Geographic Targeting System

ABSTRACT

Many states have experienced groundwater contamination problems from a wide variety of point and nonpoint sources, including agricultural chemicals. However, not enough data is available in North Dakota to determine if agricultural chemical compounds have widely impacted water quality in the state. With limited funding, it is imperative that prevention and monitoring efforts be focused on the highest priority aquifers. The North Dakota Health Department, Division of Water Quality, has developed a system for prioritizing aquifers throughout the state, known as a Geographic Targeting System (GTS).

Three factors - vulnerability, sensitivity, and risk - have been given equal weight in determining the final ranking used to direct groundwater monitoring activities. Aquifer vulnerability is determined using the DRASTIC model, developed by the EPA to be a standardized system for evaluating groundwater pollution potential. Sensitivity primarily relates to the usage of agricultural chemicals and fertilizers. The market value of agricultural production per acre, for both crops and livestock, was used as a surrogate for fertilizer and pesticide use in each county. Risk is related to the value of loss of the beneficial use of the water, or amount of harm which may result from aquifer contamination. The total volume of groundwater permitted for withdrawal from an aquifer was chosen to represent the aquifer's potential risk. Because of a greater degree of uniformity, hydrogeologic units, in this case aquifers, are used for areas of evaluation rather than counties or other political units, which may contain several widely varying geologic settings.

All of the major glacial drift aquifers were digitized on an AutoCAD and ARC/INFO geographic information system. Aquifer data was entered into a dBASE IV database program which calculated the DRASTIC and Pesticide DRASTIC scores and the groundwater monitoring priority rankings. The database was linked to the digitized aquifer maps. Colored maps representing Pesticide DRASTIC scores, chemical use, permitted water usage, and total monitoring priority were produced using ARC View and the linked database and digitized maps.

INTRODUCTION, PURPOSE, & SCOPE

Groundwater is the major source of drinking water in North Dakota. Sixty percent of the state's total population utilize groundwater to supply their drinking water needs, while 97 percent of the state's rural population use groundwater for drinking water purposes. Agriculture and industry in North Dakota also rely heavily on groundwater.

Many states in the country have experienced groundwater contamination problems from a wide variety of point and nonpoint sources of pollution. North Dakota is primarily an agricultural state. However, insufficient information is available in North Dakota to determine if agricultural chemical compounds have widely impacted water quality in the state. Nonetheless, there is the potential that groundwater quality impacts could occur or have occurred from agricultural chemicals, based on water quality monitoring conducted in other states.

North Dakota Century Code, Chapter 23-33, states that the North Dakota Health Department will conduct groundwater quality monitoring in cooperation with the North Dakota State Water Commission (SWC) and other state agencies. With limited state and federal funding, it is imperative that prevention and monitoring efforts be focused on the highest priority aquifers. With this in mind, the NDHD, Division of Water Quality (DWQ), has developed a system for prioritizing aquifers throughout the state, known as a Geographic Targeting System (GTS).

The targeting and prioritizing of aquifers will assist agencies in focusing protection efforts in areas that are considered most likely to experience contamination and would pose the greatest risk if contaminated. The benefit will be to maximize the benefits of the limited funding by not initially directing monitoring/protection efforts to aquifers with a low potential for water quality degradation. By prioritizing the groundwater resources in the state, baseline monitoring of groundwater quality can be accomplished in a more efficient and orderly fashion.

The priority list of aquifers developed from the GTS will also be used to guide the Non Point Source (NPS) Pollution Task Force in identifying aquifers for inclusion in the North Dakota NPS Pollution Management Plan as Priority I and II water bodies. The North Dakota Agriculture Department (NDAD) will also use this information in their generic State Management Plan for Pesticides. The NDAD inspection program will intensify efforts in high priority areas and will promote best management practices in cooperation with other groups and agencies. The DWQ will continue this project with an agricultural chemical monitoring program designed to evaluate groundwater quality throughout the state, starting with the highest priority aquifers. The monitoring program will determine whether contamination problems exist, and may provide direction in remediation efforts, if needed.

The scope of the GTS and groundwater quality monitoring will include all major glacio-fluvial aquifers (Figure C-1). Bedrock aquifers in the state will not be included because they are generally less vulnerable to contamination, lower in quality, and located in areas where chemical applications are less frequent - predominantly range land.

Due to budget limitations, time restrictions, and the complexity of North Dakota geology, the GTS must be implemented utilizing existing aquifer data. It is also important that the GTS process be open-ended and expandable to be compatible with more sophisticated geographic information system (GIS) methods.

The GTS is not intended to map recharge areas or critical areas within aquifers where more stringent best management practices or restrictions will be applied. Rather it will be used to compare aquifers or sub-aquifer areas as whole units. The GTS is designed to be a planning and prioritizing tool. The ranking of the aquifers and associated maps cannot be used in lieu of site specific evaluations because of local variations and complexities in hydrogeologic conditions.

The aquifer prioritization ranking will be updated as additional or new information becomes available, e.g., pesticide sales data for counties or new aquifer investigations. In the future the system can allow for inclusion of other data or GIS coverages such as other potential contaminant sources or meteorological information. The DWQ welcomes any additional data, references, or interpretations which may be used in this program.

PREVIOUS INVESTIGATIONS

The North Dakota Weed Control Association is producing maps that show areas with high water table/high leach potential soils and high water table/intermediate leach potential soils. These maps only show areas where the water table may be five feet deep or less, at least seasonally. These maps were produced with technical assistance from the U.S. Soil Conservation Service (SCS) and NDHD. These maps are distributed by the SCS with their field technical guides, which do not contain any groundwater protection mapping. The GTS will not duplicate or contradict information on these maps, but will provide information that was previously not available.

PROJECT DESIGN

North Dakota Administrative Code, Section 33-16-02-01, states that it is public policy to protect and maintain all waters of the state, including groundwater. It has therefore been the policy of the DWQ to protect all beneficial uses of water. However, from a practical standpoint, the usage of groundwater has been prioritized, with the highest priority given to water resources which are currently used as drinking water supplies. Behind that are other waters which may potentially become drinking water supplies in the future, and other current beneficial uses.

A variety of methods have been used throughout the United States to assess the relative vulnerability of groundwater resources and prioritize areas where monitoring and protection efforts should be focused. The U.S. Environmental Protection Agency (EPA) has developed and used classification methods for aquifers or regions based on geologic and/or hydrologic parameters which are thought to affect groundwater movement and contaminant transport. Several states and federal agencies have used ranking methods to identify environmentally sensitive aquifers which include other parameters such as the use of pesticides or other contaminants of concern and the total population using the groundwater in the areas being evaluated.

The question of which method or parameters to select must be based upon how the assessment will ultimately be used and the availability/reliability of the data. To assist in the selection of an appropriate method, it is important to have a clear understanding of the meaning of several terms. Vulnerability and sensitivity have frequently been used interchangeably. The environmental protection community does not seem to follow a consistent definition of these terms. Their meanings have been used interchangeably in several EPA documents.

Aller et al. (1987) and Pettyjohn et al. (1991) use the term aquifer vulnerability to describe the relative physical ease with which a contaminant could enter the groundwater system. Vulnerability includes only the hydrogeologic factors which influence pollution potential. These authors use the term sensitivity in a broader scope which reflects the use or presence of a contaminant and/or agronomic practices. For example, two aquifers may have the same degree of physical vulnerability, however the aquifer which is located beneath or near areas of heavy agricultural chemical usage would have a greater sensitivity than the aquifer where no agricultural chemicals were being used. The usage of these two terms in this document will follow that of Aller et al. (1987) and Pettyjohn et al. (1991). The term risk is used in this document simply to describe the amount or value of potential loss which would occur should an aquifer become contaminated.

All three of these factors - vulnerability, sensitivity, and risk - are important in deciding where monitoring or other protection activities should be implemented. Therefore, in the GTS they have been given equal weight in determining the final ranking used to direct groundwater monitoring activities.

Method Used To Determine Aquifer Vulnerability

Aquifer vulnerability is determined using hydrogeologic characteristics which affect the transport of contaminants to the water table. The DRASTIC model was developed by the EPA to be a standardized system for evaluating groundwater pollution potential. The acronym DRASTIC stands for ***D***epth to water, net ***R***echarge, ***A***quifer media, ***S***oil media, ***T***opography, ***I***mpact of the vadose zone, and hydraulic ***C***onductivity (Aller et al., 1987). Based on correlations between DRASTIC scores and incidents of contamination in municipal wells, Kalinski et al. (1994) state that DRASTIC can be a valuable tool for identifying groundwater supplies that are vulnerable to contamination.

The use of DRASTIC involves rating each of the individual parameters for the area and multiplying the rating by a relative importance or weight constant. The formula to determine the total score for an aquifer is:

$$DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw = \text{Total Score}$$

where: r = rating ; w = weight

Parameter weights for the DRASTIC model have been assigned ranging from 1 to 5 for generic contaminant types (Table A-1). The most significant parameters have a weight of 5; the least significant, a weight of 1. A second set of weights has been assigned to specifically reflect contamination potential from the agricultural usage of pesticides. The parameter weights used to evaluate pesticide contamination potential are included in Table A-1 under the Pesticide DRASTIC heading. Pesticide DRASTIC is a special case of the generic DRASTIC model and is calculated exactly the same except for parameter weights. The ranges and corresponding ratings for each of the DRASTIC model parameters are shown in Tables A-2 through A-8.

The total DRASTIC or Pesticide DRASTIC score is relative, with no specific units. Total scores for two or more settings can only be compared when all of the parameters have been similarly evaluated, and the weighting of each parameter is the same for each calculation. Pesticide DRASTIC scores and regular DRASTIC scores cannot be compared to one another.

A hydrogeologic setting is a composite description of all the major geologic and hydrologic factors which affect and control groundwater movement into, through and out of an area. It is defined as a mappable unit with common hydrogeologic characteristics, and, as a consequence, common vulnerability to contamination by introduced pollutants. The DRASTIC model combines the ratings and ranges for vulnerability parameters with mappable hydrogeologic units to provide the user with a relative pollution potential for various hydrogeologic settings. A "typical" range for each DRASTIC parameter is assigned to each hydrogeologic setting and a DRASTIC score is determined for each typical hydrogeologic setting. These settings are developed as guides and are not designed to be representative of each and every area. The ranges for each parameter may be adjusted by the user and the rating adjusted accordingly when available data indicate different conditions. If no specific information is available to provide a rationale for making a change from a typical media, the typical rating is used.

<u>Method Used To Determine Sensitivity</u>

Sensitivity, for use in the GTS, primarily relates to the usage of agricultural chemicals and fertilizers. Data for the actual sale and use of most pesticides and fertilizers by county are not yet available in North Dakota. However, the National Pesticide Survey (NPS) Phase II Report (U.S. EPA, 1992) indicates a strong correlation between several surrogate factors and pesticide/nitrate detections. The surrogates that correlated best to nitrate detections include market value of livestock and percentage of land farmed. A surrogate that correlated to pesticide detections was the market value of crops. This generally affirms the assumption that more pesticides and fertilizers are applied in counties with higher production per acre.

This surrogate information is available for North Dakota on a county by county basis. Therefore the market value of agricultural production per acre, for both crops and livestock, was used as a surrogate for fertilizer and pesticide use in each county. When county specific data from manufacturers on the sales of selected pesticides in North Dakota is available the system will be modified, particularly if pesticide-specific monitoring is ever necessary.

<u>Method Used To Determine Risk</u>

For the GTS, risk is related to the value of loss of the beneficial use of the water, or amount of harm which may result from aquifer contamination. This is directly related to the volume or amount of water which is used or withdrawn from the aquifer. The SWC regulates water allocation in the state and issues permits for water usage. The total volume of groundwater permitted for withdrawal from an aquifer was chosen to represent the aquifer's potential risk. Data is not available on water volume used for private domestic supplies, because these wells are not required to be permitted.

Method Used To Determine Total Groundwater Monitoring Priority Score

The GTS uses an equal weighting of the average aquifer vulnerability to agricultural chemicals (Pesticide DRASTIC score), aquifer sensitivity (chemical usage surrogate), and risk (permitted water usage) to determine monitoring priority. Each aquifer was given a relative rating of low (1 point), moderate (2 points), or high (3 points) for each of these factors. The distinction between low, moderate, and high for each factor was set so that approximately one third of the aquifers in the state fall into each range. The values for the ranges of each of these factors are listed in Tables A-9 through A-12. The total groundwater monitoring priority score is then the sum of the ratings for each factor.

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                Example Aquifer:


Pesticide DRASTIC score - High      3 points


 Chemical Use Surrogate  - Low       1 point


Permitted Water Use     - Moderate  2 points
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Total Monitoring Priority Score     6 points
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Various monitoring protocols may be used depending on the priority of the aquifer. An aquifer with a total score of 3 or 4 points will be considered low priority; 5, 6, or 7 points will be considered moderate priority; and 8 or 9 points will be considered high priority. An example of the average Pesticide Drastic score and the total groundwater monitoring priority score determinations for two aquifers is shown in Table 1.

Table 1. Examples of Geographic Targeting System Scoring For Two Aquifers In North Dakota

SETTING: Inkster Aquifer, Grand Forks County

	FACTOR	RANGE	RATING	WEIGHT	SCORE
1	Depth to water	21'	7	5	35
2	net Recharge	3.8"	3	4	12
1	Aquifer media	sand and gravel	8	3	24
3	Soil media	sandy loam	6	5	30
3	Topography	1 %	10	3	30
1	Impact of vadose zone	sand and gravel	9	4	36
1	Conductivity	1500 gpd/ft2	8	2	16
	Pesticide DRASTIC Score				249
	Pest. DRASTIC Score	249	high		3
	Chemical use surrogate	$112.90 / acre	high		3
	Permitted water use	3586.9 ac_ft / year	high		3
	Total Monitoring Score		high		9

SETTING: Emerado Aquifer, Grand Forks County

	FACTOR	RANGE	RATING	WEIGHT	SCORE
1	Depth to water	74 '	3	5	15
2	net Recharge	0"	1	4	4
1	Aquifer media	sand and gravel	8	3	24
3	Soil media	loam	5	5	25
3	Topography	1%	10	3	30
1	Impact of vadose zone	confined by till	1	4	4
1	Conductivity	603 gpd/ft2	4	2	8
	Pesticide DRASTIC Score				110
	Pest. DRASTIC Score	110	low		1

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Chemical use surrogate  $112.90 / acre         high                3
Permitted water use     0.0 ac_ft / year        low                1
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Total Monitoring Score                      moderate               5
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1 Estimated from SWC county groundwater studies for Grand Forks county.

2 Estimated as a percentage of annual precipitation.

3 Estimated from SCS county soil surveys for Grand Forks county.

4 Estimated from the North Dakota Census of Agriculture.

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Maximum possible Pesticide DRASTIC score = 249
Minimum possible Pesticide DRASTIC score =  26
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Areas Of Evaluation

A second question that is of importance is at what geographic scale do areas become sufficiently uniform for the evaluation to be valid and still feasible to perform. A large degree of heterogeneity within areas of evaluation limits the use of most models because the high and low values tend to cancel out, giving most areas a medium range score. The U.S. General Accounting Office (1991) concludes that there is virtually as much variability in hydrogeologic vulnerability within most counties as there is between counties. The NPS Phase II Report (U.S. EPA, 1992) found that pesticide DRASTIC assessments at county and sub-county levels did not correlate closely to pesticide or nitrate detections. Therefore, hydrogeologic units, in this case aquifers, are used for areas of evaluation rather than counties or other political units. There should be a greater degree of uniformity within hydrogeologic units than within the political boundaries of counties which may contain several widely varying geologic settings. Differential management of the areas would probably be easier if counties were used, however, for monitoring purposes it is technically more appropriate to use hydrogeologic units. It is not practical at this time to attempt to perform evaluations on a smaller scale for the entire state due to lack of detailed data and available funding.

IMPLEMENTATION PROCEDURES

The first implementation step for the GTS was to delineate discrete areas to be evaluated by the targeting system. Initially, these are the major glacial drift aquifers, which have been identified by the completion of detailed hydrogeologic and groundwater resource studies for each county in North Dakota.

All of the major glacial drift aquifers were digitized on an AutoCAD and ARC/INFO GIS system. The source maps used were the 1:126,700 scale (0.5 inches = 1 mile) aquifer maps from each county groundwater resource study. These maps depict aquifer yield boundaries rather than physical aquifer boundaries. In some instances the yield boundaries may closely coincide with the aquifer boundaries; however, in many cases, aquifer boundaries are gradational so the aquifer is actually larger than what is depicted on the maps. The county groundwater resource studies were written by a number of authors over a period of almost 25 years. There are a few cases where the depictions of aquifers do not correlate across county boundaries from one study to another. In these cases the investigators used their best professional judgement to make reasonable adjustments to the aquifer yield boundaries.

Step two was to collect information for each of the aquifers to be evaluated. The ratings for all of the parameters were compared to the hydrogeologic setting examples provided in the DRASTIC system manual to insure that the values assigned were reasonable. Some of the parameters were estimated if specific data was not available, or the typical rating for that type of hydrogeologic setting was used if no data was available. Because the purpose of this evaluation is to qualitatively compare aquifers rather than make site specific assessments based on quantified measurements, this was considered adequate. Specific considerations for the scoring of each parameter are as follows:

Depth To Water: The depth to water is the distance, in feet, from the ground surface to the water table. If the water table is in a saturated zone which has insufficient permeability to yield useful quantities of water or when an aquifer is confined, the depth to water is redefined as the depth to the top of the aquifer. Where semi-confined aquifer conditions exist, the user must choose to evaluate the aquifer as either unconfined or confined. The user must make a quantitative judgement of the degree of leakage with respect to pollution potential. In the case where there are multiple aquifers beneath an area, only the uppermost aquifer was evaluated. This information is generally available from the North Dakota county groundwater resource studies or can be determined by taking an average of water levels in wells dispersed throughout the aquifer.

Net ***R***echarge: Net recharge is the total quantity of water, in inches, which infiltrates from the ground surface to the aquifer on an annual basis. Because net recharge values are less precise and less easily obtained than values for other parameters, the DRASTIC model uses ranges for net recharge that are intentionally broad. These broad ranges afford the user latitude in choosing a range which is representative of the actual amount of recharge for the area. In addition to infiltration from precipitation, other sources of recharge including irrigation, artificial recharge, and wastewater application must be considered. Irrigation has been estimated to provide as much as four or more inches of recharge per year. Because specific estimates of recharge are difficult to obtain, the following percentages of average annual precipitation were used unless specific recharge data for the aquifer was available.

Estimated Recharge Soil and Vadose Zone Types

20% x avg. annual precip. - very coarse texture + excessively drained to well drained soils

15% x avg. annual precip. - coarse texture + well drained to moderately drained soils

10% x avg. annual precip. - medium texture + moderately drained soils

5% x avg. annual precip. - semi confined or fine texture + poorly drained soils

0% x avg. annual precip. - confined

Annual precipitation for an area was estimated from precipitation maps in the North Dakota State Water Resource Plan prepared by the SWC.

Aquifer Media: An aquifer is defined as a subsurface unit which will yield useful quantities of water. Each range for aquifer media has been assigned a typical rating and a variable rating. If no specific aquifer media information is available, or the user is uncertain, the typical rating for each range should be used. In unconsolidated aquifers, the rating should be based on the sorting and amount of fines within the aquifer. In consolidated aquifers, the rating should be based on the amount of primary porosity as well as secondary porosity along fractures and bedding planes. This information is available from the North Dakota county groundwater studies or can be derived from well drilling logs within the aquifer.

Soil Media: Soil is commonly considered the upper weathered zone of the earth, which averages a depth of six feet or less from the ground surface. The general soil associations for an area can be determined from soil survey maps. All of the soil horizons must be evaluated to determine which one will most significantly affect groundwater pollution potential, based on texture and relative thickness of each layer. The shrink/swell potential of the soil should also be considered. This information is available in the SCS county soil survey reports or from North Dakota State University Agricultural Experiment Station Bulletin No. 472, The Major Soils of North Dakota, 1968.

Topography: Topography refers to the slope and slope variability of the land surface. Topography helps control the likelihood that a pollutant will run off or pool and remain on the surface in one area long enough to infiltrate. Percent slopes for topography may be determined from published soil survey reports and U.S. Geological Survey quadrangle maps. Recently published soil surveys depict topographic slope on the detailed soil maps. Percent slope can be checked at intervals across the map, and the most appropriate slope range for an area can then be selected. Slope can also be estimated from USGS topographic maps.

Impact Of The Vadose Zone: The vadose zone is defined as the zone above the water table which is unsaturated or discontinuously saturated. The DRASTIC user must select the media in the vadose zone which most significantly influences pollution potential. In many situations, the effective vadose zone does not correspond to the true vadose zone, because the part of the saturated zone which will not yield useful quantities of water is treated as part of the vadose zone. An example may be a sand and gravel aquifer at 20 feet which is overlain by silty clay, with a water table at 10 feet. In this case, the 10 feet of saturated silty clay above the top of the aquifer material is considered part of the vadose zone, not part of the aquifer. In the special case where the water table is very near or at the surface, the user still must choose a vadose zone media and assign an appropriate rating. When evaluating an unconfined aquifer, the user may adjust the rating for each media to reflect aquifer specific information similar to evaluating aquifer media. When evaluating a confined aquifer, the user must choose "confining layer" as the vadose zone media.

Agency review of the geographic targeting process resulted in concern regarding groundwater movement through macropore or fracture openings in the vadose zone. It should be noted that the DRASTIC model does not specifically address the effects of macropores or fractures on groundwater movement through the vadose zone. Although it is impossible to determine quantitatively, the distribution of macropores is probably quite uniform when averaged over large areas, even in varying hydrologic settings. Therefore, the relative effects of macropores in changing the final DRASTIC scores will be neglected. In addition, it is a widely held opinion that fractures may be fairly common in settings where the vadose zone is composed of glacial till. Glacial till is not specifically listed in the DRASTIC table of vadose zone materials and their corresponding ratings. However, Aller et al. (1987) state that the user may choose silt/clay or sand and gravel with significant silt and clay as the appropriate vadose zone media and adjust the ratings accordingly. Most wells completed in glacial till in North Dakota have slow recharge and recovery rates so it will be assumed that the ratings will be similar to the ratings for silt/clay. Information pertaining to the vadose zone is available from the North Dakota county groundwater resource studies and well drilling logs within the aquifer.

Hydraulic ***C***onductivity: Hydraulic conductivity refers to the ability of the aquifer material to transmit water, which in turn, controls the rate at which groundwater will flow under a given gradient. The most accurate values for hydraulic conductivity are calculated from aquifer pump tests. Well yields may provide assistance in estimating hydraulic conductivity. Hydraulic conductivities may also be estimated from aquifer material grain size charts. The broad ranges for hydraulic conductivity provided in the DRASTIC model were designed to provide flexibility in selecting appropriate values. This information is generally available in, or can be estimated from the North Dakota county groundwater resource studies.

Agricultural Chemical Usage: Agricultural chemical usage includes herbicides, insecticides, and fertilizers. Actual figures for chemical usage in North Dakota are only available on a statewide basis. However, the National Pesticide Survey conducted by EPA showed strong correlations between the total value of agricultural production per acre in a county and pesticide and nitrate detections. Therefore, agricultural production per acre in the county is used as a surrogate for agricultural chemical usage. In a case where an aquifer is in more than one county, the values should be averaged based on how much of the aquifer is in each county. This information is available for every county in the state from the North Dakota Census of Agriculture, which is published every five years.

Permitted Water Usage: The total permitted water usage from each aquifer is used to represent the risk which contamination in the aquifer would pose. This information is available from the SWC and is updated as new permits are granted. The water usage data in this report is from November, 1993. It should be noted that these totals do not include most private domestic or stock wells which are generally not required to be permitted. In some cases, aquifers which have different names in different counties, but are nonetheless the same aquifer, have had their total water usages combined and are represented in this report as one aquifer.

The third step in the GTS process was to enter the information into a dBASE IV database program which would calculate the DRASTIC and Pesticide DRASTIC scores and the groundwater monitoring priority rankings. The database was then linked to the digitized aquifer maps in the ARC/INFO GIS system.

RESULTS

Data on each aquifer is listed in a variety of table formats and ranking orders in Appendix B. Colored maps representing Pesticide DRASTIC scores, chemical use, permitted water usage, and total monitoring priority were produced using ARC View and the linked database and digitized maps. These maps are located in Appendix C.

It must be remembered that these results are based on average values for each entire aquifer. These maps and tables cannot be used in place of site specific assessments. These maps and tables do not show areas that will be contaminated or areas that cannot be contaminated. Whether a specific site will ever have groundwater contamination depends on the likelihood of a contaminant release, the type and quantity of contaminant released, and the hydrogeologic characteristics at that location.

The DWQ would welcome any additional data from new aquifer investigations or new interpretations on any aquifer characteristics. Results of this project will be updated as necessary.

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Note: General sources of information which were used for rating aquifers are listed previously in this report. Specific references used for determining characteristics of individual aquifers are not listed. These are available upon request from the North Dakota Health Department, Division of Water Quality.