IMPROVING WATER QUALITY THROUGH ANIMAL WASTE MANAGEMENT

FINAL REPORT

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ABSTRACT

Groundwater is the major source of drinking water in rural Oklahoma. This precious commodity is constantly being threatened by non-point source pollution generated from land application of animal wastes (manure). For decades, Oklahoma farmers have been using manure as fertilizer. Manure contains high amount of nutrients (especially, nitrogen and phosphorus). Inefficient application of manure could result in leaching of these nutrients to the groundwater and could become a potential health risk to the down gradient well users. Due to the shallow groundwater level and permeable soil profile of rural Oklahoma, the groundwater quality is becoming even more threatening. Moreover, surface water contamination in the adjacent area is likely as a result of the subsurface transport of polluted groundwater. This study focuses on developing an expert system that can evaluate the groundwater pollution potential at a down gradient well from land application of manure and fertilizers. Expert systems are useful as it is simple to use, does not require skilled personnel, less expensive and requires significantly less data.

Two-tiered approach is considered for the development of the expert system. The first tier is for assessing vulnerability of the aquifer where manure is applied. This tier is useful in preliminary site screening for building new CAFO or AFO. The second tier (assessment modeling) is divided into two levels: simple expert system and advanced expert system. The simple expert system requires minimum number of input parameters for the evaluation and is useful for quick comparison of different field conditions. The advanced expert system requires more input parameters and conducts more scientific evaluation.

The simple expert system is divided into four modules: surface loading, sorption, vadose zone transport and saturated zone transport. Two-stage weighted-average method is used for the simple expert system. In the first stage, weighted average rating for each module is calculated from the rating and the relative weights assigned to each parameter within that module. In the second stage, the Overall Weighted Average Rating (OWAR) is calculated from the rating value obtained for each module (from the first stage) and the relative importance weight assigned to each module. Finally, groundwater pollution potential of each nutrient (nitrate and phosphate) is obtained from the calculated value of OWAR.

The advanced expert system conducts more scientific evaluation than the simple expert system. It has three additional modules than the simple expert system. The additional modules are general info module, health effect module and decision module. It conducts the evaluation as an integrated problem unlike the simple expert system, where every module evaluates their individual rating. Rule-based expert system model is used to develop the input file to run numerical model for evaluating vadose zone transport and analytical model for evaluating saturated zone transport. The decision module also uses rule-based model to evaluate the pollution potential from the final output obtained from the previous modules.

CHAPTER 1

Introduction

1.1 Introduction

The waste generated from Concentrated Animal Feeding Operation (CAFO), often called manure, is commonly used as supplemental nutrient (e.g. nitrogen, phosphorus) source for plants and crops. The manure from most of the CAFOs except swine is usually applied to the cultivating land without any treatment. For swine CAFOs, the manure is stabilized by lagoon prior to land application. Even after stabilization, this lagoon effluent can still contain high concentrations of nitrogen and phosphorus. Inefficient application of these wastes could result in leaching of these nutrients to the groundwater and could become a potential health risk to the down gradient well users.

Kellogg & Lander (1999) reported that the potential for groundwater pollution from manure application has increased over the years. In 1992, 114 counties in United States, as opposed to 28 counties in 1949, was in high risk of groundwater pollution since these counties produced excessive manure nutrient than the nutrient required for potential plant uptake (Kellogg & Lander, 1999). Thus, it has become a growing concern for the existing CAFOs to evaluate the risk involved from their management practices and to identify factors affecting the risk. For new CAFOs, it has become equally important to conduct site assessment with respect to groundwater pollution potential before building a new CAFO. Currently, there is no tool available that can specifically evaluate groundwater pollution potential from land application of manure (Chowdhury & Canter, 1997-98). So far, effort has been given to develop expert systems for evaluating groundwater contamination from pesticide leaching (Arora & Mcternan, 1993; Crowe & Mutch, 1992, 1994). But none of those expert systems consider manure application. Although EPA (1997) developed a methodology to evaluate overall environmental risk from swine CAFOs, it lacks in addressing land application and subsequent groundwater transport.

This study focuses on developing a hybrid (mathematics and rule-based) expert system that can evaluate the groundwater pollution potential at a down gradient well from land application of manure. Expert systems has some advantages over numerical models: it is simple to use, limits the need for skilled individual to run numerical models, relatively less expensive than conducting numerical modeling and requires significantly less data. On the other hand, expert systems often have shortcomings in proving its reliability. Expert systems could be made more reliable by validating against field data (tracer test), but such data in most cases is seldom available. Validation of the expert system against tracer test is beyond the scope of this study.

This study also focuses on developing a window-based software for the expert system. Effort has been given to make the software as user-friendly as possible so that people with minimum knowledge on computer uses can take advantage of the expert system. A window-based help file and a software manual are also developed for the software. Database files are also included with the software in order to make the software user-friendlier.

1.2 Objective

The objectives of the study are the following:

- To develop an expert system for assessment of groundwater pollution potential from land application of waste
- To help the farmers to develop best management practice in terms of minimizing groundwater pollution.
- To develop a user-friendly software for the expert system so that the farmers and the conservation district officials can take advantage of the software
- To train the farmers and the district officials using the software
- To analyze groundwater quality and soil parameters from two existing animal husbandries

1.3 Organization of the Report

This report encompasses five chapters. Soil parameter and water quality analyses for two research sites are reported in chapter 2. Chapter 3 presents the development of the expert system. Chapter 4 discusses the success of the project. Finally, conclusion and recommendation for further research are outlined in chapter 5. In addition to the five chapters one appendix (Appendix A) is added to the report to present the questionnaires set up for measuring the success of the project.

CHAPTER 2

Laboratory and Field Analyses

2.1 Site Selection

Two research sites were selected in cooperation of OCC (Oklahoma Conservation Commission) for conducting field study. Both sites are located in the central region of Oklahoma. Legal agreement with landowners for both sites was finalized. For reporting convenience, the sites are named RS1 (Research Site 1) and RS2 (Research Site 2). RS1 is raising animals for many years, while RS2 has started to operate very recently.

2.2 Monitoring Well Installation

Monitoring wells were installed in Jan-Feb, 1998. Ten wells were installed at RS1 while eight wells were installed at RS2. Figure 2.1 and Figure 2.2 show the well locations for the respective research sites. ASTM D5092 along with the Oklahoma Water Resources Board rules were strictly followed for well drilling. A company qualified for well installation according to the Oklahoma Water Resources Board conducted the monitoring well installation. Six inches diameter borings were drilled, while two inches diameter wells were installed. Two stainless steel wells were installed at each site and for rest of the wells inexpensive PVC-40 pipes were used. The stainless steel wells are MW2 and MW9 for RS1 (Figure 2.1) and MW1 and MW8 for RS2 (Figure 2.2). Since PVC pipe affects the organic content of water, stainless steel pipes were installed. Of the two stainless steel wells, one was installed down gradient from the lagoons and the other was installed in far field. For RS2, the stainless steel well near the lagoons was installed for detecting the organic compounds leaching out of the lagoon and the far field well was installed for determining the transport of those organic compounds, if any. Since it is predicted that there will be no flow from the lagoons to the surrounding area for RS1, both steel pipes were installed in the far field. As specified in the regulations, 0.01-inch slot well screens were used. Sand sample finer than No. 10 sieve and coarser than No. 20 sieve was used as gravel pack. For sealing the intermediate space between the boreholes and the pipes, bentonite grout was used. Top eight inches of the wells were sealed by concrete. For security purpose, locks were installed in every well.

2.3 Soil Sampling

Soil samples were collected from each borehole. Drilling cuttings were collected for soil classification and moisture content analyses, while push tube samples were collected for density and hydraulic conductivity measurements. Eighty drilling cutting samples were collected from both sites: 45 from RS1 and 35 from RS2. Nine push tube samples were collected from RS1. Due to extreme weather condition in January through February 1998 and limitation of the drilling company, it was not feasible to collect any push tube sample from RS2. Since RS2 soil contains considerable amount of sand, split spoon samples were collected from a borehole (Bor8, Figure 2.2).

2.4 Soil Analyses

Soil parameters e.g., gradation (ASTM D422), moisture content (ASTM D2216), specific gravity (ASTM D854), density (ASTM D1557) and hydraulic conductivity (ASTM D5084) analyses were conducted. Textural classification was conducted by sieve and hydrometer analyses. A total of 26 samples from 11 boreholes for RS1 and a total of 20 samples from 8 boreholes for RS2 were analyzed. For RS1, five different types of soil were found (Figure 2.1). In the south half (MW 1 to 4), top 10 feet soil is clay while, test results for MW 1 and 2 showed sandy soil from 10 to 15 feet. In northwest quadrant (MW 5 and 6), the top 15 feet soil is silty clay and in northeast quadrant (MW 7 to 10) the soil is shale. It should be noted that both lagoons are located in the northeast quadrant where the soil is shale. For RS2, eight different types of soils were found (Figure 2.2). Top 5 to 10 feet of the central part (MW 1,3,5 to 8) the soil is sandy clay loam. Near the lagoon (MW 5 and 8), the soil is clay from 10 to 15 feet. Finally, in the northwest corner (MW 2) the soil is mostly clay and in the southeast corner (MW 1) the soil is mostly sand.

Specific gravity analyses were conducted for 9 samples from RS1 and 7 samples for RS2. For RS1, specific gravity values are between 2.68 and 2.72 while for RS2, it is between 2.60 and 2.70. Porosity, density and moisture content values of RS1 were measured from the nine push tube samples, which were collected from 3 to 5 foot depths. Porosity is between 0.30 and 0.40 while, density is between 115 to 135 pounds per cubic foot (pcf). Moisture content varies from 13 to 19 percent during February 1998 when the sampling was done. Since no push tube samples were collected from RS2 during installation of monitoring wells, porosity and density analyses could not be conducted.

Slug test was conducted to determine average hydraulic conductivity of the saturated zone. Hydraulic conductivity for all wells in RS1 and RS2 were within very close range. For RS1, the conductivity values were between 8e-04 and 5e-03 cm/sec with MW 5 be the lowest and MW 1 be the highest. It should be noted that the average conductivity value for RS1 does not include the wells near the lagoons, where the soil in shale. Since the slug test data collected for the wells near the lagoons of RS1 were inconsistent, hydraulic conductivity measurement for those wells was ignored. For RS2, the conductivity values were between 2e-03 and 1e-02 cm/sec with MW 3 be the lowest and MW 5 be the highest. It should be noted that the hydraulic conductivity values obtained from the slug test are in compliance with the values obtained from literature for similar type of soil.

2.5 Water Sampling

Water samples were collected from March 1998 to April 2000. Samples were collected from each well and from each lagoon. According to the regulations, wells were purged for three well volumes before sampling. Land survey for both sites was also completed. From the survey data, groundwater flow direction was determined for both sites (Figure 2.1 and 2.2).

2.6 Water Quality Analysis

Assessment of water quality was done by taking field measurements and conducting laboratory analyses. A Quality Assurance (QA)/ Quality Control (QC) program was used to determine if the data from the water quality site assessment was reportable. For the description of the QA/QC measures taken as part of the data analyses, refer to Appendix. A Student t-test was performed on all the water quality data to check if the difference between background sample and filed application samples were significant. The data for the two sites were combined into yearly averages with standard deviation for the duration of the study.

Field sampling methods were done in accordance to the approved QAPP submitted at the beginning of the project. Total solids, total dissolved solids and total suspended solids were analyzed according to Standard Methods 2540. For the total solids and total dissolved solids, aluminum weighing dishes were used to hold the water samples instead of the porcelain or glass dishes specified in the method. Plastic filtration units were used in place of Gooch crucibles for the total dissolved solids and total suspended solids. Fecal Coliform (FC) and Fecal Streptococci (FS) were analyzed using membrane filter technique from Standard Methods 9221E and 9230C, respectively. For FC analysis mFC agar was used while mEnterococcus agar was used as the medium, for FS analysis. Serial dilution of 1 mL, 10 mL and 100 mL were used in all groundwater samples in both FC and FS analyses. Biological Oxygen Demand (BOD5) determinations were performed according to Standard Method 5210. The incubation bottles were sterilized as an added precaution against false positives. Standard Method 4500-P was used to analyze for Total Phosphorus (TP), Total Reactive Phosphorus (TRP), and Dissolved Reactive Phosphorus (DRP). The extractions for the pesticide samples were performed using the separatory funnel liquid-liquid extraction method taken from EPA method 3510c. The extracted liquid was analyzed using gas chromatography. This is in accordance with EPA method 8141b. Chemical Oxygen Demand (COD) was analyzed following Standard Method 5220. The analysis of total metals was performed according to Standard Method 3030G and 3111D. The termination of inorganic anions by ion chromatography was performed according to EPA method 300.1. For the analysis of cations by ion chromatography was performed according to EPA method 350.2. For both anions and cations, straight sample and 50 fold dilution sample were analyzed for each of the samples to obtain out-of-range samples.

From the measurements taken from each groundwater well samples, conductivity, water temperature, pH, dissolved oxygen and alkalinity did not fluctuate significantly. For the five-day Biochemical Oxygen Demand analysis and Chemical Oxygen Demand analysis, average values obtained were 21 ± 5 mg/L and 73 ± 5 mg/L; respectively. The BOD_5 was slightly higher for groundwater samples obtained near the lagoons, than those obtained within the irrigation fields. It should be noted that the BOD_5:COD ratio was always below 1.0. Fecal Coliform (FC) and Fecal Streptococci (FS) analysis indicated a higher presence of indicator organisms in groundwater for samples for near the treatment lagoons.

Total metals analyses were performed for Zn, Cd, Cu, and Pb. Concentrations of cadmium were not detected at any site. Lead, Chromium and copper were below detection limit. Zinc was the only metal which exceeded its detection limit. Detection limit for zinc was 0.045 ppm. Concentrations of zinc ranged from 0.1 to 0.3 ppm, with an average (over the sampling period) of 0.09 ± 0.05 mg/L. However, no correlation could be developed to determine input source.

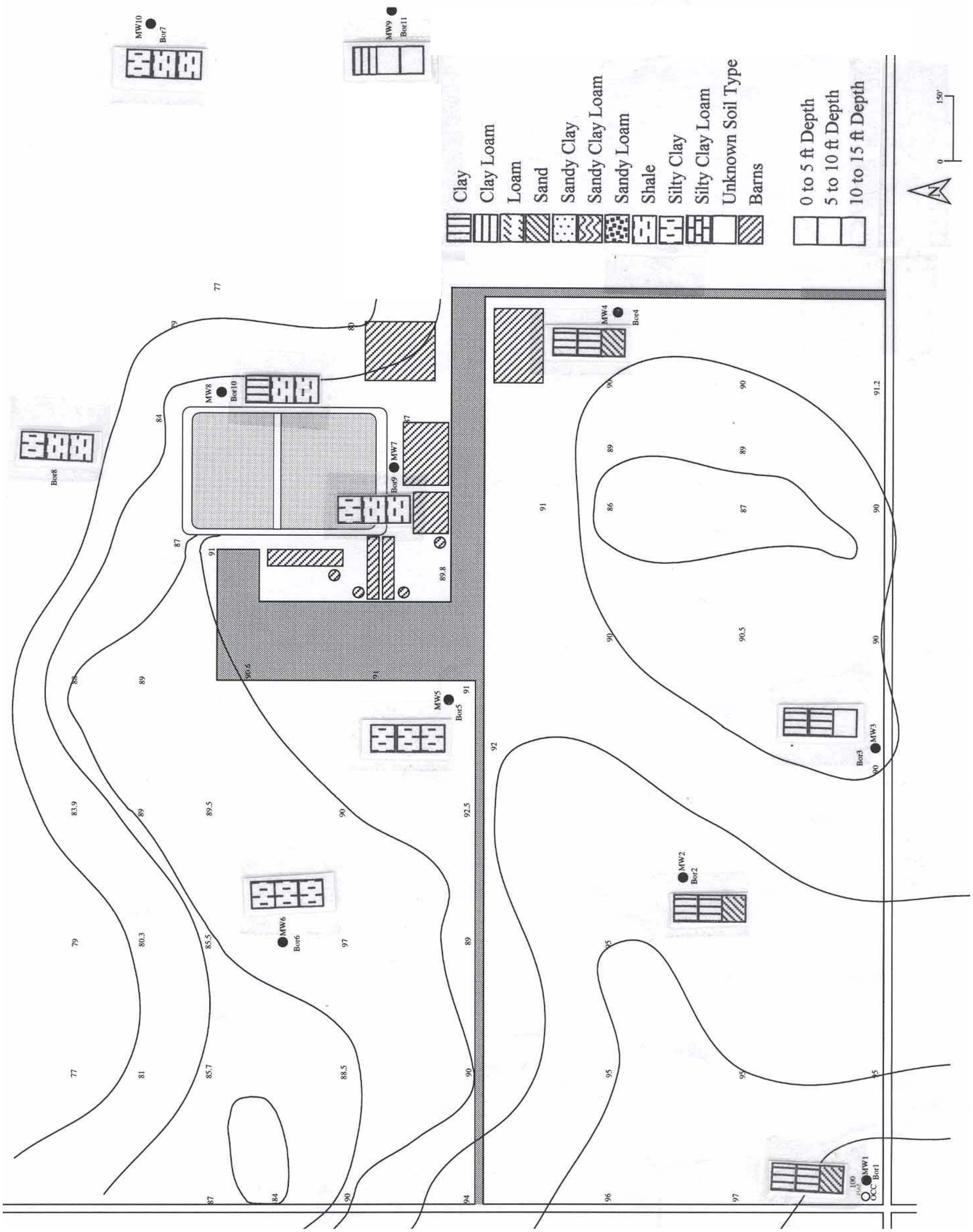

Figure 2.1 Site map for RS1 showing locations for the monitoring wells, and soil types

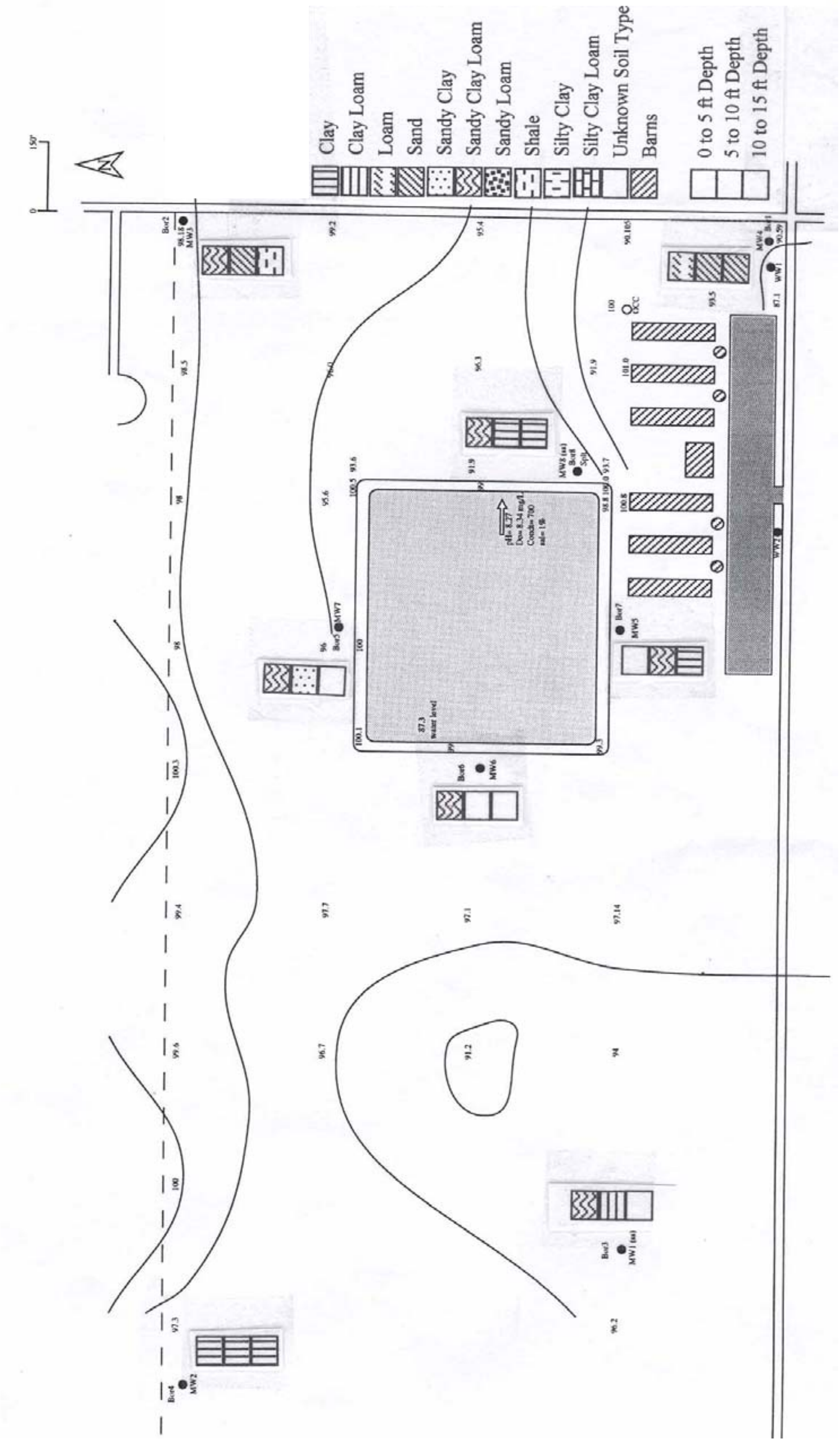

Figure 2.2 Site map for RS2 showing locations for the monitoring wells, and soil types

CHAPTER 3

Expert System for Evaluation of Groundwater Pollution Potential

3.1 Introduction

Two-tiered approach is considered for the development of the expert system. The first tier is for assessing vulnerability of the aquifer where manure is applied. This tier uses subjective approach for the evaluation of groundwater vulnerability. This tier is useful in preliminary site screening for building new CAFO or AFO. The second tier is named assessment modeling, which evaluates the groundwater pollution potential at a down gradient location (well) for land application of manure. The assessment modeling is divided into two levels. The first level is called simple expert system, while the second level is called advanced expert system. The simple expert system requires minimum number of input parameters for the evaluation and is useful for quick comparison of different field conditions. The advanced expert system requires more input parameters and conducts more scientific evaluation.

The expert system developed in this study is very simple to use and require less monetary investment in collecting data. Furthermore, the expert system would be a useful preliminary site assessment and site-screening tool for both new and existing CAFO sites. It would also be very useful for the farmers in employing better management practice for land application of manure.

3.2 Site Screening

Site screening is done by assessing vulnerability of the unconfined aquifer. DRASTIC, an aquifer vulnerability assessment model developed by Aller et al. (1985), is used for site screening. Since DRASTIC is developed for confined aquifer, modification is done to better represent the parameters for unconfined aquifers. The acronym DRASTIC is derived from the following seven factors:

D = Depth of aquifer
R = Net recharge rate
A = Aquifer media
S = Soil media
T = Topography
I = Impact of the vadose zone
C = Conductivity (hydraulic) of the aquifer

DRASTIC calculates the index value (equation 3.1) by multiplying each weight factor (suffix w) by its rating (suffix r) and summing the total. The higher the index value, the higher pollution potential is. Each factor has a rating value between 1 and 10 to represent the pollution potential from each parameter. Relative weight factor used in modified DRASTIC is obtained from Agricultural DRASTIC. Rating values and relative weight for each factor is discussed in the following sections.

$$\text{DRASTIC Index} = D_rD_w + R_rRw + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \tag{3.1}$$

For site screening, the DRASTIC indexes for several sites can be compared. There is no guideline given in DRASTIC for interpreting the DRASTIC index of a single site into the pollution potential of that site. However, Oklahoma water resources board (OWRB) has used 69 percent of the maximum possible DRASTIC Index as the upper limit and 42 percent of the maximum possible DRASTIC Index as the lower limit for rating most and least vulnerable sites, respectively (Osborn et al., 1998). Based on the approximation of Osborn et al. (1998), this study sets the upper and lower limits for rating the pollution potential to the DRASTIC Index of 170 and 105, respectively. The DRASTIC Index more than 170 is rated as high pollution potential and less than 105 is rated as low pollution potential. DRASTIC Index between 105 and 170 is rated as medium pollution potential.

3.2.1 Depth of Aquifer

Since unconfined aquifer is of concern, depth of water table would be the parameter 'D'. Rating value (D_r) is dependent of the depth of water table (Table 3.1). Data for the water table depth (D) could be obtained from the actual site. Approximate value of D can be obtained from Belden & Scurlock (1995). Relative weighting factor used for D is 5.

Table 3.1 Evaluation of depth of water table factor

Range (ft)	Rating
0 – 5	10
5 – 15	9
15 – 30	7
30 – 50	5
50 – 75	3
75 – 100	2
100 +	1

3.2.2 Net Recharge Rate

Since unconfined aquifer is recharged by rainfall, average rainfall data could be used as net recharge rate (R). Input value of R could be chosen from 30-years-average monthly, seasonal or annual rain. Since range of values in rating for R in the original DRASTIC are in the vicinity of monthly rainfall data, 30-years-average monthly rainfall data is proposed for input recharge rate (R). Rating for R is obtained from Table 3.2. Monthly average rainfall data for each county is available from Oklahoma Climatological Survey (OCS). One can choose the rainfall for the month of cultivation or the maximum monthly rainfall as R. Relative weight factor used for R is 4.

Table 3.2 Evaluation of net recharge rate factor

Range (inch)	Rating
0 – 2	1
2 – 4	3
4 – 7	6
7 – 10	8
10 +	9

3.2.3 Topography

Topography (T) refers to the slope of the land surface. Topography represents the impact of runoff on leaching of pollutant. Thus, the high the topography, the lower the rating will be (Table 3.3). Topography data for a site can be obtained from Soil Survey maps of respective county. Relative weighting factor used for T is 3.

Table 3.3 Evaluation of topography factor

Range (% slope)	Rating
0 – 2	10
2 – 6	9
6 – 12	5
12 – 18	3
18 +	1

3.2.4 Soil Media and Impact of Vadose Zone

Soil media (S) and impact of vadose zone (I) depend on the soil type of the vadose zone. DRASTIC uses different soil classification than the USDA in rating for S and I. Based on the hydraulic conductivities of the soil types used in DRASTIC and the USDA soil types (Carsel &

Parrish, 1988), soil types for S in DRASTIC and for I in Osborn et al. (1998) are changed to the USDA soil types (Table 3.4). Vadose soil type can be approximated from Oklahoma Mesonet. They have measured the soil type (USDA classification) up to 30 inches depth at more than hundred stations all over Oklahoma. Relative weighting factors used for S and for I are 5 and 4, respectively.

Table 3.4 Evaluation of soil media and impact of vadose zone factors

Soil Type	S	I
Shale	1	3*
Clay/silty clay loam/silty clay/sandy clay	2	4
Silt/clay loam	3*	5
Loam	5*	6
Silt loam/sandy clay loam	5	6
Sandy loam	6*	7
Loamy sand/sand	9*	8
Sand and Gravel	10*	9*

*Used in DRASTIC

3.2.5 Aquifer media and Conductivity

Aquifer media (A) and conductivity (C) depend on the soil type of the aquifer. Rating for C in this study is the same as the DRASTIC (Table 3.5). DRASTIC uses different soil classification than the USDA soil classification for rating A. Soil types for rating A is changed to USDA by comparing the hydraulic conductivity of the DRASTIC soil types and the USDA soil types (Table 3.6). Hydraulic conductivity data for the USDA soil types (Carsel & Parrish, 1988) is used for developing rating for C. If the user cannot input hydraulic conductivity, the expert system will use the soil type input to obtain the rating for C. Data for the unconfined aquifer soil can be obtained from the Oklahoma water resource board. They have the well logs for all wells constructed in Oklahoma. One can use the well logs at or near the proposed site to approximate the soil type. Relative weighting factors used for A and for C are 3 and 2, respectively.

3.2.6 Sensitivity Analysis

The modified DRASTIC Index ranges from a minimum value of 37 to a maximum value of 249. Sensitivity of the site screening tier is analyzed by studying the maximum and the minimum contribution of each factor to the modified DRASTIC Index (Figure 3.1). Figure 3.1 shows that the modified DRASTIC Index is mostly sensitive to the factors D and S (approximately 20%) followed by the factors R and I (approximately 14.5%). Also, the modified DRASTIC Index is least sensitive to C followed by A and T.

Table 3.5 Evaluation of conductivity factor

Range (% slope)	Rating
1 – 100	1
100 – 300	2
300 – 700	4
700 – 1000	6
1000 – 2000	8
2000 +	10

Table 3.6 Evaluation of aquifer media and conductivity from soil type

Soil	A	C
Shale	2	1
Clay/silty clay loam/silty clay/sandy clay	3	1
Silt/clay loam	4	1
Loam	5	1
Silt loam/sandy clay loam	6	1
Sandy loam	7	2
Loamy sand/sand	8	4
Sand and Gravel	9	6

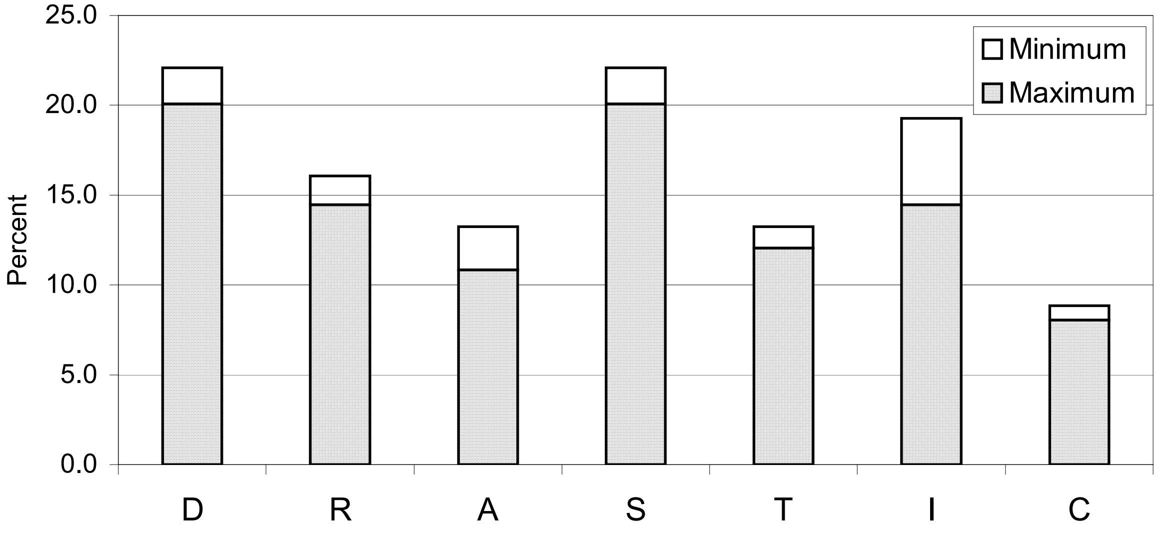

Figure 3.1 Contribution of each factor to Modified DRASTIC Index

3.3 Simple Expert System

The simple expert system is divided into four modules: surface loading, sorption, vadose zone transport and saturated zone transport. The surface loading module is developed to address the impact of the nutrient source. The sorption module addresses retardation of the nutrient transport through the subsurface soil layers. The vadose and the saturated zone transport address the nutrient transport from the source to the sink (i.e., down gradient well).

Two-stage weighted-average method is used for the evaluation of pollution potential. In the first stage, a set of most important input parameters for each module is selected. Based on input values, a rating (on 1 to 5 scale, 5 being the most critical) is assigned to each parameter within a module. For modules having more than one rating parameters, weighted average rating for the module is calculated from the rating and the relative weights (on 1 to 5 scale, 5 being the most critical) assigned to each parameter within that module. In the second stage, the Overall Weighted Average Rating (OWAR) is calculated from the rating value obtained for each module (from the first stage) and the relative importance weight assigned to each module. Finally, groundwater pollution potential of each nutrient (nitrate and phosphate) is obtained from the calculated value of OWAR.

3.3.1 Surface Loading

Surface loading module evaluates the impact of the nutrient source. This is accomplished by comparing the nutrient mass applied (from manure and fertilizer) with the potential nutrient uptake rates by the harvested crop. First, the expert system calculates (equation 3.2) the total recoverable waste (TRW) generated in the CAFO from annual livestock inventory and the data presented in Table 3.7. Common animals in Oklahoma (USDA-NRCS, 1999) are selected in Table 3.7. Nitrogen (N_{man}) and phosphorus (P_{man}) concentrations in manure for the CAFO site are calculated from equations 3.3 and 3.4, respectively. Manure nitrogen (N) and phosphorus (P) contents presented in Table 3.7 are the ones available for plant uptake i.e., after considering losses. Finally, total nitrogen (N_{app}) and phosphorus (P_{app}) applied per acre land in a cultivation season from both manure and fertilizer nitrogen (N_{fer}) and phosphorus (P_{fer}) are calculated from equations 3.5 and 3.6, respectively.

Potential crop nutrient uptake is estimated from commonly used nutrient application rates in the United States (Table 3.8). In Table 3.8, N_{crop} and P_{crop} are the nitrogen and phosphorus application rates for different crops, respectively. The crops presented in Table 3.8 are the common crops in Oklahoma. Land use percentage for different crops in Oklahoma are 73.5% for winter wheat, 8.6% for soybeans, 7.4% for sorghum, 5.7% for corn and 4.8% for cotton (USDA, 2000). However, the expert system considers all crops, hays and forages presented by Lander & Moffitt (1996). It should be noted that the minimum and the maximum P application rates for the crops having only the average phosphorus application rates (Lander & Moffitt, 1996) are calculated from equations 3.7 and 3.8, respectively. In both equations 3.7 and 3.8, a division factor of 7.2 is used to account for the stoichiometric mass ratio of N and P uptakes for the plant biomass (Nultsch, 1971). It should also be noted that for crops with no reported N or P application rates (e.g., sorghum in Table 3.8), the expert system calculates the average, maximum and the minimum N or P application rates by multiplying the nutrient contents of the crops (NRCS national agronomy manual) with the average, maximum or the minimum yield per acre land, respectively.

Table 3.7 Manure nutrient estimation.

Animal types	Animals/AU†† *	Manure produce (tons/AU)*	Manure recovery factor*	N/Animal (lb)†	P/ Animal (lb)†
Beef Cows	1.0	11.5	0.80	30. 4	29.7
Milk Cows	0.74	15.24	0.65	57.6	22.1
Heifers	1.82	12.05	0.65	7.83	4.73
Steers, Calves, Bulls	1.64	10.59	0.80	17.1	14.8
Breeding Hogs & Pigs	2.67	6.11	0.75	5.7	6.21
Other Hogs & Pigs	9.09	14.69	0.75	3.42	3.40
Broiler Chicken	455	14.97	1.0	0.883	0.257
Layer Chicken	250	11.45	1.0	1.23	0.456
Turkeys	67.0	8.18	0.8	2.97	1.16

*Lander et al. (1998), †Calculated, ††Animal Unit

$$\text{TRW (tons)} = \sum_{i=1}^{n} \{(\text{manure produce} \times \text{recovery factor}) / (\text{animals/AU}) \times \text{no. of animals})\} \quad (3.2)$$

Where, n = no. of animal types.

$$N_{man} = \sum_{i=1}^{n} \text{(N/animal)} \times \text{number of animals / TRW} \quad (3.3)$$

$$P_{man} = \sum_{i=1}^{n} \text{(P/animal)} \times \text{number of animals / TRW} \quad (3.4)$$

$$N_{app} = N_{man} \times \text{manure applied} + N_{fer} \quad (3.5)$$

$$P_{app} = P_{man} \times \text{manure applied} + P_{fer} \quad (3.6)$$

$$\text{Min } P_{crop} = (\text{Min} - \text{Avg})\, N_{crop} / 7.2 + \text{Avg } P_{crop} \quad (3.7)$$

$$\text{Max } P_{crop} = (\text{Max} - \text{Avg})\, N_{crop} / 7.2 + \text{Avg } P_{crop} \quad (3.8)$$

Table 3.8 Nutrient uptake rates for some common crops.

Crops	Yield Unit (YU)	N_{crop}^{*} (lb/acre)			P_{crop} (lb/acre)		
		Avg	Min	Max	Avg*	Min†	Max†
Corn, field	Bu	129	78	160	57	50	62
Cotton	Bale	88	66	131	48	45	54
Sorghum	Bu	-	-	-	-	-	-
Soybean	Bu	22	12	44	47	45	50
Winter Wheat	Bu	66	35	101	38	33	43

*Lander & Moffitt (1996); †Calculated

Rating for the surface loading module is provided by comparing N_{app} with N_{crop} for nitrogen and P_{app} with P_{crop} for phosphorus. Beside the average and the maximum application rates, the expert system uses two more values: critical value and the threshold value. Critical value is the nutrient application required in addition to the maximum application rate (Table 3.8) to cause the unconfined aquifer nutrient concentration to exceed EPA standard. EPA water quality standards for nitrogen and phosphorus are 10 and 5 mg/L, respectively (USEPA, 1999). These values along with an approximate void ratio of 0.4 for the saturated zone soil are used to calculate the critical value. The additional application rates found are 11 and 5.5 lb/acre per foot of the aquifer for nitrogen and phosphorus, respectively. Equations 3.9 and 3.10 are used for calculating the critical nutrient application rates. Threshold value is considered as the mean of the maximum application rate and the critical value. Rating values suggested for this module are shown in Table 3.9. The input parameters for this module are the animal inventory, fertilizer N or P, background soil N or P, crop(s), land area and the aquifer thickness.

Table 3.9 Rating for surface loading.

Condition	Rating
N_{app} or P_{app} < Avg N_{crop} or Avg P_{crop}	1
N_{app} or P_{app} < Max N_{crop} or Max P_{crop}	2
N_{app} or P_{app} < Threshold N_{crop} or Threshold P_{crop}	3
N_{app} or P_{app} < Critical N_{crop} or Critical P_{crop}	4
N_{app} or P_{app} > Critical N_{crop} or Critical P_{crop}	5

$$\text{Critical } N_{crop} = \text{Max } N_{crop} + 11 \times \text{aquifer thickness} \quad (3.9)$$

$$\text{Critical } P_{crop} = \text{Max } P_{crop} + 5.5 \times \text{aquifer thickness} \quad (3.10)$$

3.3.2 Sorption

The sorption module evaluates the impact of nutrient adsorption on the soil surface. Sorption phenomenon causes the soil to adsorb solutes (e.g. nutrients) to its surface and consequently slow down the solute transport. This slowing down of solute transport due to sorption is called retardation. The higher the retardation, the longer the transport time and thus the lower the pollution potential. Thus, rating scale of 5 in the sorption module indicates low retardation and 1 indicates high retardation.

3.3.2.1 Nitrate Sorption

Factors affecting nitrate sorption are pH, AEC (Anion Exchange Capacity) of soil and concentration and ionic strength of the adsorbate chemical (Bellini et al. 1996; Qafoku et al. 2000a). Bellini et al. (1996) concluded after studying nitrate and chloride leaching through a soil column that retardation of anions is a direct function of AEC at native soil pH. To further validate the study done by Bellini et al. (1996), which was limited to analysis on only one soil, Qafoku et al. (2000a) conducted nitrate and chloride leaching for 16 different soils from all over the world. In addition to the column leaching, soil mineralogy was also studied for all those soils by Qafoku et al. (2000b). Qafoku et al. (2000a) concluded that nitrate leaching is significantly influenced by pH and concentration of leaching solution. Nitrate adsorption is linear with any concentration of the leaching solution at pH > 6.5. While for pH <6.5, nitrate adsorption is nonlinear for leaching solution concentration less than 70 mg/L and linear for concentration over 70 mg/L. Some of the results of nitrate retardation factors (RF) at different pH from Qafoku et al. (2000a) are presented in Table 3.10. The results presented in Table 3.10 are for AEC equal to

1.15 cmol/kg, bulk density equal to 1.13 g/ml, and moisture content equal to 0.53. Another finding by Qafoku et al. (2000a) was that AEC could be correlated with the retardation factor (RF) for all soils at their native pH and for leaching solution nitrate concentration of 70 mg/L (equation 3.11). From equation 10, it is found that AEC of less than or equal to 0.14 cmol/kg there will be no sorption i.e., RF will be equal to 1.

Table 3.10 RF with pH & Nitrate concentrations.

PH	RF at different nitrate concentrations (mg/L)			
	70	140	280	420
4.21	3.86	2.96	1.87	1.58
4.45	3.19	2.39	1.69	1.32
5.47	2.24	1.81	1.64	1.55
6.47	1.92	1.32	1.32	1.49

Source: Qafoku et al. (2000a)

$$AEC = -0.1674 + 0.3061 \times RF \tag{3.11}$$

Based on the above discussion, a rating table for evaluating the impact of nitrate sorption is developed for soil native pH, AEC of soil and nitrate concentration in groundwater (Table 3.11). Relative weight of each parameter is also presented in Table 3.11. Rating values assigned for pH and nitrate concentration are based on the data presented in Table 3.10, while the rating values for AEC is obtained from equation 3.11. The five rating values in ascending order correspond to approximate RF values of 4, 3, 2.5, 2, and 1, respectively.

Table 3.11 Rating for nitrate sorption.

PH [4]*	AEC (cmol/kg) [5]	NO_3^- (mg/L) [3]	Rating
< 4.0	>1.15	< 70	1
4.0 – 4.5	0.75 – 1.15	70 – 150	2
4.5 – 5.5	0.5 – 0.75	150 – 250	3
5.5 – 6.5	0.14 – 0.5	250 – 400	4
>6.5	<0.14	> 400	5

*[ ] Relative weights of each parameter

3.3.2.2 Phosphate Sorption

Factors influencing phosphate adsorption are soil pH (Barrow, 1984; Naidu et al. 1990), aluminum and iron oxides in soil (Parfitt, 1978; Borggaard, 1983; Borggaard et al., 1990, van der

Zee & van Riemsdijk, 1986) calcium content (Naidu et al., 1990) and organic matter in soil (Borggaard et al., 1990). As discussed previously, pH has significant affect on anion sorption. Unlike nitrate sorption, phosphate (P) sorption does not always decrease with pH increase. Naidu et al. (1990) showed for four strongly acidic Fijian soils that phosphate sorption decreases with increasing pH up to pH of 6. For pH > 6, phosphate sorption begins to increase. Naidu et al. (1990) suggested that the increase in P sorption for pH > 6 was caused by formation of insoluble Ca-P compounds. Thus, presence of calcium in soil will retard phosphate leaching at pH > 6. Ratings for pH impact on P sorption (Table 3.13) were based on sorption versus pH plots for four different soils presented by Naidu et al. (1990).

Aluminum and iron oxides have significant affect on P adsorption (Borggaard, 1983; van der Zee et al., 1986). Aluminum and iron oxides exchange hydroxyl groups on the oxide surface with phosphate during formation of surface complexes (Borggaard, 1983; van der Zee & van Riemsdijk, 1986). Thus, the higher the aluminum and iron content in the soil, the higher the P sorption (Borggaard et al., 1990). Borggaard et al. (1990) and van der Zee & van Riemsdijk (1986) developed two different linear correlation equations for phosphate sorption with respect to aluminum and iron contents in soil. Since the correlation presented by Borggaard et al. (1990) was proved to be a better representation of P sorption, it was used in rating for Al and Fe (Table 3.13).

Borggaard et al. (1990) had shown that organic matter does not compete with phosphate for adsorption sites. However, organic matter affects phosphate adsorption indirectly by inhibiting aluminum oxide crystallization, which in turn results high P adsorption. Appelt et al. (1975) found no change in phosphate adsorption with addition of dissolved organic matter. On the contrary, Sibanda & Young (1986) found that organic matter in solution decreased P sorption on soils and on aluminum and iron oxides. Due to current controversy of the impact of organic content on phosphate sorption, organic content in soil is not selected as a rating parameter.

Bottani et al. (1993) conducted P sorption capacity of three different soils (named C2, R3 and LP). The authors considered a Langmuir model as the adsorption isotherm for phosphate sorption. Results of the study and calculated RF values for three phosphate concentrations (5, 10 and 50 mg/L) are presented in Table 3.12. RF values for all the soils at equilibrium phosphate concentrations (Ce) of 5 and 10 mg/L are very high, while for Ce equal to 50 mg/L RF is less than 4. Among the factors affecting phosphate sorption mentioned earlier, Bottani et al. (1993)

considered all but aluminum and iron oxides (Table 3.12). Soils R3 and LP with similar textural classification give similar RF values. Of the significant factors affecting phosphate sorption, pH and Ca content are different for these soils. Soil R3 has high pH and high Ca content, while soil LP has low pH and low Ca content. Thus, Ca content for soil R3, and pH for soil LP are the most contributing factors for phosphate sorption. Again, soil C2 and R3 has similar Ca content, but different pH. Thus, a high RF value for C2 could be due to low pH. Finally, C2 and LP have similar pH values but different Ca content. As Ca-P complexes form at pH > 6 (Naidu et al. 1990), the difference in RF values could be attributed to different Ca content in the soil. Based on the RF values for different Ca content and for different phosphate concentrations in Table 3.10, rating for Ca and phosphate concentration is done (Table 3.13). Relative weights for each parameter are also presented in Table 3.13. Since pH is the only data most commonly found in literature, it is selected as the mandatory input parameter.

Table 3.12 Typical values for phosphate sorption.

Soil	C2			R3			LP		
Clay (%)*	40.6			17			18		
Silt (%)*	40.2			60.5			61		
Sand (%)*	19.2			22.5			21		
pH (1:1)*	5.9			7.4			5.8		
Organic mater (%)*	5.1			6.2			3.41		
TKN (%)*	0.23			0.34			0.21		
Extractable Phosphate (mg/L)*	23			11.2			16.4		
Ca (mmol/kg)*	118			107			41		
K (l/mg)*	0.102			1.271			1.259		
b (mg/kg)*	274.9			261.4			258.3		
Specific Surface Area (m^2/gm)*	31.73			28.74			10.55		
Ce (mg/L) †	5	10	50	5	10	50	5	10	50
RF†	41	22	3.4	21	7	1.3	21	7	1.3

*Bottani et al. 1993; †Calculated

Table 3.13 Rating for phosphate sorption.

PH [4]*	Ca (mmol/kg) [4]	Al + Fe (mmol/kg) [5]	PO_4^{-3} (mg/L) [3]	Rating
< 4.5 & > 6.5	> 100	> 100	< 5	1
4.5 – 5.0	50 – 100	50 – 100	5 – 10	2
6.0 – 6.5	20 – 50	20 – 50	10 – 20	3
5.0 – 5.5	10 – 20	10 – 20	20 – 50	4
5.5 – 6.0	< 10	< 10	> 50	5

*[ ] Relative weights of each parameter

It should be noted that the expert system considers nitrate and phosphate transport separately. That is why one should not compare sorption ratings for nitrates and phosphates.

Furthermore, it should be noted that unlike nitrate sorption, phosphate sorption studies lack in reporting data for retardation factors. Therefore, the expert system might have some shortcomings in representing P sorption.

3.3.3 Vadose Zone Transport

The vadose zone transport module evaluates the impact of the most important parameters related to solute transport through vadose zone. One-dimensional downward transport through vadose zone is considered based on the assumption that manure is applied uniformly on a flat land and lateral dispersion is minimum due to low concentration gradient in that direction. In downward direction, the maximum possible infiltration velocity equal to the saturation permeability (K_s) could be achieved at saturation. Since during irrigation, water is applied to the land, soil moisture content is likely to be very close to the saturation point. As at near saturation point, soil suction potential reaches zero, it could be assumed that maximum possible soil moisture velocity during irrigation is equal to the unsaturated permeability (K_u). Based on the assumptions, K_u (Table 3.14) is calculated at moisture content of 0.4, which is the moisture content near saturation for most of the soils (Carsel & Parrish, 1988). Van Genucthen's model (equations 3.12, 3.13 and 3.14) is used for calculating K_u. Considering K_u as the soil moisture velocity, distance traveled in 90 (D_{90}) and 365 days (D_{365}) are calculated and presented in Table 3.14. Duration of either 90 or 365 days is chosen because the nutrient application would follow a cycle of either a minimum of one cultivation season (90 days) or a maximum of one year (365 days). Using D_{90} and D_{365}, rating values for soil types are developed (Table 3.15). Soil types having D_{90} or D_{365} values within same order of magnitude are assigned same rating value.

Effective water content, $S_e = \frac{0.4 - thr}{ths - thr}$ (3.12)

Relative permeability, $K_r = S_e^{0.5} [1 - (1 - S_e^{1/m})^m]^2$ (3.13)

$K_u = K_r \times K_s$ (3.14)

The other input parameters for the rating are depth of water table and annual rainfall. The ratings and relative weights for water table depth and rainfall are shown in Table 3.15. Water table depth is the distance the nutrients need to travel to reach groundwater. The maximum water table depth for rating is chosen on three considerations: (1) the higher the water table depth, the longer it will take to reach the groundwater, (2) for nitrate transport, longer travel time in the vadose zone might allow the nitrate to denitrified into gaseous nitrogen, and (3) only three soils could flow more than 25 foot in a year (Table 3.14). The upper and lower rating limits for annual rainfall are based on the maximum and minimum of 30-years-average rainfall in Oklahoma, respectively.

Table 3.14 Approximate moisture velocity in vadose zone for different soil types.

Soil Type	thr*	ths*	n*	m*	Se†	Kr†	Ks* (ft/d)	Ku = KrKs (ft/d)!!	D_{90}† (ft)	D_{365} † (ft)
Sand	0.045	0.43	2.68	0.627	0.792	2.40E-01	23.39	5.62E+00	5.06E+02	2.05E+03
Loamy Sand	0.057	0.41	2.28	0.561	0.830	2.35E-01	11.49	2.70E+00	2.43E+02	9.87E+02
Sandy Loam	0.065	0.41	1.89	0.471	0.826	1.48E-01	3.48	5.16E-01	4.64E+01	1.88E+02
Sandy Clay Loam	0.1	0.39	1.48	0.324	0.862	7.15E-02	1.03	7.37E-02	6.63E+00	2.69E+01
Loam	0.078	0.43	1.56	0.359	0.773	4.00E-02	0.819	3.28E-02	2.95E+00	1.20E+01
Silt Loam	0.067	0.45	1.41	0.291	0.739	1.22E-02	0.354	4.31E-03	3.88E-01	1.57E+00
Clay Loam	0.095	0.41	1.31	0.237	0.810	1.24E-02	0.205	2.53E-03	2.28E-01	9.23E-01
Silt	0.034	0.46	1.37	0.270	0.742	9.11E-03	0.197	1.79E-03	1.61E-01	6.54E-01
Clay	0.068	0.38	1.09	0.083	0.904	7.63E-04	0.157	1.20E-04	1.08E-02	4.39E-02
Sandy Clay	0.1	0.38	1.23	0.187	0.893	1.78E-02	0.094	1.68E-03	1.51E-01	6.13E-01
Silty Clay Loam	0.089	0.43	1.23	0.187	0.765	2.18E-03	0.055	1.20E-04	1.08E-02	4.38E-02
Silty Clay	0.07	0.36	1.09	0.083	0.966	6.91E-03	0.016	1.09E-04	9.79E-03	3.97E-02

*Carsel & Parrish (1988), †Calculated

Table 3.15 Rating for vadose zone transport.

Soil Type [5]*	Depth (ft) [4]	Rainfall (inch) [3]	Rating
Silty Clay, Clay, Silty Clay Loam	> 25	< 20	1
Sandy Clay, Silt	15 – 25	20 – 30	2
Silt Loam, Clay Loam	10 – 15	30 – 40	3
Sandy Clay Loam, Loam	5 – 10	40 – 50	4
Sand, Loamy Sand, Sandy Loam	< 5	> 50	5

*[ ] Relative weights of each parameter

3.3.4 Saturated Zone Transport

The saturated zone transport module evaluates impact by considering solute transport through groundwater from the CAFO to the nearest downstream water well. Factors selected for evaluating the saturated zone transport module are soil types, distance of water well (d) and years of land application (t). Rating for soil types is selected in a similar way with the vadose zone transport. Here, distance traveled in 10 (D_{10}) and 20 (D_{20}) years (Table 3.16) is calculated for selecting the rating. The groundwater velocity (V) is calculated using Darcy's equation (equation 3.15). It should be noted that the hydraulic gradient used in Table 3.16 is the average for the Central Oklahoma Aquifer (Christenson, 1992). Rating for distance of water well and years of land application is done arbitrarily, except the fact that no rating value is assigned for distance less than 300 ft. The selection of 300 ft is based on current Oklahoma regulation that states that no manure shall be land applied within 300 feet of an existing public or private drinking water well (USDA, 1998). The ratings and relative weights assigned to each parameter are shown in Table 3.17.

$$V = K_s \times i / n \tag{3.15}$$

Table 3.16 Groundwater velocities for USDA soils.

Soil Type	Ks (ft/d)*	n*	i††	V† (ft/d)	D_{10}† (ft)	D_{20}† (ft)
Sand	23.386	0.43	0.01	5.44E-01	1985	3970
Loamy Sand	11.490	0.41	0.01	2.80E-01	1023	2046
Sandy Loam	3.481	0.41	0.01	8.49E-02	310	620
Sandy Clay Loam	1.031	0.39	0.01	2.64E-02	97	193
Loam	0.819	0.43	0.01	1.90E-02	70	139
Silt Loam	0.354	0.45	0.01	7.87E-03	29	57
Clay Loam	0.205	0.41	0.01	4.99E-03	18	36
Silt	0.197	0.46	0.01	4.28E-03	16	31
Clay	0.157	0.38	0.01	4.14E-03	15	30
Sandy Clay	0.094	0.38	0.01	2.49E-03	9	18
Silty Clay Loam	0.055	0.39	0.01	1.41E-03	5	10
Silty Clay	0.016	0.36	0.01	4.37E-04	2	3

*Carsel & Parrish (1988), †Calculated, ††Christenson (1992)

Table 3.17 Rating for saturated zone transport.

Soil Type [5]*	Distance (ft) [4]	Planning period (yrs) [3]	Rating
Silty Clay, Silty Clay Loam	> 2000	< 5	1
Sandy Clay, Clay	1500 - 2000	5 - 10	2
Silt Loam, Clay Loam, Silt	1000 - 1500	10 - 15	3
Sandy Clay Loam, Loam	500 - 1000	15 – 20	4
Sand, Loamy Sand, Sandy Loam	300 - 500	> 20	5

*[ ] Relative weights of each parameter

Finally, the expert system calculates the overall weighted average rating (OWAR) from the ratings obtained for each module and from the relative weights assigned to each module

(Table 3.18). Then the expert system uses the OWAR to get the groundwater pollution potential from Table 3.19. It should be noted that phosphate pollution potential ranges from very low to high, while nitrate pollution potential ranges from very low to very high. This is because phosphate has very high sorption potential and is likely to have much less pollution potential than nitrate.

Table 3.18 Relative weigh of each module.

Module	Weigh
Surface loading	5
Sorption	2
Vadose zone transport	3
Saturated zone transport	3

Table 3.19 Pollution potential.

OWAR		Pollution Potential
Nitrate	Phosphate	
-	1 - 2	Very Low (VL)
1 - 2	2 - 3	Very Low to Low (VL to L)
2 - 3	3 - 4	Low to Medium (L to M)
3 - 4	4 - 5	Medium to High (M to H)
4 -5		High to Very High (H to VH)

3.3.5 Sensitivity Analysis

Sensitivity analysis of the simple expert system is conducted in two steps. In the first step, variation of the final rating due to any change in the rating of each module is studied. And in the second step, variation of the module rating due to any change in the rating of each parameter of that module is studied. It is found that one point change in the rating of the surface loading module changes the final rating by 0.38. Similarly, for one point change of the sorption, vadose zone transport and the saturated zone transport change the final rating by 0.15, 0.23 and 0.23, respectively. In the surface loading module, animal inventory, crop selection and land area can change the rating for the module from 1 to 5, while aquifer thickness can only change the rating between 3 and 5. Rating for nitrate sorption can change by 0.33, 0.42 and 0.25 for one point change of pH, AEC, and nitrate concentration, respectively. Rating for phosphate sorption can change by 0.25, 0.25, 0.31 and 0.19 for one point change of pH, calcium content, aluminum and iron content, and phosphate concentration, respectively. Rating for the vadose zone transport can change by 0.42, 0.33 and 0.25 for one point change of soil type, water table depth, and rainfall, respectively. Finally, rating for the saturated zone transport can change by 0.42, 0.33 and 0.25 for one point change of soil type, well distance, and years of land application, respectively.

3.3.6 Validation

The expert system proposed in this study was validated against site assessment done by a group of experts for a swine CAFO in Oklahoma. The CAFO originally had 450-acre land for applying the waste. After an extensive evaluation by the experts, appointed by the court, the farm was recommended to purchase an additional 600-acre land to get the permit. The farm was raising 27,000 sows annually and was growing corn and wheat. The input parameters for the simple expert system (Table 3.20) were obtained from soil exploration, soil and water quality analyses and from hydrogeologic atlas (Morton & Goemaat, 1973). A summarized output of the expert system is listed in Table 3.20. It is found that before purchasing additional land (original), the farm had high to very high (H to VH) pollution potential for nitrate (N) and medium to high (M to H) pollution potential for phosphate (P). While after having 1050 acres for manure application (permit requirement), the pollution potential for nitrate decreased to medium to high (M to H) and for phosphate decreased to low to medium (L to M) (Table 3.21). Thus, the expert system output is in compliance with the decision made by the group of experts.

Table 3.20 Inputs for validation

Module	Parameter	Value
Surface Loading	Hogs on feed	27000
	Aquifer thickness (ft)	200
	Fertilizer N / P	0
	Soil N / P	0
Sorption	pH	> 6.5
	Nitrate (mg/l)	3.75
	Ca (mmol/kg)	21
Vadose Zone	Soil type	Sandy loam
	Water table depth (ft)	45
	Rainfall (inch)	28
Saturated Zone	Soil type	Sand
	Well distance (ft)	300
	Time (year)	> 20

Table 3.21 Validation of the Expert System

	OWAR		Pollution Potential	
	N	P	N	P
Original	4.26	4.06	H to VH	M to H
Permit Requirements	3.67	3.49	M to H	L to M

3.4 Advanced Expert System

The advanced expert system has three additional modules than the simple expert system. The additional modules are general info module, health effect module and decision module. The general info module is developed to input information those are required in more than one module. The health effect module is developed to assess the health risk involved from exposure to the nutrients at the down gradient well. Finally, The decision module is developed to assign pollution potential (high, medium or low) from the outputs of the saturated zone module and the health effect module. The flow chart for this module is shown in Figure 3.2.

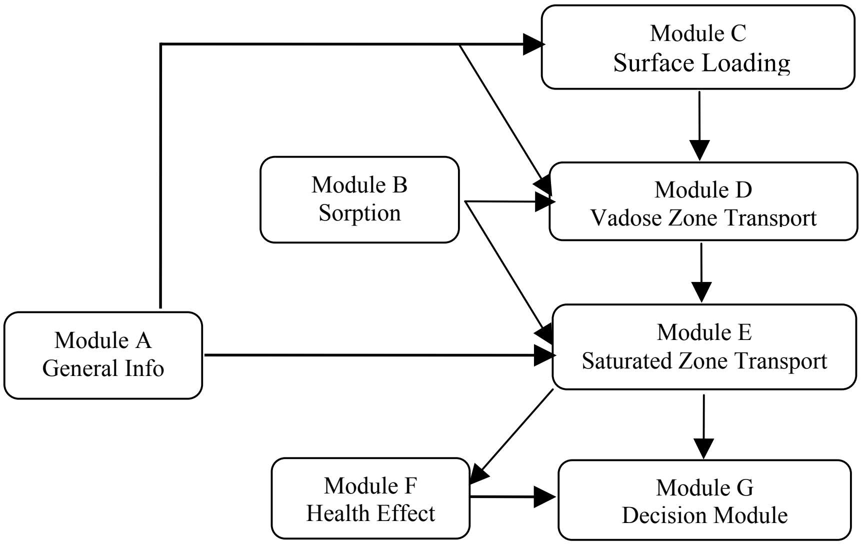

Figure 3.2 Flow chart for the advanced expert

The advanced expert system conducts more scientific evaluation than the simple expert system. It conducts the evaluation as an integrated problem unlike the simple expert system, where every module evaluates their individual rating. Modules in the advanced expert system are connected to one or more modules. Each module, except module A and module B, reads the output of the previous module and use that output as input for the evaluation. Rule-based expert system model is used to develop the input file to run numerical model for evaluating vadose zone transport and analytical model for evaluating saturated zone transport. Also, the decision module uses rule-based model to evaluate the pollution potential from the output of module E and module F.

3.4.1 General Info

The purpose of this module is to ask the user to input information those are required for more than one module. This module takes input of the site location and land area used for cultivation. From the site location, this module reads the daily rainfall for ten years (1990 to 1999) and the daily approximate grass evapotranspiration data for one year (1999). The rainfall and the evapotranspiration data are obtained from Oklahoma Climatological Survey (OCS). The daily evapotranspiration data for one year is the maximum that can be obtained from OCS. The evapotranspiration data for one year is repeated for evaluation of more than one year. Also, rainfall data for ten years is repeated from beginning for evaluation of more than ten years.

3.4.2 Sorption

Sorption module in the advanced expert system uses same input parameters as the sorption module in the simple expert system. The difference is the advanced expert system approximates the retardation factor and the linear equilibrium partitioning coefficient (K_p) instead of finding the rating for sorption.

3.4.2.1 Nitrate Sorption

Retardation factor (RF) for nitrate sorption is estimated from the study done by Qafoku et al. (2000a). Approximate value of RF can be obtained from Table 3.10 for the input of pH and nitrate concentration in groundwater. RF values for the input of pH and nitrate concentration used in the advanced expert system is shown in Table 3.21. RF value can also be obtained from equation 3.11 for the input of anion exchange capacity (AEC). If the user can input all three parameters (pH, nitrate concentration and AEC), the expert system uses the average RF value from both methods.

Table 3.22 RF value from pH and nitrate concentration.

PH	Nitrate (mg/l)	RF
< 4	<100	4
< 4	100 - 200	3
< 4	200 – 300	1.9
< 4	> 300	1.6
4 - 5	<100	2.8
4 - 5	100 - 200	2.4
4 - 5	200 – 300	1.7
4 - 5	> 300	1.3
5 - 6	<100	2.1
5 - 6	100 - 200	1.8
5 - 6	200 – 300	1.6
5 - 6	> 300	1.2
> 6	<100	1.5
> 6	100 - 200	1.3
> 6	200 – 300	1.2
> 6	> 300	1.1

3.4.2.2 Phosphate Sorption

Retardation factor for phosphate sorption is not available in literature. Therefore, the advanced expert system uses an arbitrary rule to approximate RF value for phosphate sorption. The advanced expert system uses the rating table developed in the simple expert system for phosphate sorption. The rule used is RF value for input of each parameter is equal to the division of 20 (an arbitrary maximum RF from Table 3.12) by the rating obtained from the simple expert system. For input of more than one parameter, RF is the average of the RF values obtained for each parameter.

3.4.3 Surface Loading

Surface loading module calculates the net nutrient flux for the days when nutrient loads were applied on the land. The nutrient sources considered are manure, fertilizer and background concentration in soil. And the nutrient sinks considered are the crops and the hays cultivated. This module has the option to input data for a maximum of ten years. For each year, the user needs to input the animal inventory data, select the crops and the hays, input nitrogen and phosphorus in the fertilizer, input nitrogen and phosphorus in soil, and select the days on which manure and/or fertilizer are applied on land. From the animal inventory data, the expert system calculates total waste (manure) generated, nitrogen and phosphorous concentrations in the manure using equations 3.2 through 3.4. If the user cannot input the amount of manure applied on each day, the expert system will evenly distribute the total waste among the selected loading days in a year. Same methodology as the simple expert system is used to obtain the average nitrogen and phosphorous uptake by the crops.

3.4.4 Vadose Zone Transport

Vadose zone transport module evaluates nutrient transport through vadose zone to the groundwater. Analysis of transport through the vadose zone is complicated due to the presence of air in the pore space of unsaturated soil. With air present in the pore space, the hydraulic properties of the unsaturated soil vary from that of saturated soil. In unsaturated soil, the pore water is under negative pressure due to surface tension (Fetter, 1999). This negative pressure, called matric potential, is a function of volumetric water content of soil. The lower the water content, the higher the matric potential (more negative). The relationship between matric potential and volumetric water content of soil is called soil-water characteristic curve. For saturated soil, the matric potential is zero because of the absence of air in the pore spaces. Presence of air in the pore spaces also changes the hydraulic conductivity of soil. Because of the inability to transmit water by the pore spaces occupied by air, soil at unsaturated state has lower hydraulic conductivity than that at saturation. Hydraulic conductivity of unsaturated soil is a function of the volumetric water content or the matric potential. The lower the volumetric water content, the lower the unsaturated hydraulic conductivity. Several models explain the relationship between unsaturated soil hydraulic properties (e.g., volumetric water content and unsaturated hydraulic conductivity) and soil matric potential. Of those, Brooks and Corey (1966), van Genuchten (1980), Vogel and Cislerova (1988) are most widely used.

Solution of governing equation for solute transport through unsaturated soil is very complex because of the fact that moisture content, flow and dispersion is variable. van Genuchten and Alves (1982) presented a series of analytical solutions by assuming constant moisture content, flow and dispersion. However, numerical solution is more reliable since it can consider the variability of moisture content, flow and dispersion. The advanced expert system runs a numerical solute transport model for the evaluation. HYDRUS (Simunek et al., 1998), a well-known public domain solute transport model, is used in the expert system. HYDRUS solves Richards (1928) equation (equation 3.16) for moisture flow and solves the one-dimensional advection-dispersion equation with sorption, first-order decay and zero order growth for solute transport. Assumption of one-dimensional transport in the vertical direction is justified because of the fact that for non-point source lateral dispersion is minimum.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K(\theta)\frac{\partial h(\theta)}{\partial z}\right) - \frac{\partial(K(\theta))}{\partial z} \tag{3.16}$$

Flux boundary is used at the soil surface (top of the soil profile) and free drainage boundary will be used at the bottom. Top boundary represents infiltration flow rate while, bottom boundary represents drainage of water to the groundwater. Daily rainfall and daily evapotranspiration data are set up as top infiltration flux boundary. It is assumed that groundwater level does not change due to the free drainage. The van Genuchten's unsaturated soil hydraulic properties determined by Carsel and Parrish (1988) will be used as default input for HYDRUS. Linear equilibrium partitioning coefficient (K_p) is input from the sorption module. The expert system provides option for the users to change any default input. The user also has the option to select up to three different soil types and up to five different soil layers to incorporate the heterogeneity of the soil profile. A maximum of twenty years time period is allowed for running HYDRUS.

3.4.5 Saturated Zone Transport

Saturated zone transport module determines the maximum solute concentration at the nearest well, the time required to reach the well and the size of the plume when it reaches the well. The advanced expert system runs analytical solute transport model for point sources and apply superposition technique to represent the field condition (non-point source). Superposition of analytical point source model can be done since the governing equation for solute transport in porous media (equation 3.17) is linear (Sun, 1996). The analytical solute transport model solves the basic advection-dispersion equation with linear equilibrium adsorption (equation 3.17). The model uses instantaneous injection of solute mass at the source as a point source. The solution for instantaneous injection is developed by Sun (1996) (equation 3.19).

$$RF\,\frac{\partial C}{\partial t} = -\left(v_x \frac{\partial C}{\partial x}\right) + \left(D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} + D_z \frac{\partial^2 C}{\partial z^2}\right) \tag{3.17}$$

Where, C is the solute concentration, v_x is the average velocities of water in the x directions, D_x, D_y, D_z are the hydrodynamic dispersions in the x, y and z directions, and RF is the retardation factor for sorption. For linear sorption, RF is expressed as

$$\text{RF} = 1 + \frac{p_b}{n} K_p \tag{3.18}$$

Where, p_b is soil bulk density and K_p is linear equilibrium partitioning coefficient

$$C(x, y, z, t) = \frac{M/n}{8(\pi t)^{3/2}\sqrt{D_x D_y D_z}} \exp\left\{ -\frac{(x - v_x t)^2}{4D_x t} - \frac{y^2}{4D_y t} - \frac{z^2}{4D_z t} \right\} \tag{3.19}$$

Where, M is the mass of solute injected instantaneously at the origin at t = 0

The average water velocity (v_x) used in the analytical model (equation 3.19) is obtained from Darcy's law. To incorporate the effect of sorption on groundwater velocity, the average water velocity is corrected by dividing with RF. The total transport time (t) used in the analytical model is sum of the time to reach the well by gravitational flow (Darcy) and the time for the input solute flux to reach maximum. The later is found from the output of HYDRUS (Vadose zone transport module). Longitudinal dispersivity is considered as 10% of the well distance, and transverse dispersivities are considered as 10 % of longitudinal dispersivity. Hydrodynamic dispersions (D_x, D_y, D_z) are calculated by adding molecular diffusion with advective dispersion (dispersivity times average water velocity). The effect of sorption on dispersion is incorporated by using effective hydrodynamic dispersions, which is the division of hydrodynamic dispersion by RF.

The solute mass (M) used in the analytical model (equation 3.19) is obtained from the output of HYDRUS. The expert system reads the solute flux coming out of the vadose zone and uses that to calculate solute concentration at the well from the analytical model. The solute concentration obtained from the analytical model output is for a point source. The point source in the model is considered as a small land area called cell. The total land area is summation of the area of all cells. Thus, the total solute concentration at the well is equal to the summation of the concentrations for the number of cells representing the non-point source (land area).

The advanced expert system has the option to include pumping effect at the well. Pumping from a down gradient well could have significant effect on solute transport. Pumping from a well causes drawdown in the water table, which in turn make the water to flow faster within the region of influence. Drawdown due to pumping could be approximated by using the well-known well function developed by Hantush (1956). The well function developed by Hantush (1956) is represented by a set of empirical equations for different ranges of distance from the well. These empirical equations contain several complicated mathematical functions (Walton, 1989). Thus, approximation of the well function for any distance from the well at any instance is very tedious. Also the approximation could give erroneous result if one doesn't use the math functions properly. A new empirical equation for the well function based on the data presented by Hantush (1956) is developed for the expert system. Figure 3.3a and 3.3b show the correlation between well function W(u) and u where, u is a constant defined by equation (3.20). The expert system calculates the average velocity due to pumping and uses that velocity in the analytical model (equation 3.19).

$$u = \frac{r^2 S}{4Tt} \tag{3.20}$$

Where, r = distance from the well, S = Storage coefficient, T = Tansmisivity of the aquifer, and t = time at any instance.

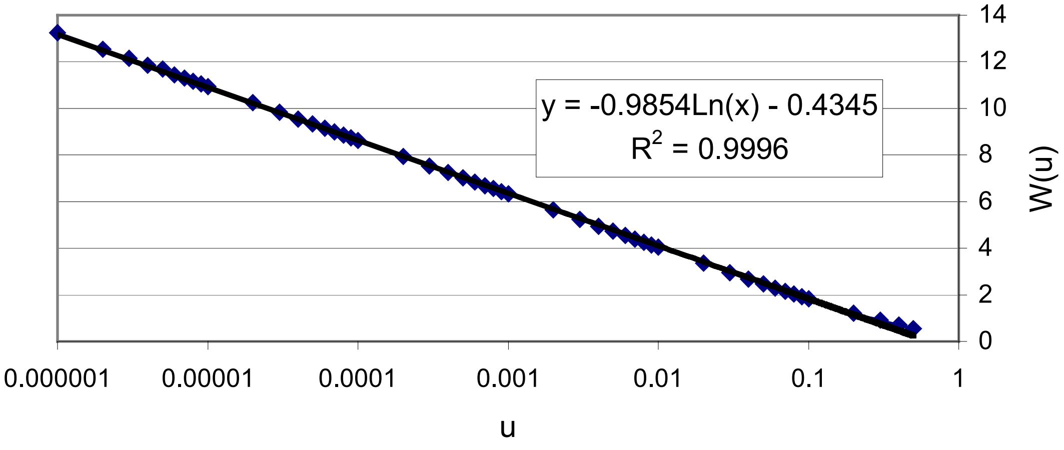

Figure 3.3a Approximation of well function

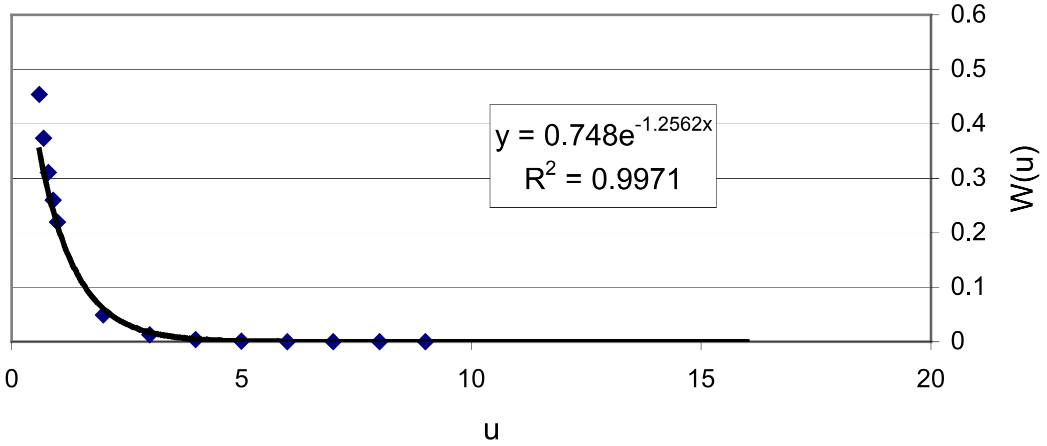

Figure 3.3b Approximation of well function

3.4.6 Health Effect

Health effect module calculates hazard index for the nitrate for the maximum concentration at the well found in the previous module. Hazard index (HI) is equal to the intake rate (I) divided by the oral reference dose (RfD). EPA's integrated risk information system (IRIS) reported that for nitrate, RfD is 1.6 mg/kg/day. Since no health hazard is reported for phosphate in the IRIS, hazard index computation is ignored for phosphate.

Intake rate is the mass of chemical ingested per day per unit body weight of a person. Intake rate is calculated from equation (3.21) (EPA, 1989). Concentration at the well (C) is obtained from the saturated zone transport module. Contact rate (CR) is the volume of water ingested every day. Age specific values for CR are list in EPA (1989). Since nitrate is toxic for infants, the age group most significant for the risk assessment is children from 2 to 6. CR for children from 2 to 6 is 1 lit/day. Exposure frequency (EF) is the number of days in a year people is exposed to the contamination. Considering the waste application cycle of one year, EF is considered as 365 days. Exposure duration (ED) is the number of years a person is exposed to the contamination. Since exposure to nitrate is toxic to younger children, the expert system assumes ED as 6 years. Body weight (BW) is the average body weight of the group of people exposed to the contamination. Since exposure is critical for age group up to 6, approximate BW is considered as 16 kg, the average body weight of the group. Averaging time (AT) is exposure duration in life. The expert system assumes AT as 6 years, the period exposure could cause health risk.

$$I = \frac{C \times CR \times EF \times ED}{BW \times AT} \tag{3.21}$$

3.4.7 Decision Module

Decision module reads the output from the saturated zone transport module and the health effect module and gives a letter rating of the pollution potential from the site. The parameters read from the saturated zone transport module are the maximum solute concentration at the nearest well (C_w), the time required to reach the well (T_w), and the area of the plume when it reaches the well (A_p). The parameter read from the health effect module is hazard index (HI). The expert system calculates the rating for each parameter in a scale of 1 to 10 (equation 3.22 to 3.25). To calculate the rating for concentration (C_r), threshold concentration (C_{th}) of each nutrient is required. EPA's drinking water standard for nitrate (10 mg/l) and phosphate (5 mg/l) are used as C_{th} in the evaluation of pollution potential for nitrate and phosphate, respectively. Rating for time (T_r) is based on the assumption that nutrient is applied in each year and rating is lower for higher value of T_w. Rating for plume area (A_r) is based on the assumption that the higher the plume area (A_p) with respect to the land area (A_l), the lower the concentration at well, the lower the rating. Rating for health effect (H_r) is simply the multiplication of HI and the maximum rating scale.

$$C_r = \frac{C_w}{C_{th}} * 10 \tag{3.22}$$

$$T_r = \frac{365}{T_w} * 10 \tag{3.23}$$

$$A_r = \frac{A_p}{A_l} * 10 \tag{3.24}$$

$$H_r = HI * 10 \tag{3.25}$$

The pollution potential is evaluated based on the rules developed by the human experts. The expert system calculates the average rating (AR) from the ratings of all four parameters.

Based on the AR value, five rules for evaluating the pollution potential (PP) are set up. Those are:

Rule #1: If AR >= 8 Then PP = “High”
Rule #2: If AR >= 6 And AR < 8 Then PP = “Medium to High”
Rule #3: If AR >= 4 And AR < 6 Then PP = “Medium”
Rule #4: If AR >= 2 And AR < 4 Then PP = “Low to Medium”
Rule #5: If AR < 2 Then PP = “Low”

3.4.8 Sensitivity Analysis

The parameters selected for the sensitivity analysis of the advanced expert system are vadose soil type (permeability), saturated zone soil type (permeability), land area and animal inventory. The common input values used in the sensitivity analysis are listed in Table 3.23. First, the model was run for clay loam type soil in the vadose zone, which has low permeability (6.24 cm/d). Two different saturated zone soils, sand (713 cm/d) and loam (25 cm/d), were selected to check the sensitivity of saturated zone soil permeability. The average ratings (AR) for the analysis were 0.23 and 0.19, respectively, while pollution potentials were low for both cases. The result indicated that saturated zone soil permeability has very little effect on the AR when vadose zone soil has low permeability. To further verify this, the expert system was run for loamy sand in the vadose zone, which has very high permeability (350 cm/d). Saturated zone soils were kept same as the first case. For sand and loam in the saturated zone, the AR values were 0.45 and 0.38, respectively. Although the results show increase in the AR values, the pollution potentials (PP) were still low. The result shows that eventhough the soil layers in the vadose and the saturated zones were highly permeable, the pollution potential was low. This could be due to low nutrient load at the land surface in comparison with the land area. To further verify this, the expert system was run for four times the animal units used in the previous compilations. For loamy sand as the vadose zone soil type and sand and loam as the saturated zone soil type, the AR values were 2.3 (PP: low to medium) and 0.7 (PP: low), respectively. Thus, the AR values for sand and loam in the saturated zone increased approximately 5 fold and 2 fold, respectively. To compare the sensitivity of the output between animal inventory and land area, the expert system was run for one-fourth of the land area (i.e., 100 acres) in the previous compilations. For loamy sand as the vadose zone soil type and sand as the saturated zone soil type, the AR values was 0.5, which is smaller than the AR value obtained for 4 fold increase of the animal unit. Thus, it can be concluded that animal inventory change will have more effect on the AR value (or PP) than the land area.

Table 3.23 Common inputs for sensitivity analysis.

Module	Parameter	Value
General Info	County and stations	Beaver
	Chemical of interest	Nitrate
	Land area (acres)	400
Sorption	pH	> 6.5
	Nitrate (mg/l)	3.75
Surface Loading	Beef cows	2000
	Hogs on feed	27000
	Crop	Winter wheat
	Fertilizer N / P	0
	Soil N / P	0
Vadose Zone	Soil type	Variable
	Compilation time (year)	10
	Water table depth (ft)	10
Saturated Zone	Soil type	Variable
	Well distance (ft)	300

3.4.9 Validation

Validation of the advanced expert system could not be done due to the lack of field data. Field data for validation is often collected from tracer test, which was beyond the scope of the project. However, the advanced experts system should produce acceptable result since it uses well-established numerical and analytical models for solute transport through vadose zone and saturated zone, respectively.

3.5 Software Development

A window-based software is developed to conduct the simulation for all tiers. Visual BASIC programming language is used to develop the software. The software is named NPATH, which stands for nutrient path. Effort has been given to make the software as user friendly as possible. A window-based help file is developed to help the users in understanding the definitions of the terms used in the software. The help file also includes two tutorials, which will help the users to know the steps to follow for each tier.

CHAPTER 4

Measure of Success

Three goals were outlined in the work plan in order to measure the success of the project. These are:

1. Better understanding of the impact of commercial fertilizers for farming, on-site irrigation to dispose animal waste and use of septic tanks on groundwater.
2. Groundwater quality improvement in impacted areas and demonstrating proper management techniques that minimizes nutrient and pathogen introduction/transport during animal waste putrefaction.
3. Exporting ideas to other similar land use impacted areas.

To accomplish the first goal, the expert system (NPATH) is developed to evaluate the impact on groundwater from land application of animal waste and commercial fertilizer. NPATH has the option to evaluate the impact from an animal husbandry in three levels. The first level, called Tier-1, evaluates the impact by assessing the vulnerability of the aquifer in the site. This level uses physical (soil type, topography) and atmospheric (rainfall) conditions to evaluate the impact. This level is useful for preliminary site selection for new animal husbandry. The second level, called Tier-2 Level-I, requires additional information on animal inventory and on chemical content of soil and groundwater. This level is useful for screening the most susceptible sites. The third level, called Tier-2 Level-II, does the most advanced evaluation. It runs a numerical model and an analytical model for solute transport through the vadose zone and the saturated zone, respectively. This level is recommended for the most susceptible sites found from the previous level. This level requires more input and compilation time than the previous level. Tier-2 is useful to conduct comparative study between different management options. For example, number and type of animal(s), type of crop(s), fertilizer application can be optimized from Tier-2. Detail discussion on each level is presented in the previous chapter.

To accomplish the second goal, soil and groundwater samples were collected from two animal husbandries in central Oklahoma. Groundwater samples were collected in regular interval for three years. Detail discussion on the water quality and soil analyses is presented in Chapter 2. The final goal is accomplished through making NPATH site independent. Although NPATH is developed mainly for any animal husbandries, it can also be used for the other non-point nutrient sources. The later can be done by adding the nutrient load to the soil and/or the fertilizer nutrient content.

To make the project successful, three panel meetings and three workshops were conducted. The panel meetings were conducted every year during the last three years to discuss the development of NPATH with the panel of experts. The panel of experts includes officials from all major federal agencies and an experience farmer. Comments from every panel meeting are implemented in development of the expert system. Every panel meeting was extremely successful in terms of participation of panel members in the discussion and in terms of the development of the expert system. The workshops were conducted to disseminate the usefulness of NPATH to the community. Of the three workshops, the first one was with the panel and the others were with farmers and conservation district officials. The objective of the workshop was to demonstrate how to use the software and to let people try the software by themselves. Questionnaires (Appendix) were distributed in the workshops to identify the level of satisfaction and also to measure the success of the project. The panel members were asked more technical questions than the farmers and the district officials. Average rating and standard deviation (SD) for each question is presented in Table 4.1. It should be noted that rating scale for each question is from 1 to 5, with 5 being the best rating.

Question numbers 1 and 5 are regarding the overall idea of NPTAH. The overall ratings for these questions (3.79 ± 0.92 and 3.80 ± 0.96, respectively) are excellent. Question numbers 2 through 4 and 6 through 8 are regarding user-friendliness in using the software. Reviewing the rating for these questions, it can be concluded that the software is fairly user-friendly. Also, Tier-2 Level-II is most complicated, while Tier-1 is most simple. It should be noted that user-friendliness of software is very tough to measure. Moreover, frequent use often improves the skill to run any software. Finally, question numbers 9 through 12 are regarding the concept of each tier. These questions were asked only to the panel of experts, who have better background to understand the methodology used in all tiers. It could be concluded from the average ratings for these questions that the methodologies used in each tier is acceptable. Also, Tier-2 Level-II addresses the science more effectively than the other tiers.

Table 4.1 Average rating and SD for each question.

Question	Panel		Farmers		Panel + Farmers	
No.	Average	SD	Average	SD	Average	SD
1	4.00	0.58	3.61	1.04	3.79	0.92
2	3.57	0.79	3.67	1.37	3.64	1.22
3	3.29	0.76	2.56	1.15	2.76	1.09
4	4.14	0.69	3.50	1.26	3.68	1.07
5	4.00	0.58	3.72	1.14	3.80	0.96
6	3.57	0.79	4.33	0.77	4.12	0.83
7	3.14	0.69	3.67	0.77	3.52	0.77
8	2.86	0.69	2.72	0.70	2.76	0.66
9	3.43	0.98	N/A	N/A	N/A	N/A
10	3.57	0.53	N/A	N/A	N/A	N/A
11	3.86	1.21	N/A	N/A	N/A	N/A
12	3.86	0.69	N/A	N/A	N/A	N/A

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusion

- Expert system developed in this study will help the farmers and the conservation district officials in assessing groundwater pollution potential from animal husbandries.
- Two tiers are considered for the expert system: site screening and assessment modeling. Site screening requires less input parameters, while assessment modeling requires more inputs.
- Site screening is recommended for preliminary site selection to build new CAFO, while assessment modeling is for existing animal husbandries. However, one may use assessment modeling for site selection if input parameters are available.
- Site screening is less reliable than the assessment modeling as it is based on subjective approach, while the later is based on scientific approach.
- Assessment modeling is done in two levels: simple and advanced. Simple assessment is useful for quick evaluation and does not require much input. While, advanced assessment is slow and require more inputs.
- The advanced assessment model should give more accurate result than the simple assessment model as it uses more advanced solute transport models and also does the evaluation as an integrated process (every module is connected to the next module).
- User-friendly software with help options and tutorials is developed to help people take advantage of the expert system.
- The results obtained from the questionnaires set up for the workshops, it could be concluded the project is successful.

5.2 Recommendation for Further Study

- To make the expert system more reliable it needs to be validated against field data collected from tracer test. Due to limitation of funding, tracer test could not be conducted in this study. It is strongly recommended to conduct tracer test for validating the expert system.

- The expert system can be further modified for analyzing impact on the watershed by assessing the TMDL from a site.
- The expert system can be incorporated into a GIS-based system to assessment the impact from multiple sites in a watershed.
- GIS-based database can be included in the expert system to make the software more user-friendly.

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APPENDIX

Quality Assurance/Quality Control

Quality Assurance/Quality Control measures were taken to ensure accuracy and precision of data obtained. The complete QA/QC plan is outlined in the QAPP, a brief summary of the QA/QC program is discussed herein. The QA/QC program was used to ensure the validity of experimental data. Because of sample contamination, equipment failure and analysis error, inaccuracies can occur. QC serves as the functional component of the QA/QC program and uses a set of measure to ensure that steps involved in sample analysis are in control. This procedure is necessary to verify that the data obtained from the laboratory analysis and the reported values are correct.

Quality Assurance

QA was evaluation processes for the laboratory operations to ensure that the report result were of defensible quality with a high level of confidence (95% CI). The following are some of the QA measures that were applied:

1. Conduct the QA program in specific laboratory instruments and perform corrective action when necessary;
2. Conduct initial demonstration of the unit performance;
3. Perform calibration check stands;
4. Perform subsequent analyses in each analysis batch of the laboratory blanks;
5. Conduct laboratory performance assessment.

Calibrations were conducted on both field and laboratory instruments prior to use and randomly during use. Field meters were check for instrument performance, and control samples were introduced. Calibration check s performed on DO, turbidity, pH and conductivity meters in accordance with instrument operational manuals.

The obtained raw data becomes reportable data only after it fulfilled the requirements of the QA/QC program. In some laboratory experiments, where quality control was not applicable, quality assurance was the only criteria considered. Solids, oil and grease, and bacterial contamination analyses were ensured by appropriate laboratory performance assessment. Laboratory blanks were used along with the experiments.

Quality Control

A field blank and field duplicates were collected at random sampling sites (one for every five samples taken) during a sampling event. Laboratory blanks were treated and tested as a sample. The following parameters were used to ensure QC control:

1. Field blanks
2. Field duplicates
3. Laboratory blanks
4. Split sample (and sample spikes).

Replicate analyses and spikes were performed on samples when application to ensure the accuracy of the obtained result. For the spikes, know concentration of analyte in solution was used as samples.

Errors and treatment of analytical data

Laboratory data was evaluated to determine if any of the questionable results (outliers) were determinate or indeterminate errors. A determinate error is the result of an analyst error, equipment error, or sample contamination. If no determinate error can be identified, the acceptable range of the indeterminate error is evaluated. For outliers, a Q-test was performed.

Final analytical results were analyzed to determine if the data were valid or invalid. The mean and standard deviations were calculated for each tested parameter based on the sampling event. The reduced data for each parameter was compared to the baseline. The baseline used in this report was the background sample taken up-gradient of farm activity. If the results were determined to be significant when compared to the baseline values, then they were compared relative to location of lagoon.

Parameters of concern

For field duplicates, a relative percent difference (RPD) was calculated for each analysis. Parameters that are of concern were FS and FC. The field blanks satisfied QC measure (i.e., below detectable limit). The allowed concentration range for MRL to 10xMRL was ±20%. The RPD reading for background was 5% of allowable range. Contamination was determined not to be a source of error. Instead, shallow groundwater and rapid transport parameters were determined to be the underlining reason.

Unimportant parameters

Parameters that are not of concern are BOD_5, COD, solids, and metals. Parameters tested for the field and laboratory analyses that were not addressed as parameters of concern were not reported.

Anions/Cations

In addition to the quality control measures mentioned above, the following quality controls were used for anions and cations:

1. Control limits for calibration verification

Concentration range:	Percent Recovery Limits:
MRL to 10xMRL	75-125%
10xMRL to highest calibration level	85-115%

2. Retention time shifts for control standards within the run (cannot shift more that 5% from the expected retention time)
3. Percent recovery for control standards within the run (same concentration range as the control limit for calibration verification).

The spike used for anions was fluoride (12 mg/L) and for cations was potassium (1.97 mg/L). After completion of QA/QC analyses, it was determined that the anion/cation data was reportable. Each constituent passed all the QA/QC requirements. The analytes did not vary significantly (95% CI, t-test) over background (up-gradient) concentrations.

MODEL EVALUATION QUESTIONNAIRE

Prepared for Model Review Panel

November 17, 2000

Please rate the following questions according to the following scale:

5 – Excellent
4 – Good
3 – Reasonable
2 – Unreasonable
1 – Unacceptable

1. Do you like the three-tiered approach used in developing NPATH?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

2. How would you rate the overall user-friendliness of the software?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

3. Would the farmers be able to use this software with proper understanding?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

4. Would the conservation district officials be able to use this software with proper understanding?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

5. Overall how would you rate NPATH?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Please rate the following questions according to the following scale:

5 – Easy
4 – Not Difficult
3 – Reasonable
2 – Difficult
1 – Extremely difficult

6. How would you rate the difficulty level for the users to collect the input parameters for Tier 1?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

7. How would you rate the difficulty level for the users to collect the input parameters for Tier 2 Level I?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

8. How would you rate the difficulty level for the users to collect the input parameters for Tier 2 Level II?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Please rate the following questions according to the following scale:

5 – Excellent
4 – Good
3 – Reasonable
2 – Unreasonable
1 – Unacceptable

9. How would you rate Tier 1, site screening using modified DRASTIC?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

10. How would you rate Tier 2 Level I, assessment modeling through simple expert system?

    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

11. How would you rate Tier 2 Level II, assessment modeling through advanced expert system?

    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

12. Would you consider the input parameters selected for Tier 2 Level II is adequate in terms of addressing the science?

    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Comments:

Tier 1:

Tier 2 Level 1:

Tier 2 Level 2:

Thank you for your cooperation

MODEL EVALUATION QUESTIONNAIRE

Prepared for Farmers & District Officials

December 21, 2000

Please rate the following questions according to the following scale:

5 – Excellent
4 – Good
3 – Reasonable
2 – Unreasonable
1 – Unacceptable

1. Do you like the three-tiered approach used in developing NPATH?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

2. How would you rate the overall user-friendliness of the software?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

3. Would the farmers be able to use this software with proper understanding?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

4. Would the conservation district officials be able to use this software with proper understanding?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

5. Overall how would you rate NPATH?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Please rate the following questions according to the following scale:

5 – Easy
4 – Not Difficult
3 – Reasonable
2 – Difficult
1 – Extremely difficult

6. How would you rate the difficulty level for the users to collect the input parameters for Tier 1?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

7. How would you rate the difficulty level for the users to collect the input parameters for Tier 2 Level I?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

8. How would you rate the difficulty level for the users to collect the input parameters for Tier 2 Level II?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

Comments:

Tier 1:

Tier 2 Level I:

Tier 2 Level II:

Thank you for your cooperation