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A GEOGRAPHIC INFORMATION SYSTEM TO PREDICT NON-POINT SOURCE POLLUTION POTENTIAL[1]

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ABSTRACT: Bacterial densities (total coliform, fecal coliform, and fecal streptococci) and suspended solids in runoff from a feedlot, pasture, and corn field were measured. Densities of fecal coliform were highest from the feedlot but were 1000 to 10,000 times greater than the water quality standard for swimmable waters from all three land uses. Densities of fecal streptococci were highest from the corn field, which suggests that wildlife are the source of bacteria. Fecal coliform/fecal streptococci ratios distinguished cattle from wildlife as the source of bacterial pollution both among land uses and among seasons of the year. Suspended solids concentrations in runoff ranged from 423 to 925 mg/l and were highest from the corn field.

A Geographic Information System (GIS), which utilizes a raster or grid-cell format, was developed to include algorithms associated with non-point source pollution. The system accepts digitally mapped information on soil type, topography, and land use. It calculates characteristics such as slope and slope length, and relates these characteristics to soils and land use parameters in order to produce three dimensional maps of runoff potential, sediment pollution potential, and bacterial pollution potential. It offers the advantages of retaining the geographic character of pollution potential information and of conveying in three-dimensional graphical terms the effects of topography, soil type, land use, and land management practices.

(KEY TERMS: non-point source pollution; bacteria pollution; erosion potential; remote sensing; geographic information system; runoff potential.)

INTRODUCTION

Non-point sources are now the major sources of conventional pollutants in surface waters of the United States. Gianessi and Peskin (1981) have pointed out that non-point sources contribute significant percentages of such pollutants as BOD (57 percent), nutrients (87 percent of phosphorus and 88 percent of nitrogen), total suspended solids (98 percent), and bacteria, and that sediment and sediment-attached pollutants have been recognized in particular as "... the most widespread source of pollutants discharged into the nation's surface waters." Agricultural sources, particularly cropland, pastureland, and rangeland, produce almost 64 percent of the sediment discharged to surface waters (Gianesi and Peskin, 1981). In Nebraska, the pollutant which most often precludes the attainment of "swimmable-fishable" national water quality goals, as set forth in the 1977 Clean Water Act, is coliform bacteria (Nebraska Department of Environmental Control, 1982). The coliform bacteria are thought to originate largely from non-point sources.

Two difficulties arise in attempting to deal with this non-point source bacterial pollution in Nebraska streams. First, the types of land uses and location of specific parcels of land that are contributing high bacterial loads are largely unknown. Thus, devising an approach to reducing bacterial loading that is both effective and economical is difficult. Second, wildlife and cattle feces, rather than human feces, are the source of some of the bacteria. Diseases can be transmitted, of course, from wildlife and cattle to humans through water (for example, giardia), but the extent to which fecal or total coliform densities reflect this potential is largely unknown. Consequently, the relationship between bacterial densities and human health (e.g., gastroenteritis) is highly uncertain, making the coliform water quality standard of questionable relevance. The result, in Nebraska, has been little incentive to deal with the problem.

Non-point source pollution models are sometimes used both to identify problem land uses and land areas and to analyze alternative mitigation strategies. Pollution from agricultural sources originates on the land, and different parcels of land exhibit different potentials for pollution production. Pollution from non-point sources is typically a function of the use and management of land by people, of the physical properties of the land, and of the hydrologic and meteorologic properties of the area. Non-point source pollution models typically represent these factors with several parameters, most of which are geographic in character, that is, they vary with location. Yet, during modeling, that geographic character of the parameters is frequently lost. For example, soil characteristics, topographic parameters, vegetative cover, and information on erosion control practice are usually taken from maps, aerial photos, and/or satellite data. In the process of transferring such information into

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a mathematical model, the site variability due to various geographic parameters is stripped from the information.

The objectives of this study were twofold: (1) to develop a geographically based tool for analyzing and communicating non-point pollution potential, with special emphasis on bacterial pollution; and (2) to examine bacterial concentrations and bacterial types from three different agricultural land uses. The tool allows the geographic character of the information to be retained and the bacterial analyses might suggest the extent to which wildlife and cattle feces are the source of high bacterial loads from different agricultural land uses.

STUDY AREA

The study area was located in the lower Elkhorn River Basin, specifically in eastern Nebraska eight miles north of the confluence of the Elkhorn and Platte Rivers. Fecal coliform bacteria standards are violated regularly in this River, with measured values commonly in the range of 10,000 to 100,000 organisms per 100 milliliters (Nebraska Department of Environmental Control, 1982). The water quality standard for water contact recreation in Nebraska is 200 organisms per 100 mililiters.

The source of these bacterial loads is highly uncertain; there are municipal sewage treatment plants in the Basin that need improvement and there are septic tanks associated with cabins along the River (Nebraska Department of Environmental Control, 1982). There are also, however, feedlots in the Basin, numbering in the thousands; livestock grazing is extensive and is commonly associated with streams in Nebraska (Nebraska Department of Environmental Control, 1982). Most of the Basin is in cropland.

In this study, a one square mile (2.59 km^2) section of land was selected for GIS modeling. There are three distinct agricultural land uses, a large feedlot, a pasture, and a corn field in this section. The site was chosen for its diversity of agricultural land uses, distinct drainage patterns, and proximity to Omaha, Nebraska. Land use and sampling sites are shown in Figure 1. A large feedlot (capacity 13,000 head) occupies the northeast quadrant; the southeast corner is occupied by a seasonally grazed pasture; and most of the remaining land is used for corn production.

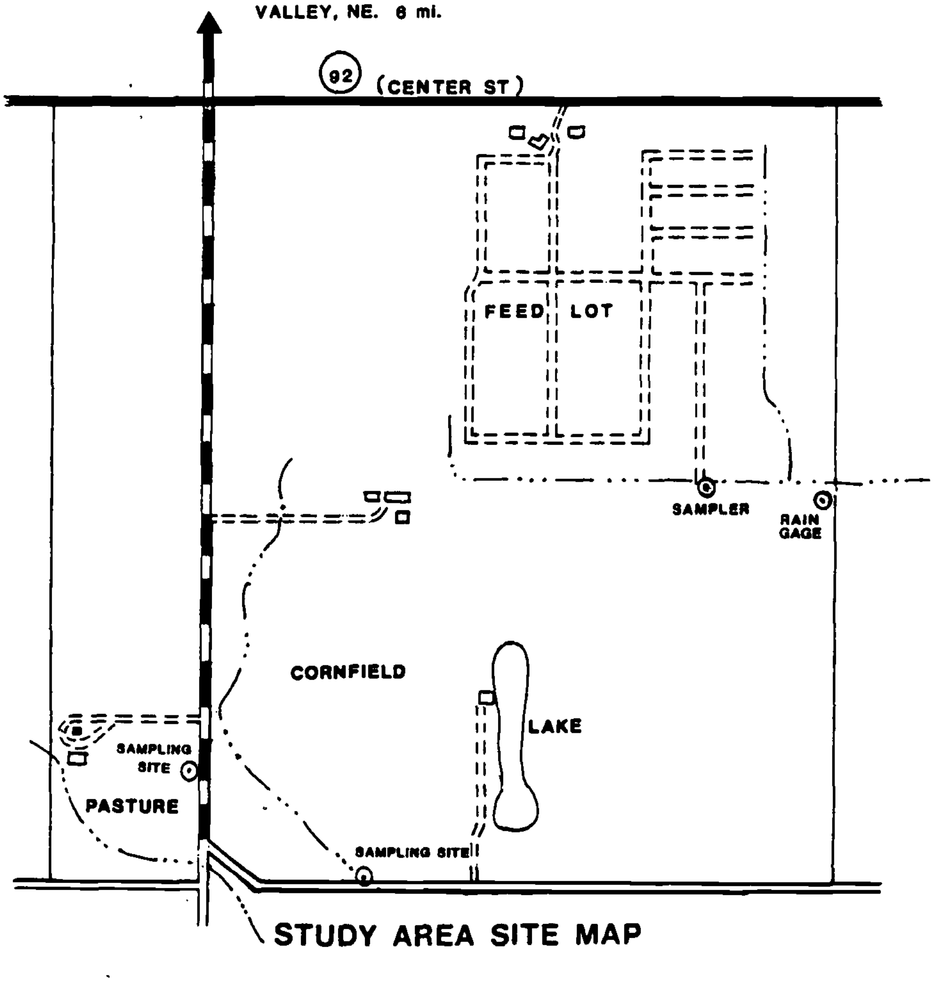

Figure 1. Study Area.

Soils on the site are loamy fine sands, fine sandy loams, and silt loams such as Alda, Cass, Inavale, Lex, and Wann. A digitized version of the Soil Conservation Service Soil Survey map (U.S. Department of Agriculture, 1975) is shown in Figure 2. Topography is given three-dimensionally as elevation (Figure 3) and slope (Figure 4). As indicated, elevations vary by only 18 feet throughout the study area, and slopes range up to 18 percent.

METHODS

Field and Laboratory Procedures

Runoff from the three agricultural land use types was collected and analyzed for suspended solids and bacteria densities, including total coliforms (TC), fecal coliforms (FC), and fecal streptococci (FS). Runoff from six precipitation events, three in late Spring and three in early Fall, 1984, was sampled. However, not all land uses yielded runoff from all six precipitation events.

Precipitation was measured using a weighing type recording rain gage, manufactured by the Belfort Instrument Company. The instrument had an eight-day clock and a capacity of 12 inches. The gage was placed in a fence row (Figure 1), and strip charts were changed after precipitation events.

Runoff from the pasture and cornfield was sampled manually at 20-minute intervals, normally from the onset of runoff until the end of the storm. Runoff from the feedlot was sampled using an automatic sampler manufactured by ISCO (Model No. 1680). The sampler could be programmed to take up to 28 samples at specified time intervals and could be actuated manually or automatically with a water level sensor. All samples were collected in sterilized, 500 ml, plastic bottles with volumes collected ranging from 30 to 500 ml, depending on runoff depth. Samples were refrigerated at 4°C within 3 hours.

The U.S. Geological Survey 7.5-minute quadrangle map provided the basic topographic data, but the detail it provided was insufficient to establish drainage patterns or to provide adequate data for the model. Therefore, the pasture and cornfield were surveyed by plane table and their topography drafted at a scale of 1:480; the contour interval was 1 foot for the cornfield and 0.5 foot for the pasture.

Procedures for laboratory analyses were from Standard Methods (American Public Health Association, 1980). TC, FC, and FS were determined by membrane filter techniques

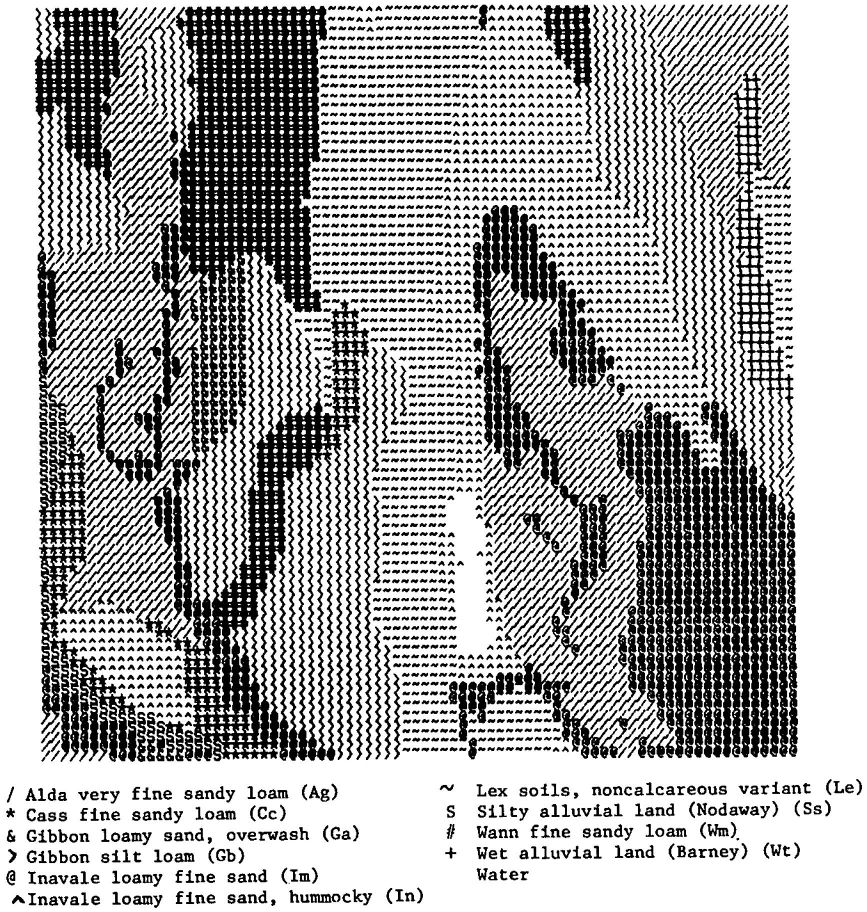

Figure 2. Soil Types in the Study Area.

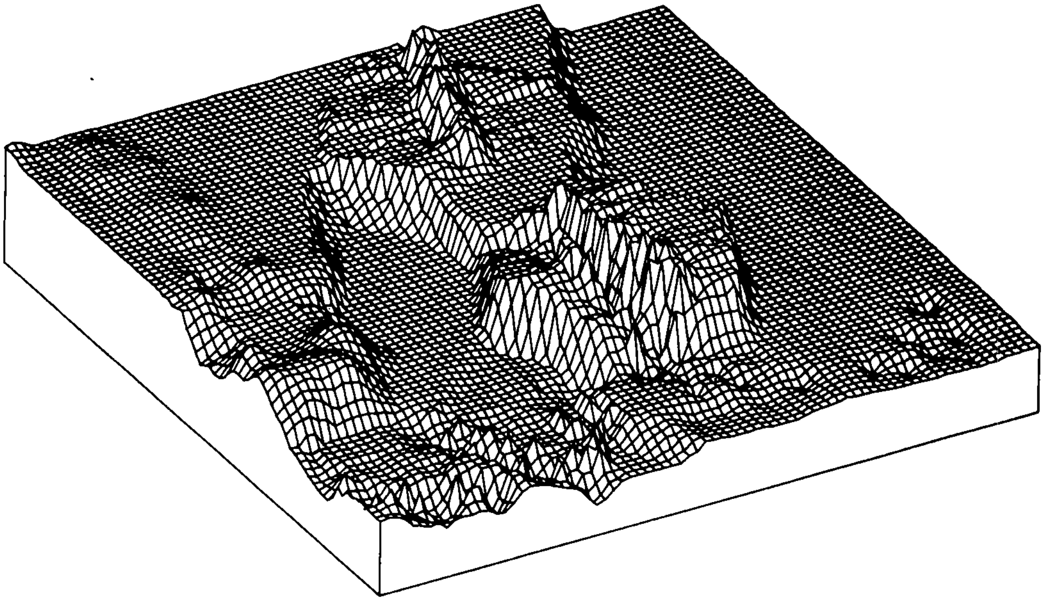

Figure 3. Topographical Map of the Study Area
(elevation range 1104 ft. to 1122 ft.)

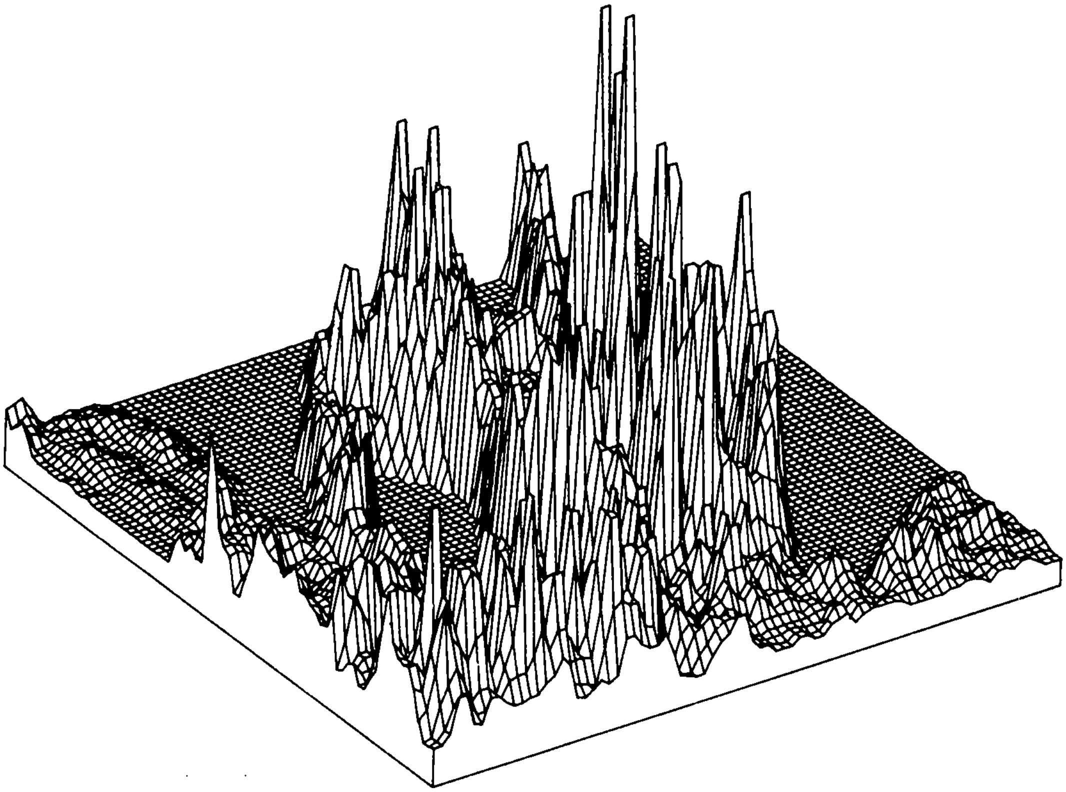

Figure 4. Map of Slope in the Study Area
(slope range 0 to 18 percent).

using presterilized, 0.45 micrometer, cellulose acetate membrane filters. Media used were M-Endo Broth MF, M-FC Broth with rosolic acid, and KF Streptococcus Agar for TC, FC, and FS, respectively. Media were prepared in accordance with Standard Methods, except that the preparation of the sterile buffered dilution water stock did not include the addition of magnesium chloride. Suspended solids were determined as total nonfilterable residue using glass fiber filters and a membrane filter funnel.

There is no general agreement on the best laboratory procedures for measuring FS. Different media and different techniques yield different results (see, for example, Pavlova, *et al.*, 1972; Switzer and Evans, 1974; Geldreich, 1976). In this study, the KF agar with the membrane filter procedure was used for all analyses. However, samples from two of the Fall events were also analyzed for FS using PSE agar in the pour plate procedure. The PSE agar in the pour plate procedure is thought to be more sensitive to FS in general, and *Streptococci bovis* and *Streptococci equinus* in particular. *S. bovis* and *S. equinus* are the predominant bio-types in cattle feces. Thus, the PSE agar in the pour plate procedure should yield higher densities of FS from cattle feces than the KF agar in the membrane filter procedure. These differences in sensitivity can help distinguish bacterial sources.

The FC/FS ratio was also calculated in order to characterize the source of the fecal pollution. Geldreich (1976) suggested that a ratio of 4 or higher implies human fecal material, a ratio of 0.1 or less is typical of wildlife, and a ratio of 0.1 to 0.6 is typical of domestic animals such as cattle. The FC/FS ratio shifts with time as a result of differences in bacterial die-off rates. Thus, because of the time lag, the ratio is more valid when the samples are taken near the point of origin. This means that ratios obtained from sampling runoff may produce more accurate results than samples taken as water in the receiving stream. Nevertheless, because of differences in the sensitivity of procedures to various bacterial species and because of differences in die off rates, there is little agreement on the validity of the FC/FS ratio or any bacterial ratio to characterize the bacterial source; this problem is discussed in more detail in Baxter-Potter and Gilliland (in press).

Model Development

The model developed is fundamentally a geographic information system (GIS) with several unique features. It utilizes raster format and is modular, transportable, and expandable. For each cell, a set of parameter values is input and manipulated according to three equations that deal with distinct dimensions of non-point source pollution. The output is in the form of three-dimensional maps, in this case of runoff and pollution potential. The study area of 2.59 km^2 (1 mi^2) is represented by an 80 by 80 cell matrix. The model has not yet been calibrated in the sense that its predictions have not been compared with field measurements of runoff from precipitation events.

The GIS was based on the Raster Geographic Information System for Mapping (RGISM), developed by Peterson and Long (1984). It is unique because it is: (1) modular rather than monolithic, (2) transportable, and (3) flexible and expandable. The system utilizes the standard operating system file structure of the host processor rather than an internal filing system. Thus, a significant amount of programming, common in more monolithic GIS's, is eliminated. RGISM is organized as a family of free standing program modules written in standard FORTRAN 77. Each module performs a specific process on, or manipulation of, data files. This approach is distinctly different from the conventional organization of monolithic GIS's which compile all manipulation programming in one large program. The module approach eliminates the necessity of loading unused programming into the host processor's core memory and in general makes more efficient use of system resources. Other GIS's may use a chained modular approach, but often these rely on nonstandard programming and thus are very system specific; they are not easily transportable to other computer system. RGISM requires only that the host processor be equipped with a FORTRAN 77 compiler and virtual memory.

To meet the goal of flexibility and expandability, user specified operations were added to the list of available map manipulations. To add an operation to RGISM the user need only write a program module to perform that operation. Due to the free-standing structure of RGISM, editing and debugging a monolithic master GIS program is not required in order to incorporate the new operation. To aid the user in the development of a new program module, a library of subroutines and functions has been developed. Most of these library operations are input/output operations. However, there are also library operations which read and display comments from input files and insert comments into output files. These library functions can be called by the user from within the new program module. The only programming burden which is left to the user is the Fortran description of the new manipulation to be performed, frequently less than ten lines of programming or a statement that simply expresses an equation in Fortran.

Three commonly applied predictive formulae were implemented as RGISM program modules in this GIS: (1) the Soil Conservation Service Curve Number technique (SCSCN) for the prediction of potential runoff (Soil Conservation Service, 1972); (2) the Universal Soil Loss Equation for the prediction of potential erosion (Wischmeier and Smith, 1978); and (3) a simple loading function for the prediction of bacterial densities in runoff.

Application of the SCSCN technique requires the assessment of: (1) antecedent soil moisture conditions; (2) soil hydrologic type; and (3) land use and treatment class. Both hydrologic soil type and land use and treatment class are geographic in nature and may vary spatially within a small watershed. RUNOFF is the module implementing the SCSCN technique. The module prompts the user to enter the 24-hour precipitation. Then, on a cell-by-cell basis, the module (1) consults the soils map and interprets hydrologic soil group, (2) consults the land use map and interprets land use and treatment class, (3) calculates the runoff potential for that cell, and (4) stores the predicted runoff potential in the appropriate location in an output map file. The consult/calculate process is repeated for each cell until the runoff potential map is complete. Output is a map of storm runoff potential.

The Universal Soil Loss Equation is an empirical equation designed to compute long-term average soil losses due to sheet and rill erosion. The equation ignores sediment yields from gully, streambank, or streambed erosion. Erosion losses are expressed as the product of five factors: (1) rainfall erosion potential, (2) soil erodibility, (3) a terrain factor which considers slope length and steepness, (4) a cover and management factor, and (5) a support or erosion control practice factor. With the exception of the rainfall factor, all of these may vary spatially within a small watershed and are geographic in nature. USLE is the module implementing the Universal Soil Loss Equation to predict erosion potential. This module also prompts the user to enter the 24-hour precipitation. The rainfall erosion potential factor is calculated from daily precipitation. Then, on a cell-by-cell basis the module executes the following five steps. (1) It consults a slope map and a slope length map and calculates the terrain factor. The slope and slope length maps must have been created earlier using an RGISM program module called SLOPE. (2) The module consults the soils map and assigns a soil erodibility factor based on soil type. (3) The land use map is consulted and a cover factor is assigned. (4) A practice factor is assigned on the basis of land use class and slope. Finally, (5) the predicted erosion potential is stored in the appropriate location in an output map file. This consult/calculate process is repeated for each cell until the erosion potential map is complete. The output is a map of erosion potential. Its value is in the visual representation of the relative erosion potentials of different parcels of land. Because the Universal Soil Loss Equation is not storm specific nor does it consider redeposition, the model does not predict actual erosion for a given storm nor does it predict the amount of sediment reaching a stream.

Bacterial densities in runoff are affected primarily by stocking rates, age and type of fecal deposits, antecedent conditions, temperature, season, and rainfall intensity. The relationships of all of these factors to bacterial densities are not well defined and are not quantified in a predictive fashion. McElroy (1976) has suggested that bacterial densities in runoff from feedlots might be approximated simply by relying on typical density values from the literature. This approach is clearly a simplification since it ignores factors (other than land use) that can cause extreme variations in bacterial density. Nevertheless, it is used here as a first approximation. GERMS is the module that predicts bacterial densities in runoff. This module simply consults the land use map and, on a cell-by-cell basis, assigns a typical TC and FC density for each land use class. Typical densities were compiled from the literature (Baxter-Potter and Gilliland, in press). Two potential bacterial density maps are produced, one for TC densities and one for FC densities.

The data base for this GIS model consists of four maps: a land use map, a soils map, an elevation map, and a base map. The land use map was compiled from aerial photographs and field scouted information. The soils map is a digitized version of the SCS Soil Survey map (Figure 2). The digital elevation model was produced using an RGISM program module to interpret a compilation of contour information (Figure 3). The base map is an outline of the 2.59 km^2 study area and contains locations of match points used to align and rescale other digitized maps before converting them to raster format.

All three of the predictive equations utilized contain some type of land use factor. However, each of the predictive equations relies on a slightly different land use classification system. In order to avoid the necessity of compiling and digitizing three separate land use maps, a full purpose land use classification system was devised; the SCSCN "cover" classes (U.S. Soil Conservation Service, 1972) were harmonized with "Universal Soil Loss Equation" classes (Wischmeier and Smith, 1978; Novotny and Chesters, 1981) and with land use distinctions which affect bacterial densities in runoff. The final full purpose classification system contained 46 land use classes (Baxter-Potter, 1985).

RESULTS

Water Quality of Runoff

Mean measured bacterial densities are tabulated and compared with values from the literature in Table 1. Although the field data were inadequate to be predictive or to calibrate the GIS model, they suggested some areas for further research and they confirmed conclusions of other researchers. Basically, these data suggested, as did those of other researchers (Table 1) that TC and FC densities in runoff from agricultural lands consistently exceed the surface water quality standards. Moreover, corn fields can contribute bacterial densities similar to those from a feedlot (Table 1).

From the corn field and pasture, mean bacterial densities measured were higher than the range of values given in the literature. From the feedlot, measured bacterial densities were somewhat low but near the range reported in the literature. FC/FS ratios, while they must be interpreted with caution, did support the expected conclusions. They suggest but do not prove that bacteria associated with wildlife (birds and rodents) dominate runoff from the corn field while bacteria associated with cattle dominate runoff from the feedlot.

Mean measured bacterial densities from each of the three land use types for each event sampled are given in Table 2. For the corn field, the most striking pattern was the sharp increase in bacterial densities, particularly TC and FS, that occurred as the year progressed. This probably reflected an increase in wildlife activity in the field as it recovered from the relatively sterile condition of a newly disked and planted seedbed. The mature standing corn in early October and the partially picked field condition of mid-October provided a source of plant material. Coliforms may be associated with this plant material, and it may have attracted birds and rodents. The FC/FS ratio confirmed this trend; whether it indicated wildlife, plant material, or both by mid-October is uncertain.

TABLE 1. Mean Bacterial Densities and FC/FS Ratios for Each Land Use (organisms/100 ml).

Land Use	Field Data[a]	Literature
CORN FIELD		
TC	3,500,000	15,800[1] – 145,000[2]
FC	410,000	5,400[2] – 14,300[1]
FS[b]	3,700,000	16,200[2] – 39,000[2]
FC/FS	0.17	
PASTURE		
TC	820,000	6,000[2] – 329,000[3]
FC	320,000	1,000[2] – 57,000[3]
FS[b]	500,000	1,750[2] – 172,000[3]
FC/FS	0.50	
FEEDLOT		
TC	4,500,000	22,000,000[4] – 348,000,000[4]
FC	1,900,000	1,350,000[5] – 79,000,000[4]
FS[b]	730,000	8,000,000[4] – 79,000,000[4]
FC/FS	1.45	

[a] Mean values are means of probable densities for all samples analyzed. All sample densities were equally weighted. For some fall events, only single samples were obtained, or the few samples obtained were composited to a single sample for analysis.

[b] All FS values included were determined using membrane filter on KF agar medium.

[1] Sewell and Alphin (1975) as reported by Doran, *et al.* (1984).

[2] Harms, *et al.* (1975).

[3] Doran, *et al.* (1981).

[4] Miner, *et al.* (1966).

[5] Kries, *et al.* (1972).

In the pasture, bacterial densities rose sharply between May 25 and June 9, reflecting the introduction of cattle to the pasture. Bacterial densities and the FC/FS ratio dropped sharply in October as grazing ceased. On June 9, the FC/FS ratio of 1.4 was higher than Geldreich (1976) suggested was typical of livestock. This may have been due to the underestimation of FS by the procedure (membrane filter on KF agar). Again, field data are sparse, but trends did correlate with the seasonal activity of cattle and wildlife.

Differences in recovery of *S. bovis* between analyses using a membrane filter on a KF agar medium and a PSE agar in a pour plate procedure should show up best in analysis of runoff contaminated with cattle feces. The PSE pour plate procedure was used only on two October events and, unfortunately, no runoff from the feedlot occurred in October. But comparisons of data from the corn field and pasture support those researchers who contend that the PSE pour plate procedure should be used when analyzing water in which the principal source of fecal contamination is livestock. The PSE pour plate procedure did not recover as many organisms from the corn field as did the membrane filter on KF agar; for the two October events, KF densities were 2.5 times the PSE densities. The reverse was true in the pasture; PSE densities were 2.4 times the KF densities.

Measured suspended solids concentrations in runoff ranged from 137 to 1724 mg/l for the various storm events. Mean values were 423, 638, and 925 mg/l for the feedlot, pasture, and cornfield, respectively. As expected, the feedlot was least prone to soil erosion, while the cornfield was most prone.

Pollution Potential Maps

Three dimensional maps of runoff and pollution potential were produced using the algorithms in the GIS Model. Three examples, one of each map type, are provided in Figures 5, 6, and 7. The maps are oriented as though viewed from the southwest. The feedlot is in the northwest corner and the pasture in the southwest corner.

Runoff potential (Figure 5), associated with a storm of 24-hour duration with 1.4 cm of precipitation, ranged from a high of 0.57 cm from the feedlot to 0.0 cm in some areas of the pasture and corn field. Since the soils map was not consulted in estimating feedlot runoff, there was no reflection of soil type patterns in the predicted feedlot runoff. Within the corn field, variations reflected soil types, with the Alda soils (Figure 2) yielding the highest runoff. Although Alda soils were present over part of the pasture, land use dominated as the factor controlling runoff, and runoff potential from the pasture was low. A comparison of runoff potential among storms of different magnitude suggested that the volume of feedlot runoff became less significant with respect to overall runoff as storm size increased. This is the expected result since soils in the corn field and pasture were more fully saturated during large storms, while the permeability of the feedlot is essentially zero regardless of storm size. Swanson, *et al.* (1970), showed that infiltration on an established feedlot is restricted to that which can be stored in the manure pack, and Gilbertson, *et al.* (1971), showed that, in eastern Nebraska, the manure pack can store up to 0.5 inches (1.27 cm) of precipitation.

Erosion potential (Figure 6) associated with a storm of 24-hour duration with 3.3 cm of precipitation, ranged from zero to 7.79 metric tons per hectare. The influence of several factors in the Universal Soil Loss Equation are evident. First, erosion from the feedlot was virtually zero, a reflection of a low erodibility factor (K). Second, land use distinctions (which were considered in the cover and management or C

TABLE 2. Mean[a] Bacterial Densities and FC/FS Ratios for Each Precipitation Event for Each Land Use (organisms/100 ml).

Land Use and Event Date, 1984	TC	FC	FS[b]	FC/FS
CORN FIELD				
May 25	14,000	– – – –	11,000	– –
June 9	45,000	6,200	28,000	0.22
June 16	– – – –	– – – –	– – – –	– –
October 9	570,000	850,000	2,600,000	0.33
October 10	1,100,000	180,000	1,800,000	0.10
October 14	16,000,000	640,000	14,000,000	0.04
PASTURE				
May 25[c]	36,000	– – – –	48,000	– –
June 9	2,700,000	840,000	600,000	1.40
June 16	– – – –	– – – –	– – – –	– –
October 9[d]	– – – –	– – – –	– – – –	– –
October 10[d]	360,000	110,000	1,100,000	0.10
October 14[d]	180,000	4,600	260,000	0.02
FEEDLOT				
May 25	190,000	– – – –	22,000	– –
June 9	270,000	14,000	9,600	1.40
June 16[d]	7,400,000	2,100,000	1,400,000	1.50
October 9	– – – –	– – – –	– – – –	– –
October 10	– – – –	– – – –	– – – –	– –
October 14	– – – –	– – – –	– – – –	– –

– – – No samples obtained.

[a] Mean values (arithmetic means) are means of probable densities for all samples analyzed. All sample densities were equally weighted.

[b] All FS values included were determined using membrane filter on KF agar medium.

[c] Samples aged 48 hours.

[d] Grab sample.

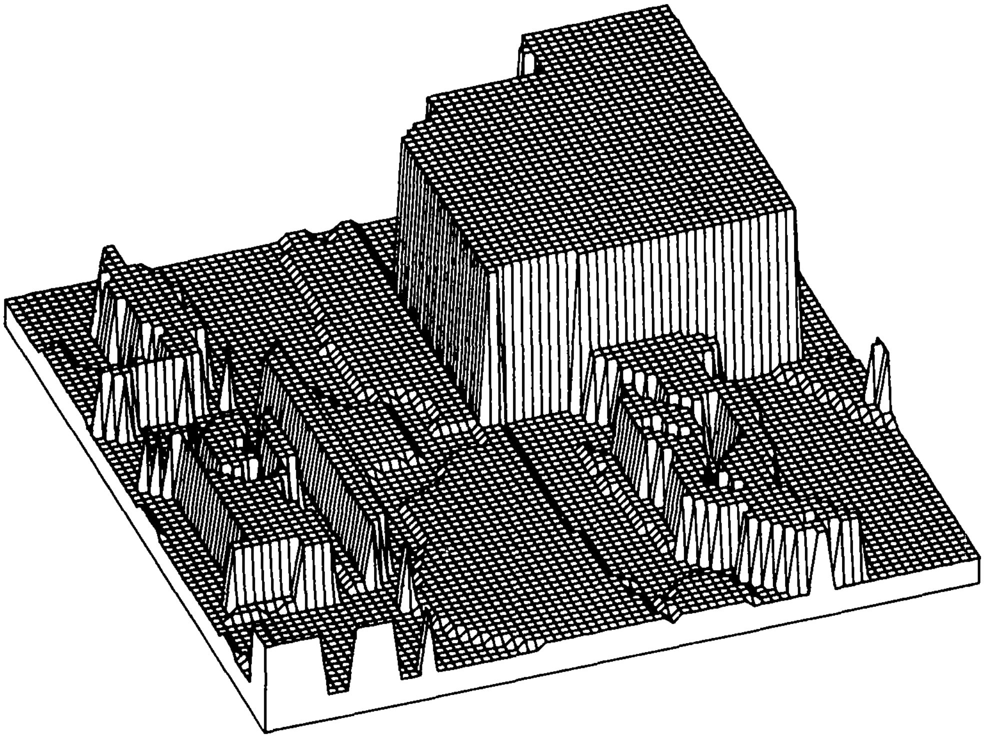

Figure 5. Runoff Potential from the May 25 Precipitation Event (24-hour precipitation was 0.55 inches; maximum runoff potential is 0.23 inches).

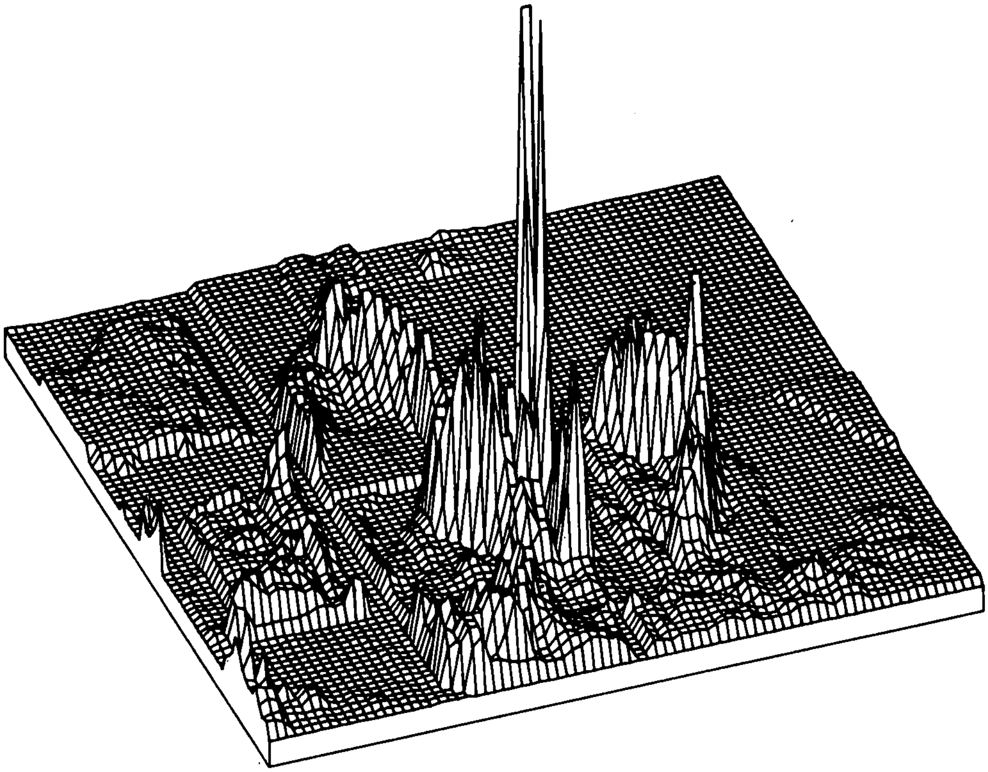

Figure 6. Erosion Potential from the June 9 Precipitation Event (24-hour precipitation was 1.32 inches; maximum erosion potential is 3.47 tons/acre).

factor) were evident, particularly in the SW 1/4 of the SW 1/4 of the study area where the erosion potential for the pasture was distinctly lower than that for the surrounding areas. Roads were also clearly discernable because of their low erosion potential. Third, in the corn fields the interplay of the soil erodibility (K) and the terrain factor (LS) was apparent. For example in the southeast quadrant, an area of Inavale soils (loamy fine sands) yielded low erosion potential and was distinct from its neighboring soils (Gibbon silt loam to the northeast of the Inavale soils and Alda fine sandy loam to the west). Elsewhere in the corn field, the terrain factor dominated; maximum erosion potential coincided with maximum slope (see Figure 3).

Bacterial pollution potential for fecal coliform is shown in Figure 7. Clearly, the feedlot predominated as a source of high concentrations of fecal coliform. Moreover, the significance of the presence of livestock was indicated by the fact that the pasture and grazed corn field yielded higher FC densities than the roads, ungrazed corn fields, or idle land.

SUMMARY AND CONCLUSIONS

Non-point source pollution is recognized as a major nationwide problem. As an agricultural state, Nebraska's principal water quality problems are associated with agricultural non-point sources – in particular, bacterial pollution. The objectives of this study were to measure bacterial loads from three agricultural land uses and to develop a geographically based model for locating, analyzing, and communicating non-point pollution potential.

Several conclusions are indicated from the results of these bacterial analyses as well as those of other researchers. First, TC and FC densities in runoff from agricultural land can be very high and consistently exceed surface water quality standards. Second, bacterial pollution from pastures and grazed fields is significant, possibly overshadowing that from feedlot sources in the total number of bacteria delivered. Third, the FC/FS ratio, if developed and validated further, might be a responsive indicator of bacterial contamination source and might be able to reflect changes in the principle source of contamination. Fourth, although the PSE pour plate method is preferable for the enumeration of FS when the principle contamination source is cattle or horse feces, the membrane filter on KF agar may be more successful in recovering FS when the principal source is wildlife feces. Fifth, the appropriateness of water quality standards for total and fecal coliform when the source is agricultural lands is questionable.

The three-dimensional maps of runoff, erosion, and pollution potential offer unique advantages when communicating or illustrating non-point source pollution potential. Such maps retain the geographical nature of non-point pollution, conveying the effects of soil type, land use, and management

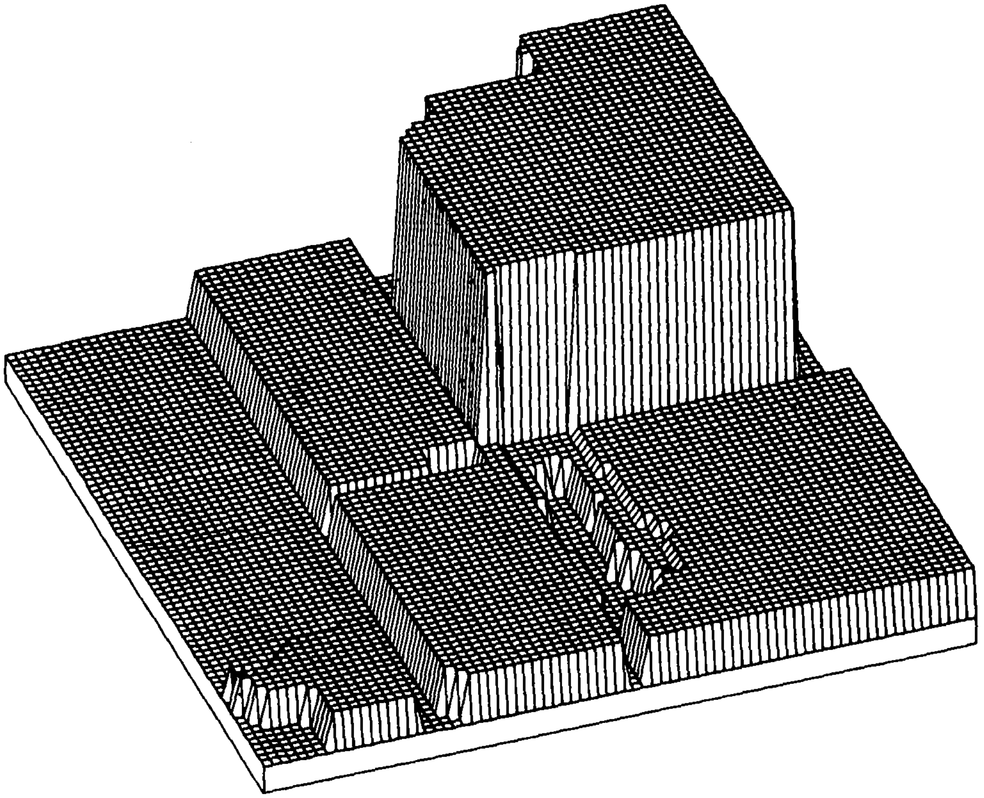

Figure 7. Bacterial Pollution Potential for Fecal Coliforms (maximum density is 1,900,000 organisms per 100 milliliters).

practices. The model that produced these specific maps has not yet been calibrated; yet, it is clear that pollution potential maps may be worth a thousand words when communicating with a non-technically-oriented audience about the need to control non-point pollution. In Nebraska, the 24 Natural Resources Districts work with farmers in their districts to set priorities, develop, and cost share best management practices for erosion control. These three-dimensional maps can help set priorities for implementation of the practices.

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