. Net Recharge – Based on section 7 of the DRASTIC manual, “Ground-Water Regions and Hydrologic Settings of the United States”. Descriptions from the sections on glaciated and non-glaciated central regions were used. A special region for the karst region around Arrow Rock was created to indicate higher recharge through these features. Typical values were assigned for the various regions of the county. These were: Non-Glaciated Central – 6, Solution Limestone – 9, River Alluvium – 8, Glacial Till Over Sedimentary Rock – 6, Buried Valley – 8.
Figure 10. Aquifer Media – Based on the groundwater regions of Saline County. The Missouri River floodplain and Teteseau Flats were placed into the Sand and Gravel category. The floodplain was assigned 8, while Teteseau Flats was assigned a rating of 9, reflecting the slightly coarser composition. Most of the remainder of the county was placed into the Massive Limestone category rated at 6, with the karst region again separated with a rating of 10.

Figure 11. Soil Media – Based on the 1:24,000 scale Soil Survey of Saline County. Soils were rated according to the soil textural classification chart. Assignments varies from 1 to 9, with high clay content soils receiving lower ratings. Where clay soils had a high shrink-swell potential, however, a high rating (7) was assigned to account for transport of contaminants through fractures. In general, the bedrock and Teteseau Flats groundwater regions received moderate ratings, while the Missouri River floodplain varied greatly.
Figure 12. Topography (Slope) – Based on the 1:24,000 scale USGS DLGs for the Saline County area. The lower the percent slope, the greater the potential for infiltration. Slope ranges were rated as follows: 0 – 2% - 10, 2 – 6% - 9, 6 – 12% - 5, 12 – 18% - 3, 18%+ - 1. All five categories were present in Saline County, with ratings of 10 and 9 being dominant.

Figure 13. Impact of Vadose Zone Media – This component defines the material below the soil and above the aquifer. The DRASTIC manual provides descriptive categories and rating ranges for each category. Most of the bedrock aquifer area of the county was categorized as limestone with a rating of 6. The exceptions to this were the karst region around Arrow Rock, rated at 10, and the confining areas of thick Pennsylvanian, rated at 1. The thick Pennsylvanian areas were derived from the previous analysis, with modifications made to the eastern portion to more accurately reflect the geology. The Teteau Flats and Missouri River floodplain were categorized as sand and gravel, receiving ratings of 8 and 7 respectively.
Figure 14. (Hydraulic) Conductivity – Refers to the ability of the aquifer media to transmit water. This was the most difficult information to collect. Ratings were assigned based on descriptions in the DRASTIC manual. For most of the bedrock area the Springfield aquifer was rated. This was assigned a rating of 1. The exception, again, was the karst region around Arrow Rock, which was rated at 10. Teteseau Flats and the Missouri River floodplain were rated at 9.

To create a final composite score, each rating in each layer was combined by the weights in table 1. The weighted layers were then combined to produce a final DRASTIC score layer. Figure 15 shows the results of the DRASTIC analysis. The scoring system is relative; areas with higher scores have a greater vulnerability to contamination compared to those with low scores. The Missouri River floodplain and the karst area around Arrow Rock have generally high scores. Moderate scores are found in Teteseau Flats and other shallow alluvial areas. The bedrock areas have the lowest relative vulnerability.

The pesticide weighted DRASTIC scores (Figure 16) shows the results of the analysis for vulnerability to agricultural contaminants. This analysis places a higher weight on topography and soil information, creating a more complicated map. However, the same pattern is generally evident. Higher vulnerabilities are present in the Missouri River floodplain and lower vulnerabilities in the bedrock areas. Greater variability in the unconfined bedrock areas is evident, however, suggesting less uniformity than the DRASTIC score would indicate. Scores the Pesticide DRASTIC analysis are higher, but it should be noted that these scores are relative within each analysis, and a direct score comparison between the two is not advisable.
Figure 15. DRASTIC Scores.

Figure 16. Pesticide DRASTIC Scores.
Although the better quality data, the soils and topography data, are more heavily weighed in the Pesticide DRASTIC analysis, this analysis does not necessarily produce more meaningful results. The intent of the two analyses is to present two approaches to measuring groundwater vulnerability using the same data and tools. The resulting scores of either analysis do not mean much, however, when trying to provide a simple view of vulnerability. A statistical grouping of results, using quantiles, into three ratings – high, medium and low – produces a more meaningful map of the area. Interestingly, although the score ranges for each analysis vary, this type of grouping produces very similar maps for both the DRASTIC and Pesticide DRASTIC analyses. Figure 17 shows the grouping of Pesticide DRASTIC scores.

![Figure 17. Grouped DRASTIC Scores.](image)

It should be noted that DRASTIC has many shortcomings. It does not take into account aquifer gradient, direction of groundwater flow or surface activities. It does not rate absolute vulnerability. It does not estimate vulnerability to any particular contaminant, nor does it take into account contaminant concentrations.

CONCLUSIONS

Three methods, simple permeability mapping, recharge potential, and DRASTIC modelling, were used to attempt to determine vulnerability. Of these, the permeability mapping is the simplest and quickest to generate, but the resulting maps show great variability and it is difficult to use the soil and geologic information in conjunction. This difficulty exists because of the different approaches in each field to permeability measurement. The soil permeability
information may be adequate to rate vulnerabilities of the Missouri River Alluvium and Teteseau Flats, but the extreme variability of the soils in these areas would prevent any general vulnerability assignments.

Recharge potential mapping is usable as a vulnerability determination method, but it is most applicable for the Springfield Aquifer, which is not highly utilized as a drinking water source in Saline County. Recharge for deeper aquifers is most significant outside Saline County, and the alluvial aquifers, which receive recharge from a number of sources, have vulnerability to local surface activities most strongly based on soil and topographic properties. For the Springfield Aquifer, the vulnerability map (Figure 7) shows highly vulnerable areas in a wide band from Nelson to the Teteseau Flats, with other highly vulnerable areas around Arrow Rock and Gilliam. Low vulnerability areas are those with thick Pennsylvanian cover, mainly in west-central and northeast Saline County.

Among the three methods, DRASTIC modelling produces a vulnerability determination which best accounts for characteristics influencing vulnerability. The final map (Figure 17) is similar to the recharge map, but shows the alluvial aquifers as the most vulnerable, followed by areas without or with thin Pennsylvanian. Areas with thick Pennsylvanian are the least vulnerable. This probably best depicts the potential for surface activities to influence groundwater quality. The main drawback to this method is difficulty in obtaining input data, particularly conductivity and recharge information.

None of the methods used take into account specific properties of any contaminant, but rather present a vulnerability to general surface activity. It may be possible to use land cover information in conjunction with these vulnerability maps, but any such application would be limited due to lack of information on specific locations and amounts of contaminants.

Statewide application of these methods is possible. Soil data at an adequate scale is available for much of Missouri, which could be used to generate soil permeability maps. Limited availability of detailed geologic information, especially in digital format, would limit the geologic permeability mapping. Recharge potential at this scale depends on several data sets which are not available at this time – detailed geology data, structural contour data and surface elevation data. Data sets do exist, however, to perform this on a very generalized scale (1:500,000), but this would be prone to errors and over simplifications. The DRASTIC model is the most scale independent, but requires difficult to obtain input data. However, even with its many drawbacks, DRASTIC is likely the best of the simple approaches to determining groundwater vulnerability. Statewide application of the DRASTIC model has been done in other parts of the country with reasonable results.

Further investigation into these methods, particularly the DRASTIC method is warranted. This report was generated using certain assumptions and subject to many limitations. Evaluation of this report by a qualified hydrogeologist would be necessary before any further investigations are initiated.
References


