Spatial Distribution of Nitrate Leaching "Hot Spots" and Nitrate Contributions to the South Platte River Basin Aquifers

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ABSTRACT

SPATIAL DISTRIBUTION OF NITRATE LEACHING "HOT SPOTS" AND NITRATE CONTRIBUTIONS TO THE SOUTH PLATTE RIVER BASIN AQUIFERS

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This project specifically addresses the issue of ground water quality in the South Platte River Basin Aquifer due to nitrate contamination. Areas north and south of Greeley, Colorado, currently have many wells supplying groundwater containing more than 10 ppm of nitrates. A numerical model, the Nitrate Leaching and Economic Analysis Package (NLEAP) is used to estimate nitrates leached (NL) from agricultural crop root zones by simulating weather, fertilizer inputs, irrigation practices, evapotranspiration, soil types and a variety of other cropping practices. Combining such a model with the spatial distribution of soils and cropping practices within a geographic information system (GIS) framework allows the identification of the geographical extent and spatial distribution of nitrate leaching "hot spots."

Model runs were correlated to groundwater NO_3-N for 37 pumping irrigation wells within the study area for the 1989-1991 growing seasons. The strongest single nitrate leaching factor correlated to groundwater NO_3-N concentrations was proximity-to-feedlots. Manuring practices or inadequate crediting of manure-source nitrogen in determining fertilizer requirements are possible causes of the importance of proximity-to-feedlots. The reason is unclear at this level of analysis. Variation in NLEAP NL estimates associated with soil variability was the second strongest leaching factor related to groundwater NO_3-N concentration. Fertilizer application rates varied as a function of organic matter in the soil and potential crop yields for that soil. The combination of two nitrate leaching factors that gave the strongest correlations to groundwater NO_3-N concentrations was proximity-to-feedlots and soils. Conclusions reached from the research suggested that spatial variations in *NLEAP simulated NL*, associated with *proximity-to-feedlots*, was related to groundwater NO_3-N contamination in the study area.

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INTRODUCTION

Areas north and south of Greeley, Colorado, currently have many wells supplying groundwater with more than 10 ppm nitrates (North Front Range Water Quality Planning Association, 1990). Non-point source nitrate contamination of the South Platte aquifer is difficult to quantify due to the lack of a data base of information and a method of identifying and quantifying the nitrate leaching amounts or potential for nitrate leaching.

This project specifically addresses the issue of ground water quality in the South Platte River Basin Aquifer due to nitrate contamination. Figure 1 shows the location of the study area. Critical issues influenced by the research project are: conjunctive management of surface and groundwater, reclamation of polluted groundwater, and regulation of groundwater recharge through control of deep percolation water quality. High levels of nitrates in drinking water are a threat to human health. The Colorado Health Department recommends that drinking water have less than 10 ppm NO^3-N.

Non-point source contamination of ground water aquifers from irrigated agriculture varies significantly because of different management practices, soils, and climate. A numerical model, the Nitrate Leaching and Economic Analysis Package (NLEAP), provides a means for estimating levels of nitrates leached (Shaffer et al., 1991). Combining such a model with the spatial distribution of soils and cropping practices within a geographic information system (GIS) framework allows the identification of the geographical extent and spatial distribution of nitrate leaching "hot spots."

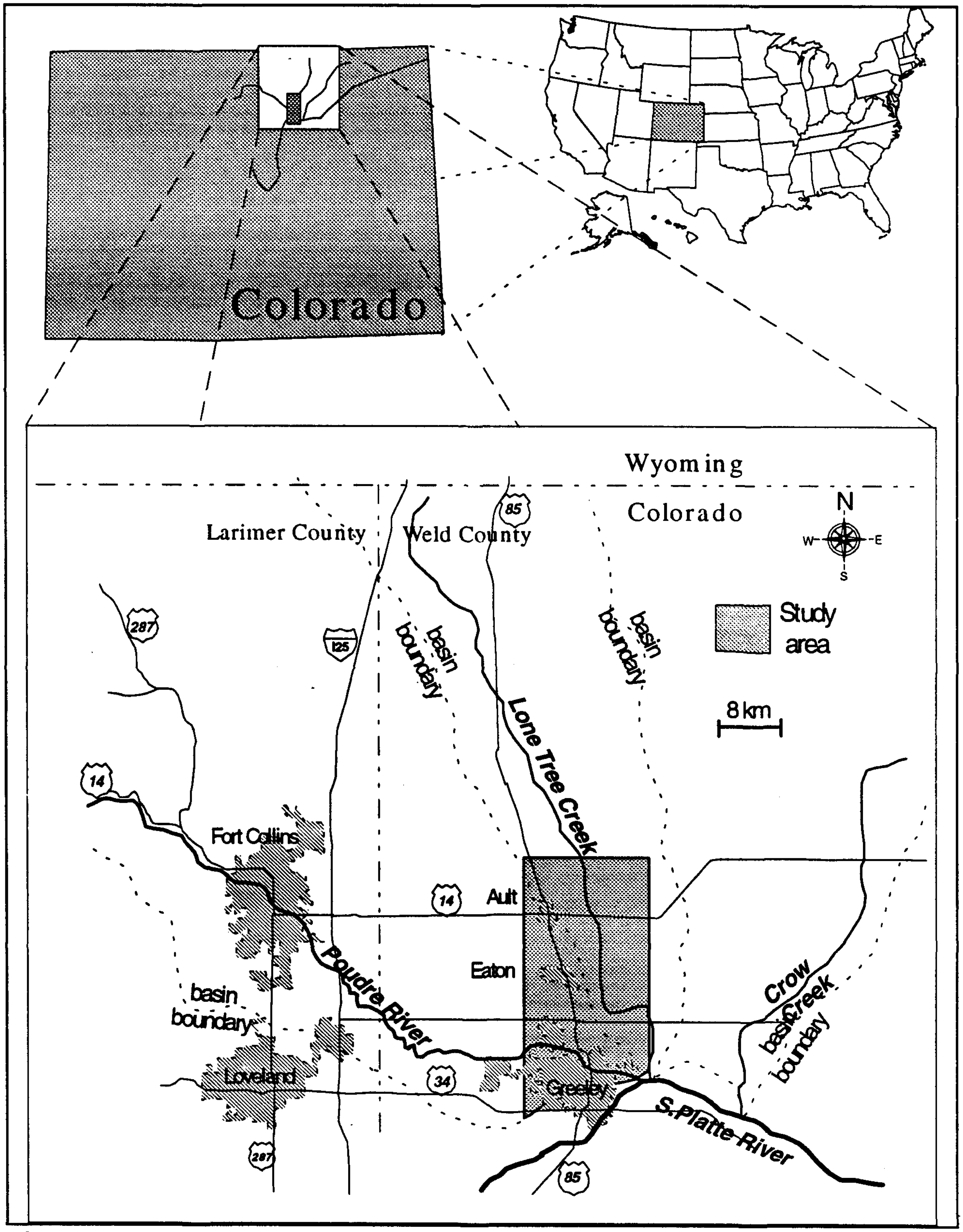

Figure 1, Study Area

Two outputs of NLEAP are Nitrogen Leached (NL) and Annual Leaching Risk Potential (ALRP) indices. The NLEAP (Nitrate Leaching and Economic Analysis Package) model was developed to implement the theories, methods, and equations for estimating the nitrogen application, flow through the biological and physical processes of agricultural crops and leaching below the root zone of the crops. The Nitrate Leached (NL) index is the amount of NO_3-N (lb acre^{-1} time step^{-1}) leached from the root zone. The Annual Leaching Risk Potential (ALRP) gives a qualitative estimate of the combined effects of the total annual deep percolation of water and the amount of NO_3-N available for leaching (Shaffer et al, 1991). These indices for agricultural lands can be modeled using various combinations of spatial data (soil type, irrigation type, proximity to feedlots, and crop type, weather, etc.) computed by GIS operations and input into the NLEAP simulation model. The NLEAP modeling with spatially distributed data inputs, allows identification of nitrate leaching "hot spots" and more accurate management of the aquifer water quality in the South Platte River basin. The "hot spots" may be areas where existing cropping and fertilization practices combined with specific "sensitive soil types" are presently contributing excessive nitrates to groundwater aquifers. When the GIS-NLEAP model is used as a predictive tool for screening large areas of river basins for areas of potential concern, "potential hot spots" may be identified by simulating changes in cropping activities on sensitive soils with inappropriate fertilization or irrigation methods.

By making farmers and extension agents aware of potential or existing nitrate leaching "hot spots" on agricultural land, best management practices (BMP) can be proposed to reduce nitrate leaching. The output from this study adds additional information to two hydraulic and hydrologic data bases now being developed by water resource researchers at Colorado State University: the Prototype Water Database Management System for the South Platte River Basin, and the Integration of GIS and Conjunctive Stream-Aquifer Management Model. The output of this project is also considered directly applicable to the Sustainable Agriculture Project being coordinated by the Central Colorado Water Conservancy District.

The objectives of this research are to: 1) use crop maps developed from from multitemporal Landsat TM images, 2) incorporate crop use, aquifer characteristics, soils, climate, and other geographic data layers within a GIS to provide data inputs for nitrate leaching estimation via NLEAP, and 3) produce maps showing the spatial distribution of Nitrate Leached (NL) for a selected test area (study area) within the Poudre River basin. Proof of operation in this test area would allow the extension of these new methodologies to the aquifers of the South Platte River Basin that are currently indicating high NO_3-N concentrations in the aquifer groundwater.

LITERATURE REVIEW

Nitrates (NO_3-N) in drinking water can pose health threats to both humans and animals (Keeney and Follett, 1991; and Fletcher, 1991). High concentrations on NO3-N in the groundwater along the South Platte River in north central Colorado are known to occur (Schuff, 1992). Indeed some feedlot operators in the area have been forced to haul drinking water for their livestock (Frazier, 1992). Sources of NO_3-N in groundwater supplies can be related to animal sources (Gormly and Spalding, 1979; Spalding et al., 1982), poultry operations (Smith et al., 1992), septic systems (Robertson et al., 1991), and farming practices. To identify areas vulnerable to NO_3-N contamination, Geographic Information System (GIS) and remote sensing technologies have been applied. Utilized in several previous studies, model estimation with GIS has been a useful source of information. Hamlett et al. (1992) combined GIS technology with a pollutant generation and transport model to rank critical pollutant source areas in the northeastern U.S. DRASTIC, a index ranking pollution potential model was utilized in Florida in conjunction with a GIS to map aquifer vulnerability (Hatchitt and Maddox, 1993) and in Wisconsin with GIS and remote sensing to assess NO_3-N water contamination (Bishop et al., 1992). LEACHM (Leaching Estimation And CHemistry Model) has been used in conjunction with a GIS to map areas vulnerable to pesticide leaching in Connecticut and Rhode Island (Bleecker, 1990) and in New York (Petach et al., 1991). Tools are being developed that will facilitate the use AGNPS (AGricultural NonPoint Source) and ANSWERS (Areal Nonpoint Source Watershed Environmental Response Simulation) within a GIS (Srinivasan et al., 1992).

NLEAP (Nitrate Leaching and Analysis Package) was recommended as a tool for regional assessment of NO_3-N leaching problems in Colorado (Paris, 1993). NLEAP has been applied across regions to map potential NO_3-N leaching hot spots in Michigan (Pierce, 1991) and Colorado (Schuff, 1992; Wylie, in press). NLEAP has been shown to have comparable results to a more detailed research model called LEACHM (Khakural and Robert, 1993).

METHODS

INTRODUCTION

This chapter describes the activities involved in 1) the remote sensing and image processing of Landsat 5 Thematic Mapper data into crop maps, 2) the generation of GIS data layers and supporting data used in the GIS operations, 3) the modeling activities including the GIS operations and the NLEAP modeling using GIS output tables, and 4) the statistical analysis of the model results.

REMOTE SENSING AND IMAGE PROCESSING

Data from a previous remote sensing project were used for part of the input data for this project. Three Landsat 5 Thematic Mapper satellite images were acquired on May 25, July 12, and September 14, 1991. These three images provided classified crop maps for the study area. The digital maps were derived from classification of the digital data in the seven spectral bands of each of the three satellite scenes. A brief synopsis of the general techniques used in generating the crop maps and the use of the crop maps in this research project is appropriate in this discussion, although a complete description of the methodologies used to generate the digital crop map is beyond the scope of this report. Figure 2 shows the flow chart with the general activities involved in the image processing of the Landsat 5 Thematic Mapper data to generate crop maps.

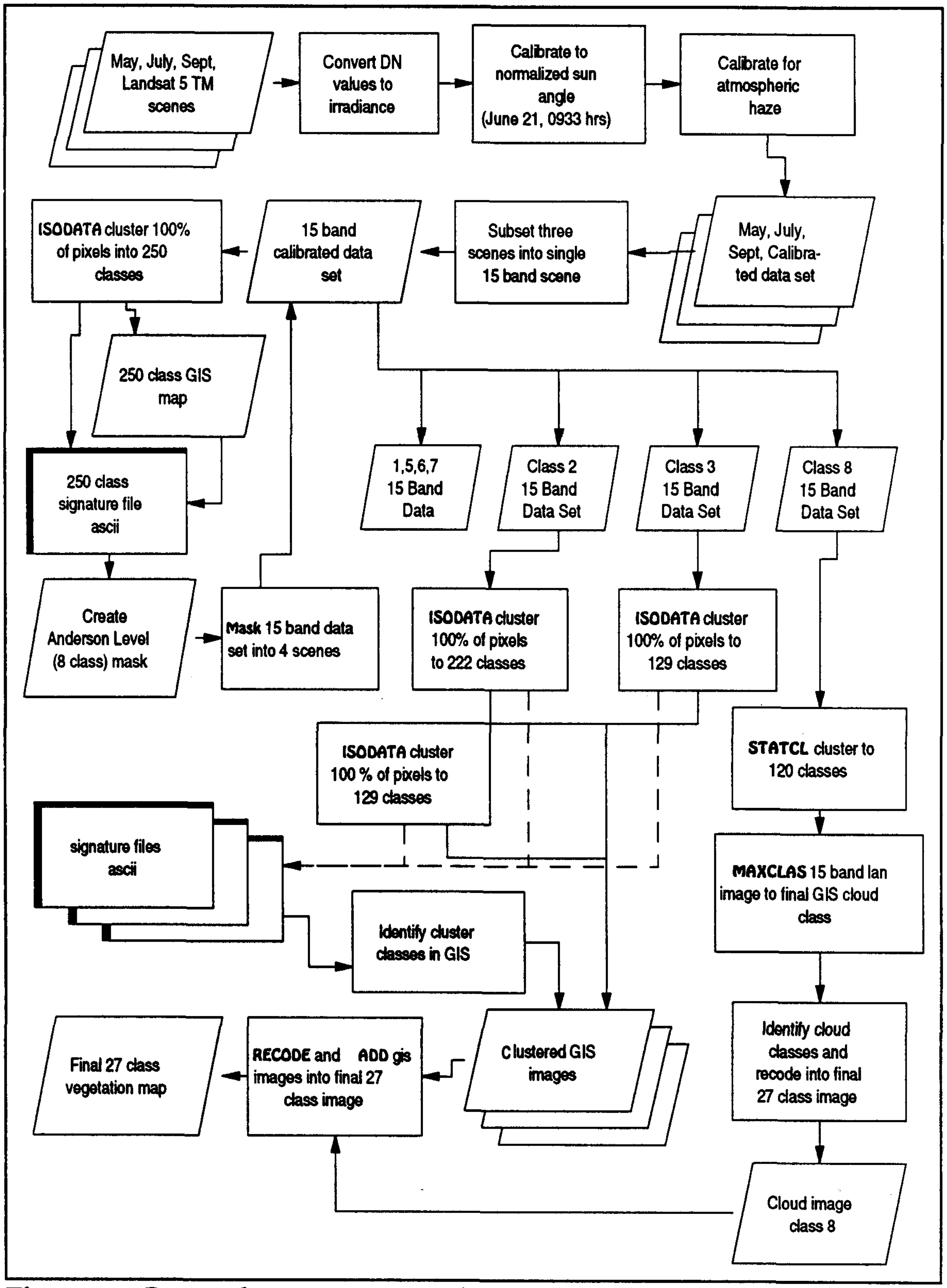

Figure 2, General Image Processing Activities for Satellite Data

Since all three satellite images are georectified to a common map reference system, the UTM coordinate system for Zone 13 (the Universal Transverse Mercator coordinate system for the State of Colorado), each image could be overlaid with the other images for a combination image of three dates. This multitemporal - multispectral digital image contains 21 spectral bands of reflectance/emittance (TM 6) data from three different phenological periods of the growing season. The implication of a multitemporal data set is that the data reflects not only reflectance data from the land surface for water, bare soil, crops and non-agricultural vegetation, but the growth patterns for the various vegetation types are also contained in the data set. Using computer analysis techniques provided by image processing software, the various crop species and other vegetation types were identified. The crop map used for the study area contained 27 classes of vegetation as indicated in Table 1 below:

Table 1, Vegetation Class Description

1	Water
2	Roads
4	Shrub/grass range
5	Medium grass range
6	Short grass range
8	Non-agric. grass
9	Non-agric. bare soil
10	Riparian wetland
11	Perennial wetland
12	High veg. residential
13	Med. veg. residential
14	Agric. bare soil/fallow
15	Alfalfa
16	Corn
17	Sugar Beets
18	Pinto beans
19	Onions
20	Irrig. grass/hay/sod farms
21	Irrig. barley/wheat
22	Dryland wheat
23	Field borders
24	Clouds
25	Squash/Pumpkins
26	Carrots
27	Trees

The accuracy of the crop map varies for each of the vegetation/crop map categories. Each of the 27 categories identified in Table 2 is analyzed for the number of correctly identified pixels within specific test polygons in the study area that were identified with field verification. The classified crop map is "overlaid" on the test polygon map and, with a GIS "crosstab" operation, the correctly identified pixels in the classified crop map are related to the corresponding pixels in the test polygons for that specific vegetation category. The ratio of correctly identified pixels in the crop map to total pixels in the test polygons, for that category, is the percent accuracy for that category. The overall crop map accuracy is the ratio of the total number of correctly identified pixels in all test polygons to the total pixels in all test polygons. When individual category accuracy is considered, the overall crop map accuracy is 66 percent. The meaning of this accuracy value is that only the number of correctly identified pixels for *each vegetation category* are considered as correctly identified. When the accuracy for correctly identifying whether the pixel is *irrigated cropland* or *non-irrigated* land, the overall map accuracy is 85 percent. Misclassification of vegetation or crops often drops the identification of a pixel into a similar class. For example, since alfalfa is similar to corn biomass at certain times of the year, corn may be misclassified as alfalfa, leading to a *lower overall accuracy* for identification by category, but both would be correctly identified as irrigated crops, which would *increase overall accuracy* for identification by irrigated/non-irrigated land cover. Individual category classification accuracies for the four most common crops are: alfalfa - 89%, corn - 83%, sugar beets - 76%, and onions - 37%.

PREPARATION OF GIS DATA LAYERS

Additional operations within the image processing software generated variations of the crop map. One of the variations used in the GIS was a map of irrigated crop land and non-irrigated land. Simple manipulation of the crop classes into the categories, irrigated and non-irrigated, provided a binary map or "mask" that could be used in the GIS, with "map algebra" operations, to select only areas within the irrigated portions of the study area. Similarly, a binary map (mask) of center pivot irrigated land was generated and combined with the irrigated lands to generated a two class GIS data layer providing a map of surface irrigated lands and center pivot irrigated lands. This GIS data layer, see Color Plate 1-(Irrigation Type) was used to identify types of irrigation for the NLEAP simulation runs. Plate 1 shows the four GIS data layers that were used in deriving the combinations of inputs to the NLEAP simulation runs.

The crop map as a GIS data layer was only used for the identification of lands under irrigated agriculture (2-category irrigation mask), the identification of center pivots and feedlots. Identification of feedlots was an outcome of the generation of the crop map, as the soil in the feedlot areas exhibited unique reflective characteristics related only to feedlot operations.

MODEL DEVELOPMENT AND OPERATION

Introduction: Previous modeling work (Wylie et al. in press) indicated that single year simulations for a large region are highly dependent on assumed initial conditions, particularly residual soil NO_3-N levels--which can be highly variable and related to field management histories (Ball et al. in press)--at the beginning of simulation. Long term or steady state simulations reflect the long term leaching potential of various soils and management combinations, and were better correlated to regional groundwater NO_3-N concentrations than single year simulations. Thus to utilize sequential long term simulations, crop rotations by region were needed: however, the satellite derived crop map for one year could not be used to determine regional trends in crop rotation patterns.

Model Development and Operation: Important factors that affect nitrate leaching from agricultural lands within the study area included soils, proximity to feedlots, and irrigation type (center pivot or furrow). Figures 3 and 4, indicate the general flow of model activities. Model simulations were used to estimate nitrate leaching below irrigated agricultural lands in the study area using input assumptions associated with each factor. The model used was NLEAP (Shaffer et al. 1991). Model simulation of single factors (soil, feedlot proximity, and irrigation type, respectively) assumed that all other factors were held constant.

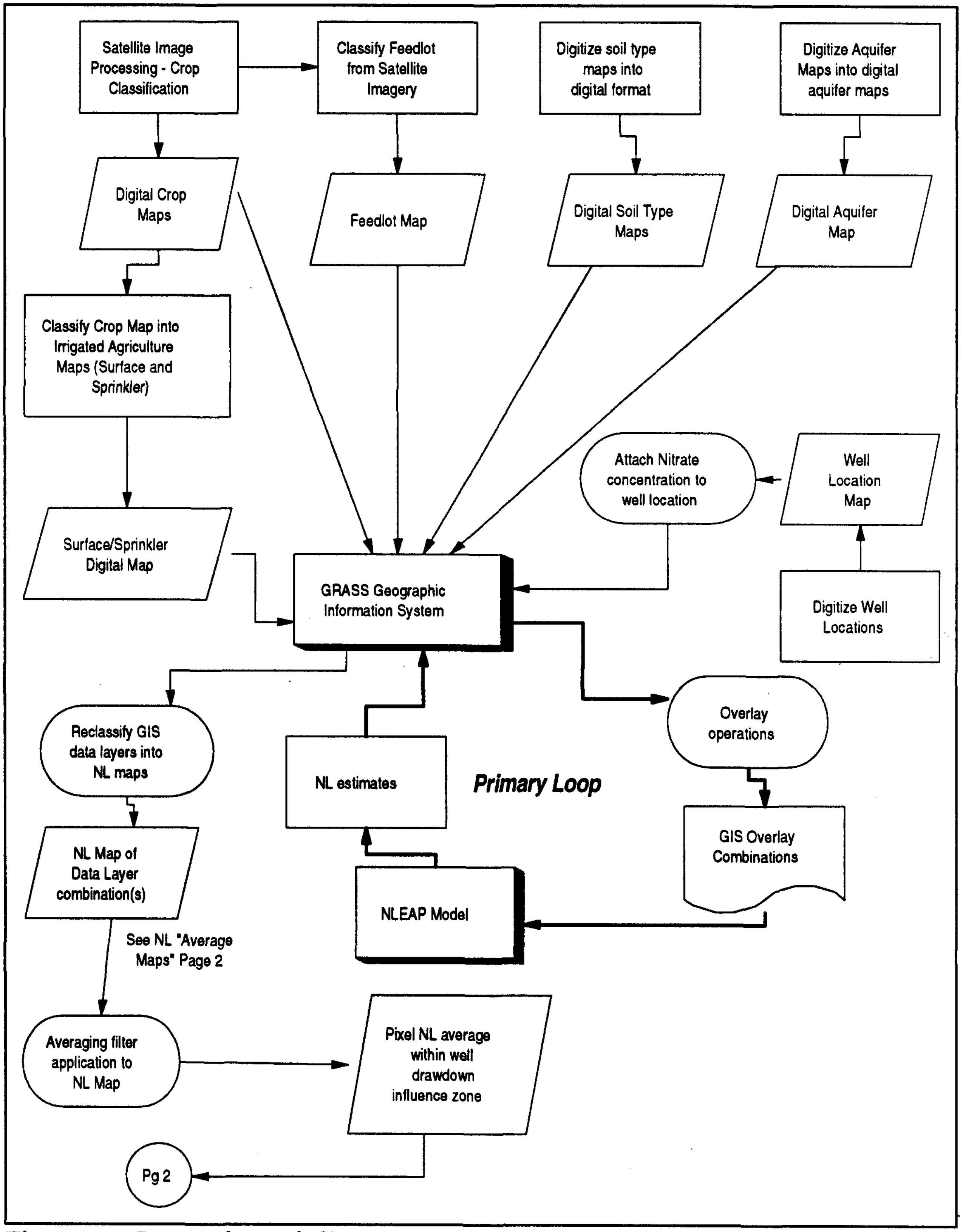

Figure 3, General Modeling Activities, Page 1

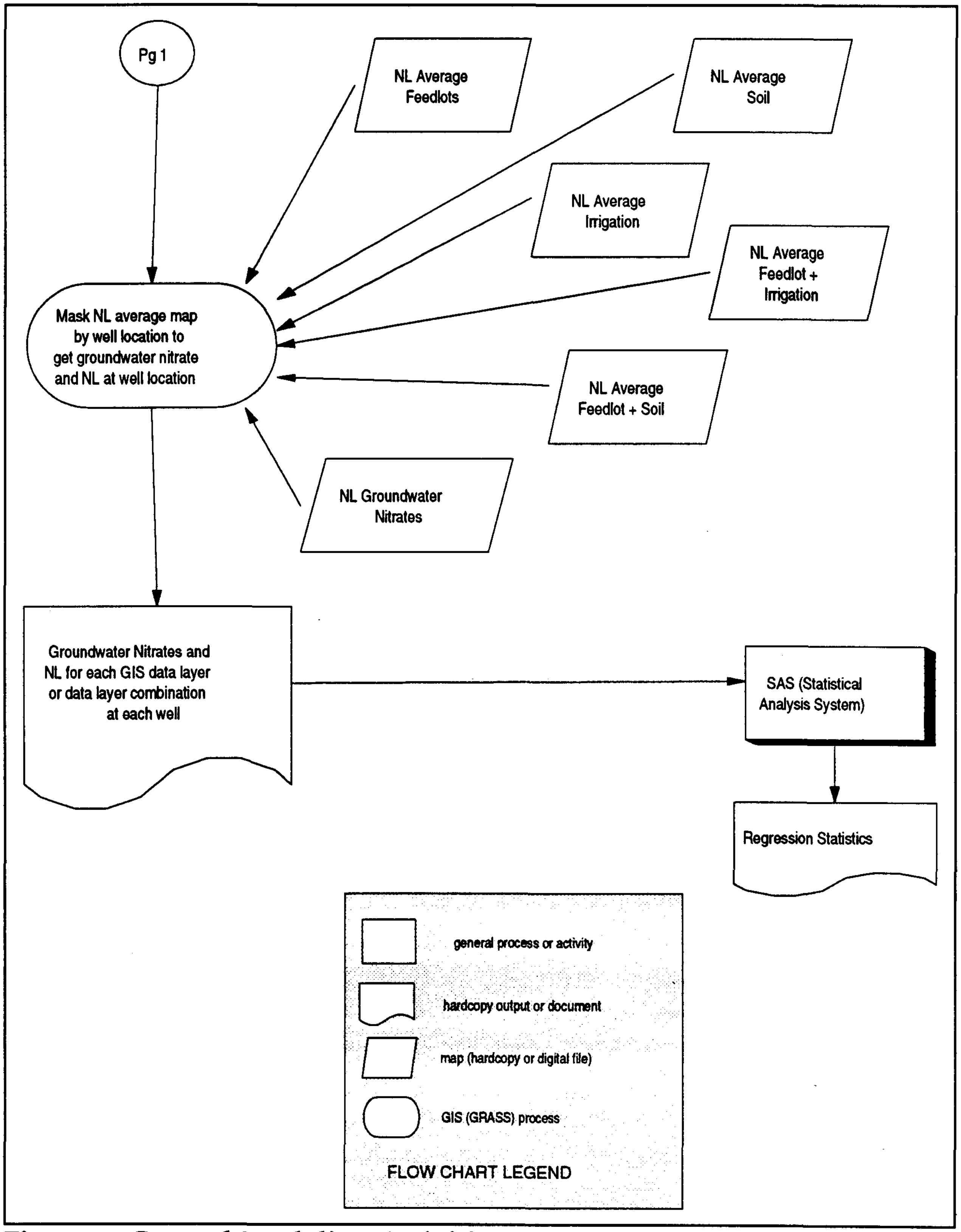

Figure 4, General Modeling Activities, Page 2

Assumptions were that, 1) corn was a good index crop for nitrate leaching and model simulations; therefore, continuous corn was used in all simulations, 2) residual soil NO_3-N levels for the 0 - 1.5 m zone were 112 kg/ha for all soils, and 3) Colorado State University fertilizer recommendations were employed for commercial fertilizers (Soltanpour et al., 1985) .

Irrigation amounts for fine and coarse textured soils for furrow and center pivot irrigation were derived from local farm data (NCWCD, 1990; NCWCD, 1991; and Crookston and Hoffner, 1992). NLEAP simulation indicated NO^3-N leaching levels from fallow land to be around 11 kg/ha. This amount was assigned to all areas not under irrigated agriculture. NLEAP model simulations were used to adjust irrigation amounts and timing such that leaching events occurred to avoid salt build up, and no major crop transpiration deficits occurred. Respective irrigation amounts are shown in Table 2.

Table 2. Growing season irrigation amounts as a function of soil texture and irrigation type.

Irrigation type	Soil texture	Irrigation amounts (cm)
Sprinkler (center pivots)	fine	67
	coarse	62
Furrow	fine	76
	coarse	127

Assumptions concerning manure applications were: 1) use of manure was more probable in fields near feedlots due to economies of transport; 2) fields within a 4 km radius (first buffer zone) of large feedlots and 1 km radius (first buffer zone) of small feedlots received 14.7 dry metric tons of manure annually; and 3) an application of half manure and half commercial fertilizer was made to an additional 1 km wide secondary buffer zone on the periphery of the primary buffer zone. Outside the first and second buffer zones, only commercial fertilizers were applied. Assumptions associated with soils variation across the area included that crop yields were varied as a function of SSURGO soil map unit as published in the county soil survey (NCSS 1980) . For simulations where soils were not varied, the most common soil in the study area (Kim loam) was used. All simulation results were long term steady state estimates for that particular scenario or set of factors.

The Geographical Resources Analysis Support System (GRASS, 1991) in conjunction with "GrassWorks", (a proprietary form of GRASS from OSIRIS Systems, Vancouver, Canada), was used to construct nitrate leaching index maps for the study area. GIS operations using masks for irrigated agriculture and alluvial aquifers (see Plate 1) restricted analysis to areas in the study area which had *only irrigated agriculture* and also that are *over the alluvial aquifer*.

The model output parameter that appears to be best related to groundwater contamination of NO3-N is NL, the simulated NO3-N leaching estimate (Khakural and Robert, 1993 and Wylie and Shaffer, in press). Nitrate leaching (NL) estimates from NLEAP steady state simulations were assigned to appropriate regions, based on the respective NLEAP scenarios. These scenarios included: 1) proximity to feedlots, 2) soils, 3) irrigation, 4) proximity to feedlots *with* soils, 5) proximity to feedlots *with* irrigation, and 6) proximity to feedlots *with* soils *and with* irrigation type.

Areas not under irrigated agriculture were assigned a NO_3-N leached value of 11 kg/ha. Since pumping irrigation wells draw groundwater from all directions and create a drawdown cone of influence, a 0.7 km^2 averaging filter (29 x 29 pixel- rectangular moving averaging filter) was used in the GIS to reflect the aquifer withdrawal impact of the wells on NL. Each pixel value in the resulting *AVERAGE NL* map represented the average of NO_3-N leached value from the surrounding 0.7 km^2 area around each sampled irrigation well. This is the average filter value that represents the drawdown area of the wells from the NLEAP simulation runs in the following discussion. Values were then extracted from each sampled irrigation well location pixel in the *AVERAGE NL* map for *each* respective NLEAP scenario, for comparison between the model output and the groundwater NO3-N concentrations from well sampling..

STATISTICAL ANALYSIS

The average (1989-1991) growing season groundwater NO_3-N concentration (mg/l) at 37 pumping irrigation wells across the study area were compared to nitrate leaching estimates from NLEAP representative of the respective well's draw down area . Combinations of the three independent variables (NLEAP nitrate leached estimates averaged for the well head draw down area for each NO_3-N leaching factor - proximity to feedlots, soils, and irrigation type) were regressed against the dependent variable, average groundwater NO_3-N concentrations at each respective well, using linear regression analysis and r^2 comparisons of all possible combinations (SAS 1989). Plots of the data were used to visually determine that nonlinearity and data distributions were not a problem. Regression diagnostics indicated that collinearity was not a problem (Belsley et al. 1980). Regression results and correlation coefficients indicated which NLEAP scenarios were best related to observed groundwater NO_3-N concentrations.

Aside from evaluating the combination of NLEAP simulations from single NO_3-N leaching factors, combinations of leaching factors within NLEAP were also examined. NLEAP scenarios evaluated combinations of remaining factors given that the strongest NLEAP factor was already included in the modeling scenario. It was felt that the regression analysis of combinations of single NO_3-N leaching factors would give crude approximations about the importance of various factors to groundwater NO_3-N contamination. However, the combining of the multiple factors in a process based model, such as NLEAP, would allow interrelationships and interactions between factors to be better taken into account.

RESULTS AND DISCUSSION

All combinations of NLEAP NL factors were significant ($p< 0.5$) with 21-41 percent of the variability in well NO_3-N concentrations being explained by regional NLEAP NL estimates (r^2) using scenarios associated with single and multiple nitrate leaching factors(Tables 3 and 4). Standard errors for the regressions ranged from 5.3-6.1 (concentration of NO_3-N in mg/l).

Single Factors: The strongest single nitrate leaching factor correlated to groundwater NO_3-N concentrations was proximity to feedlots ($r^2 = 0.33$), indicated by a high r^2 and a low standard error (Table 3).

Table 3. Coefficient of Determination (r^2) and Standard Errors for Regression Analysis on Groundwater NO_3-N Concentration (mg/l)

Variables in the model	r^2	Standard Error
feedlot	0.33	5.6
soils	0.30	5.7
irrigation type	0.21	6.1

Table Notes: Groundwater concentrations were regressed on Regional NLEAP NL estimates (kg/ha) for simple nitrate leaching factors.

This indicates that feedlots are probably an important factor in groundwater NO_3-N contamination in the study area. An organic source of nitrates in the groundwater (human or animal wastes) has been independently indicated by N_{15} tracer studies in (USDA ARS unpublished data) the study area. Organic nitrates detected by N_{15} have been found in groundwaters adjacent to the study area (USDA ARS unpublished data and McMahon et al., 1993). This could be associated with liberal applications of manures on irrigated fields and/or inadequate or lack of crediting of manure source N when determining fertilizer applications on farm fields. Variation in NLEAP NL estimates associated with soil variability was the second strongest leaching factor related to groundwater NO_3-N concentration. Color Plate 2 shows the results of the model simulation runs when proximity to feedlots was taken into account, and the comparison with the groundwater nitrates. Variation in NLEAP NL related to soils is probably attributable to poorer irrigation water efficiencies (large amounts of deep percolation) and weaker retention of NO_3-N associated with coarser textured soils. Crop yields varied as a function of soils and this, together with percent soil organic matter, was related to fertilizer application rates.

NLEAP NL associated with variation in irrigation type (center pivot versus furrow) was the weakest of the three nitrate leaching factors simulated ($r^2 = 0.21$).

Good management of water is fairly easy with center pivot irrigation systems and an economic incentive exists for good water management (i.e. pumping costs). Since there were few center pivots in the study area, there was a weak correlation to sprinkler irrigation as an NL leaching factor. Good water management is not always practiced under center pivot systems. Groundwater contamination by NO_3-N appears to be primarily related to proximity to feedlots and soil variability in the study area.

Multiple Factors: The combination of two nitrate leaching factors which gave the strongest correlations to groundwater NO_3-N concentrations were proximity to feedlots and soils (Table 4).

Table 4. Coefficient of Determination (r^2) and Standard errors for Regression Analysis

VARIABLES IN THE MODEL	REGRESSION r^2	REGRESSION Standard Error	NLEAP r^2	NLEAP Standard Error
feedlot, soils	0.41	5.3	0.36	5.5
feedlot, irrigation	0.34	5.6	0.3	5.7
feedlot, soil, irrigation	0.41	5.4		

Table Notes: Groundwater NO_3-N concentration (mg/l) was regressed on regional NLEAP NL estimates (kg/ha) for combinations of nitrate leaching factors (ie. proximity to feedlots *with* soils, etc.) using multiple regression or multiple factor incorporation into NLEAP.

Multiple regression analysis of the single factor NLEAP NL estimates for feedlot proximity and soils accounted for 41 percent of the variability in groundwater NO_3-N concentrations. However when these two factors were combined in the spatial NLEAP simulations (Color Plate 3), the percent of the variability explained was only 36 percent. The trend of slightly lower r^2 values and larger standard errors when factors were combined within NLEAP as compared to the combination of simple NLEAP NL factors in a multiple regression analysis was consistent with feedlot proximity and irrigation type as well. However, these differences were small. Possible explanations for these differences are that 1) manures may be preferentially applied to some soil and/or cropping patterns or 2) that manure application rates are varied as a function of soil type. The "blind" annual application of a fixed rate of manure across all soils did result in very high levels of simulated soil NO3-N levels available to leaching on some soils and may have been unrealistic.

CONCLUSIONS

Spatial variations in NLEAP simulated NL associated with proximity to feedlots was related to groundwater NO^3-N contamination in the study area. More investigations into manuring practices are needed to better understand this problem. Best Management Practices (BMP's) should be developed for fields with a long history of manuring. Management practices should be developed which utilize organic manures to promote soil porosity, retention of pesticides, soil texture, soil tilth, soil microbial environment and the same time properly credit their delayed release of NO^3-N. The delayed release of NO^3-N from manures maintains higher levels of soil NO^3-N for longer periods of time. This is good from a crop yield perspective but effectively creates a very wide window of opportunity for NO^3-N leaching should deep percolation events occur.

The combination of proximity to feedlots and soils information improved the association between groundwater NO^3-N contamination and NLEAP simulated NL. The location of center pivots did not seem to greatly improve the association between regional NLEAP NL and groundwater NO^3-N contamination. More detailed information is needed for manuring practices, identification of regions or soils that have a tendency toward certain crop rotation patterns, and the location of poultry operations and application practices of poultry manure.

NLEAP, when combined with spatial data from remote sensing and GIS applications appears to have potential for identifying possible sources of groundwater NO^3-N contamination across a large area. NLEAP and/or mapping of nitrate leaching factors seems to do a fair job of identifying areas vulnerable to NO^3-N leaching.

FUTURE DIRECTIONS

Future regional NLEAP simulations will be oriented to testing the effect of regional NL estimates when based on continuous corn versus a crop rotation. Also poultry sources of manures need to be taken into account. Hopefully the identification of significant factors associated with groundwater NO3-N will allow GIS mapping and modeling efforts to map larger areas for the identification of areas vulnerable to NO3-N leaching without detailed NLEAP simulation of all possible combinations of leaching factors.

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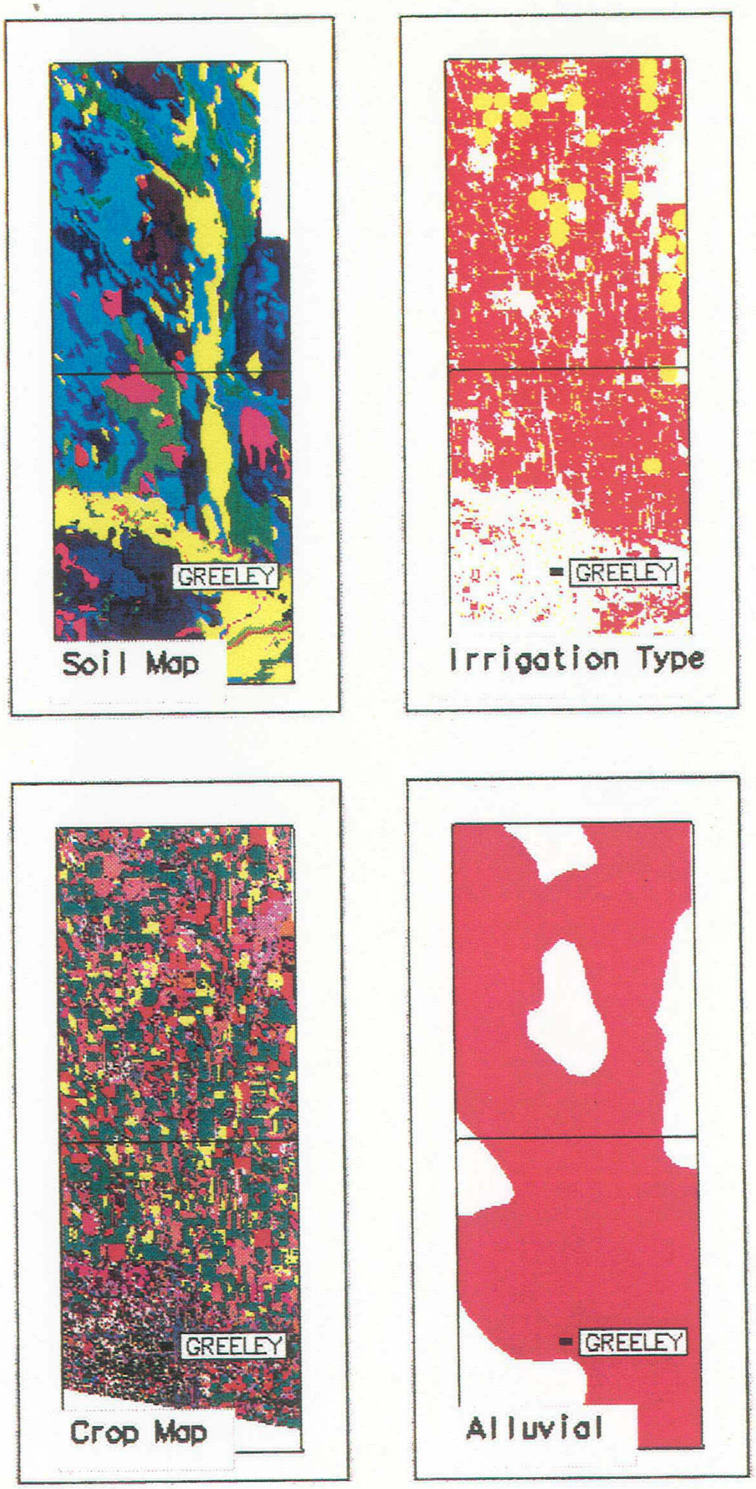


Comments:

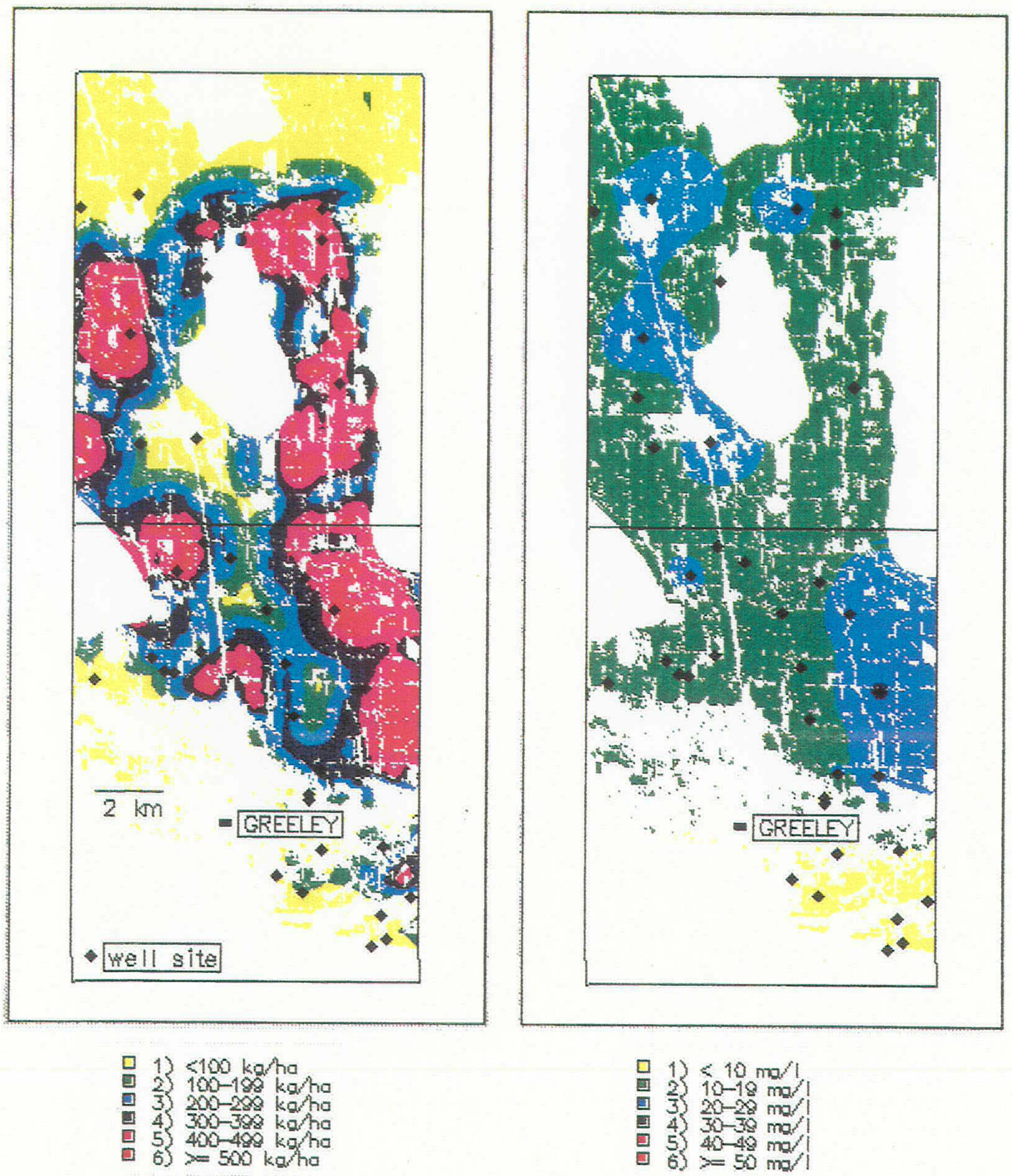
Soil Map (Left): Data digitized from Soil Survey maps of Larimer and Weld Counties, Colorado, and entered in to GIS data base.

Irrigation Type Map (Right): Map is a mask generated from recoding of Crop Map. Surface Irrigation shown in red and center pivots in yellow. Center pivots rasterized from on screen digitizing of ERDAS lan image from Landsat 5 TM data set.

Crop Map (Left): GIS data layer is a subset of the crop map generated from classification of 1991 May 25, July 12 and September 14, Landsat 5 TM data set for Poudre River Basin.

Alluvial Map: (right): Map is a binary mask generated from table digitizing of alluvial maps of Poudre River and South Platte Basin. Red is area overlying alluvial aquifers. White is non-alluvial area.

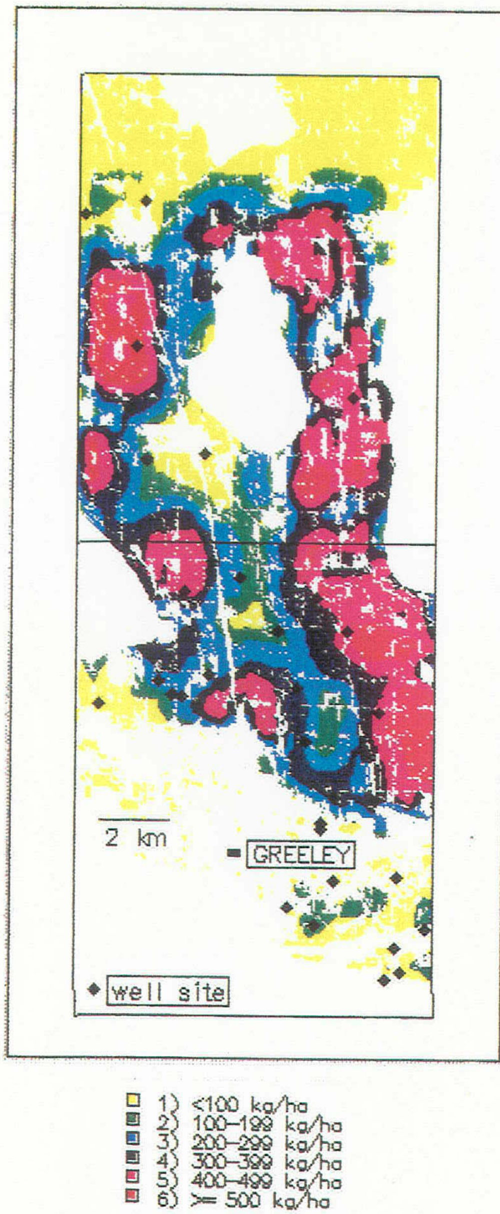
Plate 1, GIS Data Layers Used in Model



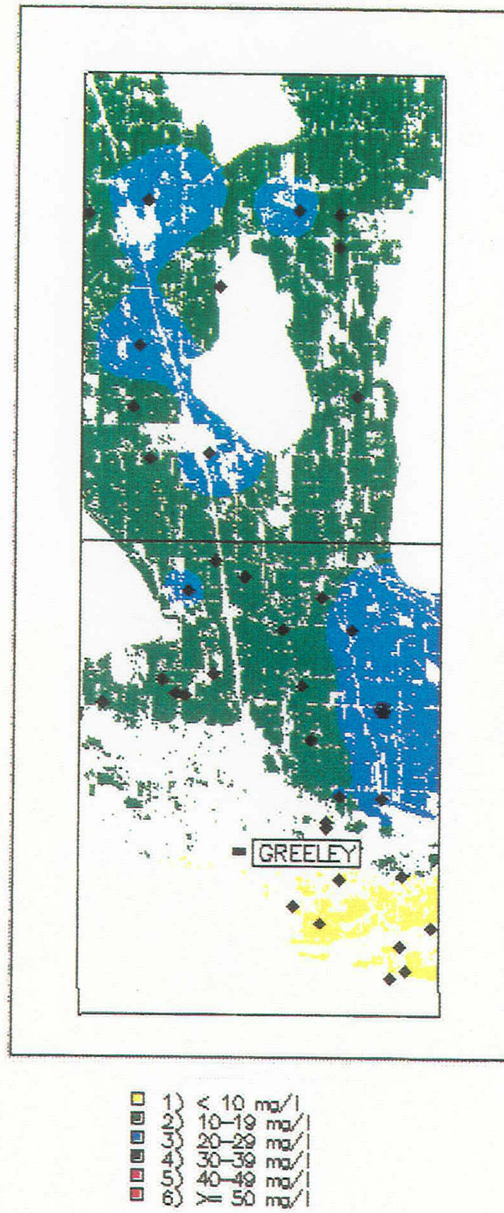
Model Output

Groundwater Nitrates

Plate 2, Model Output to Groundwater Nitrates (Feedlots only)



Model Output



Groundwater Nitrates

Plate 3, Model Output to Groundwater Nitrates (Feedlots and Soil Type Combinations)