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WATER QUALITY MODELING USING GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

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Abstract

Protection of the environment and natural resources at the Kennedy Space Center (KSC) is of great concern. The potential for surface and ground water quality problems resulting from non-point sources of pollution was examined using models. Since spatial variation of parameters required was important, geographic information systems (GIS) and their data were used. The potential for groundwater contamination was examined using the SEEPAGE (System for Early Evaluation of the Pollution Potential of Agricultural Groundwater Environments) model. A watershed near the VAB was selected to examine potential for surface water pollution and erosion using the AGNPS (AGricultural Non-Point Source Pollution) model.

Summary

Protection of the environment and natural resources at the Kennedy Space Center (KSC) is of great concern. The potential for surface and ground water quality problems resulting from non-point sources of pollution was examined using models. Since spatial variation of parameters required was important, geographic information systems (GIS) and their data were used. Soil property data were unavailable, so GIS layers of soil properties were derived from the Soils 5 database. The potential for groundwater contamination was examined using the SEEPAGE (System for Early Evaluation of the Pollution Potential of Agricultural Groundwater Environments) model. The SEEPAGE model indicated that from a hydrologic factors standpoint nearly all of KSC has a high potential for groundwater contamination. A watershed near the VAB was selected to examine potential for surface water pollution and erosion. The watershed was simulated for a series of rainfall events using the AGNPS (AGricultural Non-Point Source Pollution) model. Based on the simulation results, the watershed did not have significant erosion problems and only small amounts of nutrients and sediment were transported from the watershed into surface waters.

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INTRODUCTION

The Kennedy Space Center (KSC) is not only important because of the NASA activities but is also home to 22 wildlife species listed as Endangered or Threatened on either the Federal or State lists. When NASA purchased land for the development of KSC in the early 1960's, not all of the land was needed for the space program. As a result, the U.S. Fish and Wildlife Service in cooperation with NASA established the Merritt Island National Wildlife Refuge in 1963. Thus, the effects of NASA activities on the environment and natural resources are of great concern.

A variety of monitoring and research activities are conducted by scientists at KSC to protect the KSC environment and natural resources and to better understand the relationships between these systems and NASA operations. These activities include: water quantity and quality monitoring and modeling (Dwornik, 1984; Heaney et al., 1984; Bennett, 1989; Dierberg and Jones, 1989), soil resources inventory development (Schmalzer and Hinkle, 1990a and 1991), climate monitoring (Madsen et al., 1989; Dreschel et al., 1990; Mailander, 1990), wildlife monitoring (Breininger and Schmalzer, 1990; Dreschel et al., 1991), and vegetation monitoring (Breininger, 1990; Schmalzer and Hinkle, 1990b; Provancha and Hall, 1991).

Computer based tools play an important role in the monitoring and research activities listed above (Hinkle et al., 1988). An extensive GIS database has been developed for KSC by the KSC GIS (Geographic Information Systems) and Remote Sensing Laboratory. The data in the GIS has many potential uses for studies such as those described above. For example, Breininger et al. (1991) interpreted remotely sensed data using the computer to obtain vegetation maps for use in the GIS. The vegetation map layer and other map layer data within the GIS were used to map scrub jay habitat.

The objective of this project was to begin development of a prototype computer-based spatial decision support system to address environmental and natural resources issues for the Kennedy Space Center. Water resources concerns were selected as the first component to be examined. The decision support system was expected to utilize GIS, simulations, and expert system techniques.

PROCEDURES

2.1 Identification of Environmental and Natural Resource Concerns

The first step in the project was to identify environmental and natural resource concerns for the Kennedy Space Center that have an important spatial component. Previous and current projects were reviewed to gain an understanding of KSC concerns in these areas. Publications describing environmental and natural resource work conducted at KSC were reviewed. Some of the publications reviewed were referenced in the INTRODUCTION section of this document. Scientists working for Bionetics that are responsible for environmental and natural resource monitoring and research at KSC were asked to describe their current projects and possibilities for future projects.

Based on these discussions and the literature review, the following concerns having a significant spatial component were identified:

1. Surface and ground water quality and quantity
   Water quality and quantity are concerns for several reasons. Large volumes of water are used for KSC operations. In the future it may be necessary to obtain some of the water required from on-site sources, likely groundwater. The groundwater is also closely linked to surface water since the water table is very shallow. Thus, degradation of groundwater quality will affect surface water quality. Water is also important to much of the wildlife and vegetation at KSC. Numerous wetlands and water impoundments are located on KSC that provide homes for a variety of vegetation and wildlife.

2. Wildlife protection
   Because of the number of Threatened or Endangered species and the wide variety of species that make their homes at KSC for all or part of the year, protection of wildlife is of great concern. A better understanding of the wildlife and the systems in which they live is needed so that NASA activities can be designed to minimize effects on wildlife.

3. Vegetation protection
   Vegetation is important to the wildlife that reside at KSC. In addition, numerous Threatened or Endangered vegetation types are located at KSC.

4. Climatic conditions
   A variety of climatic conditions are of interest. Climatic parameters are important for many reasons including the understanding of vegetation and wildlife systems, understanding the effects of NASA activities as opposed to climate changes, and planning NASA activities.

2.2 Water Resources Problem

Water resources problems were selected for further investigation in this project. The problems to be explored were the potential for groundwater contamination at KSC and potential for runoff, soil erosion, and contamination of surface water. These problems have spatial components that can best be solved using GIS data and techniques. Groundwater contamination potential for all of KSC was to be explored. A watershed near the VAB (the area surrounding the VAB and to its north and east) was selected to examine runoff, erosion and chemical movement with runoff and sediments. This watershed was selected since mitigation of the wetland into which it drains is being considered.

The models selected for use in this project were SEEPAGE (System for Early Evaluation of the Pollution Potential of Agricultural Groundwater Environments) (Carpenter, 1992) and AGNPS (AGricultural Non-Point Source Pollution) (Young et al., 1989). SEEPAGE is used to evaluate the potential for groundwater contamination from both point and non-point sources considering hydrologic factors. AGNPS is used to analyze runoff, erosion and non-point source pollution of surface waters in watersheds. These models were selected since both use a distributed parameter approach, thus providing the capability to consider spatial variation of the processes modeled. Additional model details are provided in the sections that follow.

2.3 SEEPAGE Model

SEEPAGE (Carpenter, 1992) is used to evaluate the potential for groundwater contamination from both point and non-point sources from a hydrologic factor standpoint. SEEPAGE considers hydrologic factors to locate areas with low, moderate, high, and very high potential for groundwater pollution using GIS data. SEEPAGE considers the following factors:

1. Soil slope
2. Depth to water table
3. Vadose zone material
4. Aquifer material
5. Soil depth
6. Attenuation potential

The attenuation potential factor further considers the following factors:

1. Soil surface texture
2. Subsoil texture
3. Surface layer pH
4. Organic matter content of surface
5. Soil drainage class
6. Soil permeability

These factors are combined using a weighting scheme described in detail by Carpenter (1992). This approach is similar to that used in the DRASTIC model (Aller et al., 1987). For each factor considered, weights are assigned to possible values of the factor. For example, the soil slope factor has the possible values shown in Table 2.1 and associated point source and non-point source weights.

Table 2.1 SEEPAGE Soil Slope Factor Weights

Percent Slope	Point Source	Non-Point Source
0-2	10	30
2-6	9	27
6-9	5	15
9-12	3	9
>12	1	3

2.4 AGNPS Model

Distributed parameter watershed models such as AGNPS are able to incorporate the influences of the spatially variable controlling parameters (e.g., topography, soils, land use, etc.) in a manner internal to computational algorithms. The primary advantage of a distributed parameter model is its potential for providing a more accurate simulation of the system being modeled. For watershed models, a second advantage of this approach is its ability to simultaneously simulate conditions at all points within the watershed. This allows simulation of processes that change both spatially and temporally throughout the watershed such as erosion.

AGNPS has been developed to analyze non-point source pollution in watersheds. It uses a distributed parameter approach to quantify a watershed by dividing the area into a grid of square cells as shown in Figure 2.1. Within this framework, runoff characteristics and transport processes of sediments and nutrients are simulated for each cell and routed to its outlet. This permits the runoff, erosion, and chemical movement at any point in the watershed to be examined. Thus, it is capable of identifying upland sources contributing to a potential problem and prioritizing those locations where remedial measures could be initiated to improve water quality. Runoff in AGNPS is predicted by applying the Soil Conservation Service (SCS) curve number runoff method to each cell. Erosion in AGNPS is predicted by a modified version of the USLE (Young et al., 1989) applied to each cell. Sediment routing is performed for five particle size classes: clay, silt, small aggregates, sand and large aggregates. Sediment is routed through the watershed as described by Young et al. (1989). The nutrient movement components of AGNPS are adapted from CREAMS (Frere et al., 1980). Chemical transport calculations are divided into soluble- and sediment-adsorbed phases. Runoff, erosion, and nutrient movement within cells are routed to the watershed outlet.

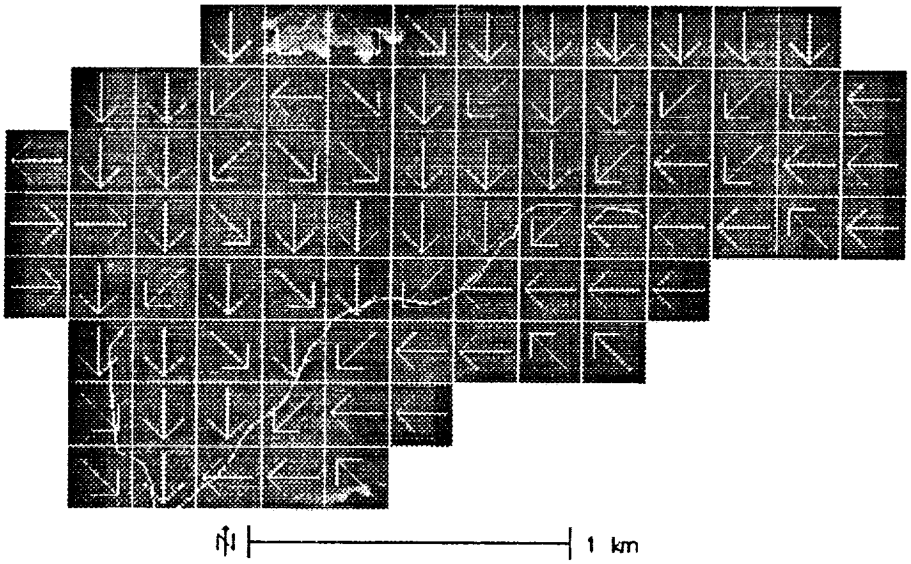

Figure 2.1 Grid Cell and Flow Direction Representation of a Watershed

When modeling with AGNPS, a watershed is divided into square grids (cells) usually ranging in size from 1 to 40 acres. In general, large cell sizes have been used because of the time required to collect model input requirements. The AGNPS inputs required for each cell are shown in Table 2.2, and outputs by cell are shown in Table 2.3.

Table 2.2 AGNPS Cell Input Requirements

Cell number	Cell into which it drains	SCS curve number
Average slope (%)	Slope shape factor	Average slope length
Average channel slope	Mannings *n* for channel	USLE K factor
USLE C factor	USLE P factor	Surface condition constant
Overland flow direction	Soil texture	Nutrient level
Fertilizer incorporation	Point source indicator	Gully source level
Chemical oxygen demand factor	Impoundment factor	Channel indicator
Channel side slope		

Table 2.3 AGNPS Cell Output

Runoff volume	Delivery ratios by particle size
Peak runoff rate	Sediment associated phosphorus mass
Sediment yield	Soluble phosphorus mass
Upland erosion	Soluble phosphorus concentration
Deposition	Fraction of runoff generated
Sediment generated	Enrichment ratios by particle size
Chemical oxygen demand concentration	Chemical oxygen demand mass
Sediment concentration	Sediment particle size distribution
Soluble nitrogen mass	Soluble nitrogen concentration
Sediment associated nitrogen mass	

The problems with models such as AGNPS include the time, expertise, and cost of acquiring the model data, running the model, and interpreting model results. To help overcome these problems, AGNPS was integrated with a raster-based GIS tool called GRASS (Engel et al., 1992). GRASS (Geographical Resource Analysis Support System) (U.S. Army, 1991) is a widely used GIS tool for natural resource applications. The integrated system assists with development of AGNPS input from GIS layers, running the model, and interpretation of the spatially varying results. It can significantly reduce the time required to generate and manage data for AGNPS, to evaluate non-point source pollution problem areas, and to identify potential solutions for these problem areas.

2.5 GIS Data

The next step was to identify GIS databases available or under development for KSC and those that would be required for AGNPS and SEEPAGE. Numerous GIS datasets were available from the KSC GIS and Remote Sensing Laboratory. These datasets were in either the ERDAS or ARC/INFO data formats. ERDAS is a GIS and remote sensing classification tool, and ARC/INFO is a GIS tool. To facilitate the use of the AGNPS/GRASS system and SEEPAGE, ERDAS and ARC/INFO datasets were moved to GRASS. GRASS also provides several other benefits including cost (it is public domain), source code availability, expert system development tools are available within GRASS, and it is well suited for modeling. A listing of the datasets moved to GRASS is provided in Appendix A.

Numerous soil properties were required for SEEPAGE and AGNPS but were unavailable in the existing KSC GIS data. However, a soil series layer was available for which the required soil property layers were derived from the Soils 5 database using the GRASS r.soils5 command. Additional soil property layers that were of interest to scientists conducting ecological studies at KSC were derived using this process. The soil property layers derived and their brief descriptions are listed in Appendix B. Other soil property data that is available in Soils 5 could be easily extracted to build GIS data sets if desired using the r.soils5 command in GRASS. GRASS data layers can also be moved to either ERDAS or ARC/INFO using the procedure described in Appendix C.

Additional GIS layers required by SEEPAGE and AGNPS were obtained by reclassifying existing data layers. Several elevation derived layers (slope steepness, slope length, overland flow direction or aspect) were required for AGNPS, however, elevation data were not available in GIS form. Elevation contours for the VAB watershed area were obtained from the USGS 1:24,000 topographic maps for the area. An elevation surface was fit to the area using surface fitting tools in GRASS. Once an elevation surface was obtained, elevation derived layers were obtained using the GRASS r.watershed command (U.S. Army, 1991). SCS CN values required by AGNPS and other spatial inputs were derived from GRASS data using techniques described in Engel et al. (1992), Rewerts and Engel (1991), Srinivasan and Engel (1991a), and Srinivasan and Engel (1991b).

Several GIS data layers should be developed for KSC in the future. These include: elevation (including layers that can be derived from elevation), drainage, and locations and types of potential contaminants. These data layers would have many potential uses.

RESULTS AND DISCUSSION

3.1 Groundwater Quality

GIS layers were developed for each of the factors considered in SEEPAGE using tables such as Table 2.1 above. For the example in Table 2.1, the GIS slope layer was assigned the weights in the table using the GRASS r.reclass command. GIS data layers for the other factors considered were assigned weights in a similar manner. Once all layers had been assigned weights, the weighted layers were added together using the GRASS r.mapclac command to produce new GIS layers: point source pollution potential and non-point source pollution potential. These layers were then reclassified using the GRASS r.reclass command to obtain qualitative pollution potential categories from the numerical weights based on the SEEPAGE table for doing so (Carpenter, 1992).

As expected, the model predicted that from a hydrologic standpoint most of KSC has a high potential for groundwater contamination for both point and non-point sources as shown in Table 3.1.

Table 3.1 Hydrologic Potential for Groundwater Contamination at KSC

Contaminant Source	Low (acres)	Moderate (acres)	High (acres)	Very High (acres)
Non-Point Source	0	671	54,733	0
Point Source	0	691	54,714	0

Tables 3.2 and 3.3 provide information on the areas of SEEPAGE contamination potential by aquifer recharge zone. These values were obtained by overlaying the SEEPAGE layers with the aquifer recharge layer. Areas that have high potential for contamination and are located in primary and secondary aquifer recharge areas are of the greatest concern. These areas are shown for point source contaminants as the dark areas within the KSC boundaries in Figure 3.1. The areas are nearly identical for non-point source contaminants.

Table 3.2 NPS Contamination Potential by Aquifer Recharge Zone

Recharge Potential	Moderate (acres)	High (acres)
Primary recharge	0	4,934
Secondary recharge	3	13,962
Tertiary recharge	669	35,301

Table 3.3 Point Source Contamination Potential by Aquifer Recharge Zone

Recharge Potential	Moderate (acres)	High (acres)
Primary recharge	0	4,934
Secondary recharge	3	13,962
Tertiary recharge	688	35,281

Figure 3.1 Areas with High Potential for Point Source Groundwater Contamination and Primary or Secondary Aquifer Recharge

One should keep in mind that the SEEPAGE results are based only on hydrologic factors and do not consider groundwater recharge locations, distances to water uses, aquifer water use volume, land uses, contaminant locations, contaminant characteristics, or potential for introduction of potential contaminants to the soil. One should also note that SEEPAGE does not provide information about potential for surface water contamination. However, based on SEEPAGE results, care should be taken when working with potential contaminants at KSC, especially in the areas with a high potential for contamination based on hydrologic factors that are located in primary or secondary aquifer recharge areas as shown in Figure 3.1.

3.2 Erosion and Surface Water Quality

The watershed near the VAB was delineated using watershed boundary information from an ERDAS GIS layer as a starting point. Watershed boundaries were refined using the elevation data and watershed delineation functions within GRASS. Based on these items of information and visits to the watershed site, the watershed to be simulated was delineated. A better estimate of the watershed boundaries would require a detailed elevation survey. A cell size of 148 feet (0.5 acres in area) was selected for the simulation. This cell size was selected due to the variability in soils and vegetation within the watershed. Simulations for a cell size of 296 feet (2.0 acres in area) were also run for comparison purposes.

Once all of the spatial inputs were derived for AGNPS, a series of weather events was selected for simulation. AGNPS requires a rainfall amount and a rainfall erosivity (energy-intensity EI value) to describe a rainfall event. The rainfall events that were selected for simulation are listed in Table 3.4. These events are representative of the range of storms experienced at KSC that are likely to cause erosion and surface water quality concerns.

Table 3.4 Simulation Rainfall Events Used With AGNPS

Rainfall Event	Rainfall Depth (inches)	Rainfall Erosivity (EI)
1	1.0	10
2	1.0	25
3	2.0	10
4	2.0	25
5	2.0	50
6	2.0	75
7	3.0	25
8	3.0	50
9	3.0	75
10	4.0	25
11	4.0	50
12	4.0	75
13	5.0	25
14	5.0	50
15	5.0	75
16	6.0	50
17	6.0	75
18	7.5	75

Using tools developed by Engel et al. (1992), the study watershed was simulated for the above rainfall events using an antecedent moisture condition of II (AMC II) when estimating the SCS curve numbers needed by AGNPS. In addition, some of the rainfall events were simulated using other AMC conditions (I or III corresponding to dryer and wetter conditions, respectively).

Results of the model runs were returned to the GRASS GIS using tools developed by Engel et al. (1992) for interpretation and analysis of AGNPS results. The results for the parameters of interest are summarized in Table 3.5 for events shown in Table 3.4. The runoff depth is the average depth of runoff from the 1127 acre watershed. Volume of runoff can be obtained by multiplying the watershed area by the runoff depth. The peak runoff is the peak rate at which water leaves the watershed for an event. Upland erosion is the amount of soil eroded as a result of interrill and splash erosion. Channel erosion is the amount of soil moved as a result of concentrated flow processes including those in channels. The sediment delivered column is the amount of soil that leaves the watershed. One should note that this value is much less than erosion since much of the soil that is eroded is deposited within the watershed. The nitrogen, phosphorus, and COD columns indicate the total masses of nitrogen, phosphorus, and chemical oxygen demand that leave the watershed. For nitrogen and phosphorus, these masses are the total for the runoff and sediment phases. Total masses of nitrogen, phosphorus, and COD leaving the watershed can be obtained by multiplying the values in the columns by the watershed area (1127 acres).

Table 3.5 VAB Watershed Simulation Results for a Grid Cell Size of 0.5 Acres and AMC II

Rainfall Event (Table 3.4)	Runoff Depth (inches)	Peak Flow (cfs)	Upland Erosion (tons/acre)	Channel Erosion (tons/acre)	Sediment Delivered (tons)	Nitrogen (lbs/acre)	Phosphorus (lbs/acre)	COD (lbs/acre)
1	0.0	16	0.00	0.63	49.4	0.23	0.13	0.97
2	0.0	16	0.01	0.63	49.7	0.23	0.13	0.97
3	0.3	86	0.00	1.48	118.3	0.52	0.25	5.58
4	0.3	86	0.01	1.48	119.3	0.52	0.25	5.58
5	0.3	86	0.02	1.48	120.8	0.52	0.26	5.58
6	0.3	86	0.03	1.48	122.4	0.54	0.26	5.58
7	0.6	199	0.01	2.28	190.5	0.79	0.37	13.16
8	0.6	199	0.02	2.28	192.5	0.80	0.37	13.16
9	0.6	199	0.03	2.27	194.5	0.81	0.38	13.16
10	1.1	340	0.01	3.04	269.9	1.08	0.49	22.72
11	1.1	340	0.02	3.04	272.1	1.08	0.50	22.72
12	1.1	340	0.03	3.04	274.3	1.08	0.50	22.72
13	1.7	498	0.01	3.75	346.6	1.35	0.60	33.60
14	1.7	498	0.02	3.75	348.9	1.36	0.60	33.60
15	1.7	498	0.03	3.75	351.3	1.37	0.60	33.60
16	2.3	667	0.02	4.41	421.9	1.62	0.70	45.40
17	2.3	667	0.03	4.41	421.9	1.62	0.70	45.40
18	3.4	936	0.03	4.90	526.7	1.99	0.85	64.45

A limited number of watershed simulations were run for other moisture conditions as indicated above. A portion of these results are shown in Tables 3.6 and 3.7 for AMC I and AMC III, respectively. Results for the watershed simulation using a cell size of 2.0 acres for a limited number of rainfall events with AMC II are shown in Table 3.8.

Table 3.6 VAB Watershed Simulation Results for a Grid Cell Size of 0.5 Acres and AMC I

Rainfall Event (Table 3.4)	Runoff Depth (inches)	Peak Flow (cfs)	Upland Erosion (tons/acre)	Channel Erosion (tons/acre)	Sediment Delivered (tons)	Nitrogen (lbs/acre)	Phosphorus (lbs/acre)	COD (lbs/acre)
7	0.2	65	0.01	1.33	102.5	0.41	0.22	4.29
8	0.2	65	0.02	1.33	102.8	0.42	0.22	4.29
9	0.2	65	0.03	1.32	103.6	0.42	0.22	4.29

Table 3.7 VAB Watershed Simulation Results for a Grid Cell Size of 0.5 Acres and AMC III

Rainfall Event (Table 3.4)	Runoff Depth (inches)	Peak Flow (cfs)	Upland Erosion (tons/acre)	Channel Erosion (tons/acre)	Sediment Delivered (tons)	Nitrogen (lbs/acre)	Phosphorus (lbs/acre)	COD (lbs/acre)
7	1.3	393	0.01	3.18	296.0	1.42	0.58	25.42
8	1.3	393	0.02	3.17	297.5	1.42	0.59	25.42
9	1.3	393	0.03	3.17	299.1	1.43	0.59	25.42

Table 3.8 VAB Watershed Simulation Results for a Grid Cell Size of 2.0 Acres and Rainfall of 3.0 Inches with Rainfall Erosivity (EI) of 50

Antecedent Moisture AMC	Runoff Depth (inches)	Peak Flow (cfs)	Upland Erosion (tons/acre)	Channel Erosion (tons/acre)	Sediment Delivered (tons)	Nitrogen (lbs/acre)	Phosphorus (lbs/acre)	COD (lbs/acre)
I	0.2	126	0.02	0.57	41.3	0.27	0.12	4.63
II	0.7	382	0.02	1.01	83.8	0.53	0.21	13.96
III	1.4	740	0.02	1.36	129.3	1.27	0.39	26.45

Based on the AGNPS simulation results presented in Tables 3.5 to 3.8, the VAB watershed does not have an erosion problem. This is expected since the terrain is flat, the vegetation provides good cover, and the soils are resistant to erosion (low USLE K factors). Upland erosion rates are extremely small. Most of the erosion that occurred was a result of concentrated flow and channel processes, and these values are well within acceptable ranges. To minimize erosion from this watershed, efforts should be focused on maintaining the channels. Good vegetation in the channels will minimize erosion. Very little of the soil eroded actually leaves the watershed. The sediment delivered column shows the masses of soil that leave the watershed. Most of the soil that is eroded is deposited within the watershed. Since this watershed is similar to much of KSC, erosion in other areas of KSC is expected to be similar and thus is not likely a problem.

The nitrogen, phosphorus, and COD columns of Tables 3.5 to 3.8 indicate that movement of nutrients and chemical oxygen demand from the watershed are relatively small. The values for nitrogen and phosphorus include the amounts moved with both the runoff and sediment. The simulated masses of nitrogen and phosphorus moved from the watershed are likely higher than actual values since the minimum levels of soil nitrogen and phosphorus allowed by AGNPS are likely higher than those encountered for the soils and land uses within the study watershed. The masses of nitrogen, phosphorus, and COD moved from the watershed should not create problems in the waters into which they are moved. Since this watershed is similar to much of the rest of KSC, movement of nutrients into surface water is not expected to be a significant problem for other areas of KSC. The masses of nutrients moved into surface waters near citrus production may be higher but are not likely to present significant problems.

The simulated runoff volumes and peak rates of runoff shown in Tables 3.5 to 3.8 are within expected ranges and should not create problems in receiving waters. The soils, highly vegetated areas, and flat terrain result in relatively low volumes of runoff and peak rates of flow from the watershed.

SUMMARY AND CONCLUSIONS

The environment, wildlife, and natural resources are important considerations in KSC operations. Research and monitoring concerns within these areas with significant spatial components were examined to determine the role that geographic information systems (GIS) can and should play. Water quality, both ground and surface, was identified as an important concern. The SEEPAGE model was selected to examine the hydrologic potential for contamination of groundwater from both point and nonpoint source pollutants. To explore potential surface water quality issues, the AGNPS non-point source pollution model was selected. This model has been integrated with a GIS system that greatly simplifies its operation and interpretation of its results.

To facilitate the use of these models, existing GIS data was moved from the ERDAS and ARC/INFO GIS tools to the GRASS GIS tool. The AGNPS model had already been integrated with GRASS and numerous hydrologic modeling tools are available within GRASS to assist in preparing spatial data inputs for AGNPS and other models. The SEEPAGE model was easily implemented using using functions within GRASS. Several GIS data layers were unavailable for KSC including soil properties required for AGNPS and SEEPAGE. Using tools within the GRASS GIS, the Soils 5 database, and the soil series GIS layer, the required soil property GIS layers were developed. Additional soil property data layers that were useful for research and monitoring studies at KSC were also derived.

Once the required spatial inputs had been obtained, the SEEPAGE model was implemented within the GRASS GIS for both point and non-point sources of contamination. GIS layers were produced showing potential for groundwater contamination for KSC. The resulting layers indicated that nearly 99 percent of the KSC area has a high potential for groundwater contamination from both point and non-point sources from a hydrologic conditions perspective. The remaining area (approximately 1 percent) has a moderate potential for groundwater contamination. The groundwater contamination potential layers were overlain with the aquifer recharge layer to determine the areas that are of the most concern. Approximately 9% of the KSC land area has a high potential for groundwater contamination from a hydrologic factor standpoint and is a primary aquifer recharge area. Approximately 25% of the KSC land area has a high potential for groundwater contamination from a hydrologic factor standpoint and is a secondary aquifer recharge area. Keep in mind however, that contaminant locations, contaminant properties and numerous other factors that would be important in determining the true potential for groundwater contamination were not considered.

The AGNPS model was run for an approximately 1127 acre watershed located near the VAB, largely to the north and east. A series of rainfall depth and erosivity (related to intensity) events were used to study the effects of rainfall event characteristics. A watershed grid cell size of 0.5 acres was used for most of the simulations, although a cell size of 2.0 acres was used to explore potential differences in simulation results due to cell size. Smaller rainfall events, similar to those that occur on many afternoons during the summer months, caused very little nutrient movement as a result of non-point sources and resulted in very little soil erosion. The erosion that did occur was largely the result of concentrated flows. Most soil that was eroded did not leave the watershed but was deposited in concentrated flow areas within the watershed.

A series of larger rainfall events that would be expected approximately once every 10 years was also simulated using AGNPS. As with the smaller storms, erosion and nutrient movement are not significant problems. Most of the erosion that occurs is the result of concentrated flows, such as water in ditches. With good vegetation in these areas, erosion and soil leaving the watershed can be minimized. The amount of nitrogen and phosphorus leaving the watershed should not create problems and are likely larger than actual values because of the conservative minimum nutrient availability assumption within AGNPS.

The watershed simulated with AGNPS is similar to most other areas of KSC. Thus, erosion and non-point source pollution are not likely to be problems within KSC. Potential pollutants from the developed areas (parking lots, building rooftops, etc.) were not considered by the simulation and may contribute pollutant loads that are of concern to some surface water bodies.

RECOMMENDATIONS FOR CONTINUED WORK

Suggestions for continued work on this project are presented in this section.

Development of a decision support system to assist with environmental and natural resource issues at KSC that uses GIS, simulations, expert systems, and other computer-based tools should continue. This project demonstrated the potential for using a portion of these tools to quickly identify environmental and natural resource problems.

The potential for movement of contaminants from parking lots and areas with buildings into surface and ground water should be explored.

Additional GIS data layers are needed for projects such as this and other applications. One of the more important layers is elevation. Elevation can be used to derive other data layers including slope and aspect (flow direction). Drainage and locations and types of potential contaminants are among other layers that should be developed.

Existing KSC GIS and remotely sensed data should be fully documented. Documentation should include history of GIS data layers, scale of map from which they were developed, description of content, definitions of categories, persons who developed layer, and other information that would be useful to those interested in using the data.

Existing KSC databases that would be useful to research and monitoring programs concerned with the environment and natural resources should be fully documented.

APPENDIX A DATA IMPORTED TO GRASS

Raster Data Imported to GRASS

GRASS Raster Name	Content
sorecotm	Original soil series data from ERDAS
farfldep	Far field deposition from ERDAS
fedlantm	Vegetation on federal land from ERDAS
habitsj	Scrub Jay habitat from ERDAS
ignition	Burned areas from ERDAS
impoundm	Impoundment areas from ERDAS
ksccnsaf	
kschydro	KSC hydrology from ERDAS
kscjuwet	KSC wetlands from ERDAS
kscmask	KSC boundaries from ERDAS
kscrectm	KSC vegetation from ERDAS
poparea	Scrub Jay population areas from ERDAS
rechartm	Aquifer recharge areas from ERDAS
savrectm	Scrub area vegetation and density from ERDAS
soils	Soil series from ERDAS
vegclass	Vegetation map from ERDAS
watersheds	Watershed boundaries from ERDAS

Vector Data Imported to GRASS

GRASS Vector Name	Content
builds	KSC buildings from ARC/INFO
flood	Flood plain from ARC/INFO
ksc.contours	USGS 1:24000 contour lines for KSC from ARC/INFO
lcafar	Launch pad A farfield deposition from ARC/INFO
preserves	from ARC/INFO
roads	Roads in Brevard County from ARC/INFO
roadscl	KSC roads from ARC/INFO
upwrcl	KSC underground power lines from ARC/INFO
usewercl	KSC underground sewer lines from ARC/INFO
ustmdrncl	KSC underground storm drains from ARC/INFO
uwatercl	KSC underground water lines from ARC/INFO

Point (Sites) Data Imported to GRASS

GRASS Sites Name	Content
biosites	Biomass monitoring sites from ARC/INFO
boat	from ARC/INFO
fh20inpu	from ARC/INFO
manatee	Manatee sites from ARC/INFO
miscvege	from ARC/INFO
savbiomas	from ARC/INFO
savtransect	Monitoring transects from ARC/INFO
testfish	from ARC/INFO
waterlevel	from ARC/INFO
waterquality	Water quality testing sites from ARC/INFO

APPENDIX B SOIL PROPERTY GIS LAYERS DEVELOPED

Soil Property Data Layers Developed in GRASS Using Soils 5

GRASS Raster Name	Content
sorecotm	Original soil series data from ERDAS
soils.short	Reclassified soil series from sorecotm; used to obtain soil properties from Soils 5
aashto	AASHTO from Soils 5
avail.water	Available soil water in soil layer 1 (in/in) from Soils 5
avail.water2	Available soil water in soil layer 2 (in/in) from Soils 5
avail.water3	Available soil water in soil layer 3 (in/in) from Soils 5
avail.water4	Available soil water in soil layer 4 (in/in) from Soils 5
avail.water5	Available soil water in soil layer 5 (in/in) from Soils 5
avail.water6	Available soil water in soil layer 6 (in/in) from Soils 5
bedrock.depth	Depth of bedrock (inches) from Soils 5
bedrock.hard	Bedrock hardness from Soils 5
bulk.density	Bulk density of soil layer 1 (g/cm3) from Soils 5
caco3	$CaCO_3$ content of soil layer 1 (%) from Soils 5
cec	CEC of soil layer 1 (mg/100g) from Soils 5
cemented.pan.depth	Depth of cemented pan (inches) from Soils 5
class.expand	Expanded soil class from Soils 5
clay	Clay content (%) of soil layer 1 from Soils 5
corrosivity.concrete	Corrosivity of soil layer 1 to concrete from Soils 5
corrosivity.steel	Corrosivity of soil layer 1 to steel from Soils 5
drainage	Soil drainage class from Soils 5
flood.dur	Flooding duration from Soils 5
flood.freq	Flooding frequency from Soils 5
frac10	Fraction of soil particles in layer 1 greater than 10 inches from Soils 5
frac3-10	Fraction of soil particles in layer 1 between 3 and 10 inches from Soils 5
great.grp	Soil great group from Soils 5
gypsum	Gypsum content of soil layer 1 from Soils 5
hydgrp.project	Hydrologic soil groups from Soils 5; Highest group used if ranges were given
hydgrp.project2	Hydrologic soil groups from Soils 5; Lowest group used if ranges were given
k.usle	USLE K (soil erodibility) value from Soils 5
layer1.depth	Depth of soil layer 1 from Soils5
layer2.depth	Depth of soil layer 2 from Soils5
layer3.depth	Depth of soil layer 3 from Soils5
layer4.depth	Depth of soil layer 4 from Soils5
layer5.depth	Depth of soil layer 5 from Soils5
layer6.depth	Depth of soil layer 6 from Soils5
liq.limit	Liquid limit of the soil from Soils 5
minerology	Soil minerology from Soils 5

GRASS Raster Name	Content
organic.matter	Organic matter content of soil layer 1 from Soils 5
pan.hardness	Hardness of cemented pan from Soils 5
permeability	Permeability of soil layer 1 from Soils 5
permeability.2	Permeability of soil layer 2 from Soils 5
permeability.3	Permeability of soil layer 3 from Soils 5
permeability.4	Permeability of soil layer 4 from Soils 5
permeability.5	Permeability of soil layer 5 from Soils 5
permeability.6	Permeability of soil layer 6 from Soils 5
ph	Soil pH of soil layer 1 from Soil 5
plasticity.index	Plasticity index from Soils 5
salinity	Salinity of soil layer 1 from Soils 5
sand	Sand content of soil layer 1 (%) from Soils 5
sar	Sodium Adsorption Ratio from Soils 5
shrink.swell	Soil shrink-swell potential from Soils 5
silt	Estimated silt content of soil layer 1
slope.low	Lowest slope expected from Soils 5
slope.up	Highest slope expected from Soils 5
soil.class.exp	Expanded soil classes from Soils 5
soil.class.reaction	Reaction of soil class from Soils 5
soil.descrip	Soil description from Soils 5
soil.other	from Soils 5
soil.part.size	Soil particle size from Soils 5
soil.prop.note	Soil property note from Soils 5
soils	Soil series from ERDAS
soils.hydg	Hydrologic soil groups from Soils 5
soils.mlra	Soil mlra from Soils 5
soils.short	Soil series names; Reclassed from soils
sub.grp.mod	Sub-group modifier from Soils 5
subsidence.init	Initial subsidence from Soils 5
subsidence.total	Total subsidence from Soils 5
t.usle	USLE T factor from Soils 5
texture.layer2	Soil texture of layer 2 from Soils 5
texture.reclass	Soil texture of layer 1 from Soils 5
unified	unified from Soils 5
wattbl.depth	Water table depth from Soils 5
wattbl.depth.lower	Lower water table depth from Soils 5
wattbl.depth.upper	Upper water table depth from Soils 5
wind.erosion	Wind erosion expected from Soils 5
wind.ifact	Wind erosion equation i factor from Soils 5

APPENDIX C EXPORTING DATA FROM GRASS

C.1 Exporting GIS Layers from GRASS to ERDAS

The most efficient way to export GRASS raster data layers to the ERDAS GIS format is using ARC on a SUN workstation. Before starting ARC, the GISDBASE variable should be set to the location of the GRASS data. For example:

setenv GISDBASE /export/local/apps2/grass4/data

Next start ARC. From the ARC prompt, use the convertimage command to convert a GRASS raster file into the ERDAS format. The convertimage command requires the following arguments in the order given:

1. GRASS raster file name in the format LOCATION:MAPSET:raster file
2. ERDAS GIS file to be created
3. ERDAS (this indicates that an ERDAS format file is to be created

An example use of the command is:

convertimage ksc:PERMANENT:ph ph ERDAS

This command would convert the GRASS raster file ph into an ERDAS GIS format file also called ph.

Before using the file in ERDAS, the ERDAS fixhed command should be run to edit the categories, cell size, and coordinates.

C.2 Exporting GRASS GIS Layers to ARC/INFO

The following describes the process to export GRASS vector files into the ARC/INFO format and then import into ARC/INFO. GRASS contains the v.out.arc command for exporting vector data into an ARC/INFO format. Its arguments are the coverage type (polygon or line), the GRASS vector file name, and the name of the ARC file that will be created. Additional details of the v.out.arc command are provided in its GRASS man page. Once the new ARC file is created, the ARC generate command is used. The following sequence of commands are used in ARC.

generate
input arc_line_file_name
LINES

In the above sequence, arc_line_file_name is the file name that is created by the GRASS v.out.arc command.

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