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MANAGING RUNOFF WATER QUALITY FROM CLAY SETTLING AREAS USED FOR INTENSIVE AGRICULTURAL PRODUCTION

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MANAGING RUNOFF WATER QUALITY FROM CLAY SETTLING AREAS USED FOR INTENSIVE AGRICULTURAL PRODUCTION

FINAL REPORT

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DISCLAIMER

PERSPECTIVE

According to the Department of Environmental Protection, Bureau of Mine Reclamation, there are more than 110,000 acres of active and inactive clay settling areas in Florida as a result of phosphate mining and upgrading of ore. Because of the physical properties of the clays, the reclaimed settling areas are unsuitable for urban or suburban development. However, the clays are high in fertility and have high moisture holding capacities so that the settling areas do have great potential for intensive agriculture. Reclamation for intensive agricultural production would result in higher land values (and greater tax revenues to the counties) than if the lands were reclaimed to pasture or wildlife habitat.

The Mined Lands Agricultural Research and Demonstration Project was funded, beginning in late 1985, to study the technical and economic feasibility of agricultural production on phosphatic clay settling areas. The research has included: (1) identification of various crops and cropping systems suitable for production on phosphatic clay in central Florida; (2) development of soil management techniques for coping with a clay soil in a rainy environment; (3) participation in studies to assess the extent of any radionuclide hazard from consuming foods produced on phosphatic clay; and (4) analysis of production costs and markets for various crops. A comprehensive report published in 1996 (The Mined Lands Agricultural Research and Demonstration Project: Summary of Experiments and Extension Recommendations, FIPR Publication No. 03-090-128) summarized the findings from nearly ten years of research.

In the course of the Mined Lands Agricultural Research and Demonstration Project it was learned that crop production on phosphatic clay and timely access to the fields for critical management actions such as pest control and harvesting could be enhanced by creating large gently-sloped (2% grade) planting beds to promote runoff of precipitation and thereby reduce soil water-logging and mud puddle formation. However, the slightly increased slopes of the planting beds and the greater frequency of soil disturbance associated with intensive farming, compared to using the land for pasture, could possibly result in greater runoff volumes and greater sediment loads in the runoff. The purpose of this project was to quantify the impacts of agricultural production on the quantity and quality of runoff water from agricultural fields on a clay settling area and to examine techniques for minimizing or eliminating possible negative impacts on water quality. The study compared runoff from plots with a continuous cover crop (bermudagrass) versus plots with a corn and wheat rotation. They also evaluated a stilling (wet detention or settling) pond and chemical flocculants for reducing the discharge of nutrients and sediment.

Steven G. Richardson, Ph.D.
Reclamation Research Director

ABSTRACT

Clay settling areas from phosphate mining in central Florida contain fertile, highly productive agricultural soils. However, gently sloped (2% grade) beds intended to improve surface drainage, combined with increased soil disturbance associated with intensive crop production, could lead to greater runoff volumes and sediment loads.

The objective of this work was to examine surface water quality discharged from agriculturally utilized phosphatic clay settling areas. Two preliminary replicated small plot (1 m x 1.5 m) field trials were used to describe the characteristics of runoff from bare, bermudagrass-covered, or ryegrass-covered phosphatic clay at either 2% or 8% slope. Results from the first small plot experiment were used to calibrate the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model with respect to sediment and runoff predictions. Water quality measurements included runoff and sediment amounts and N and P concentrations.

The calibrated GLEAMS model was successfully used to predict runoff and sediment loading observed in a second small plot experiment. The GLEAMS model also predicted N loading in runoff and sediment, but over-predicted P. Sensitivity analysis showed that the current GLEAMS model does not have appropriate mechanisms for addressing the high mineral-P concentration of phosphatic clays.

Sediment loading varied with slope, and bare phosphatic clay generated greater than nine times as much sediment as ryegrass-covered small plots at the 2% slope. The amounts of N and P found in the runoff were more than values reported in the literature for native prairies, but much less than values observed for agricultural soils receiving P fertilization. P was strongly correlated with sediment.

Large field plots (approximately 1.2 ha each) were established in bermudagrass or corn followed by wheat. Both fields were landformed into macrobeds with 2% slopes. Flumes and automated water sampling equipment were installed at the discharge end of each macrobed. A weather station was used to collect rainfall amount, temperature, and wind data pertaining to the field plots. The corn/wheat rotation field produced more runoff events than the bermudagrass field. While all measures of N were low, measures of sediment and P from the cornfield were 2 to more than 6 times the concentration found in runoff from the bermudagrass field.

TABLE OF CONTENTS

TABLES OF CONTENTS (CONT.)

APPENDIXES

LIST OF FIGURES

LIST OF FIGURES (CONT.)

EXECUTIVE SUMMARY

The objective of this work, *Managing Runoff Water Quality from Clay Settling Areas Used for Intensive Agricultural Production*, was to enhance surface water quality discharged from agriculturally utilized phosphatic clay settling pond areas. Two preliminary replicated field trials using 1 m x 1.5 m plots were used to describe the characteristics of runoff from bare, bermudagrass, or ryegrass-covered phosphatic clay at either 2% or 8% slope. Results from the first small plot experiment (Green Bay Mine site) were used to calibrate the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model with respect to sediment and runoff predictions. The calibrated model was then used to predict runoff and sediment from the second small plot experiment, which was conducted at the Ft. Green Mine site.

Water quality measurements included runoff and sediment amounts at both sites. Nitrate-N, ammonium-N, total Kjeldahl N, total P and Soluble Reactive P were measured and modeled only for the second small plot experiment.

The replicated small-plot research found that sediment loading varied with slope, and that bare phosphatic clay generated greater than nine times as much sediment as ryegrass-covered small plots at the 2% slope. The amounts of N and P found in the runoff were more than values reported in the literature for native prairies, but much less than values observed for agricultural soils receiving P fertilization. Therefore, phosphatic clay does pose a problem with respect to runoff water quality, but no more so than other agricultural lands.

The calibrated GLEAMS model was successfully used to predict runoff and sediment loading observed in the second small plot experiment. The GLEAMS model also predicted N loading in runoff and sediment, but over-predicted P. Sensitivity analysis showed that the current GLEAMS model does not have appropriate mechanisms for addressing the high mineral-P concentration of phosphatic clays. P was strongly correlated with sediment.

Large field plots were established in bermudagrass or temperate corn (approximately 1.2 ha each). Both fields were landformed into macrobeds with 2% slopes. Flumes and automated water sampling equipment were installed at the discharge end of each macrobed. A weather station was used to collect rainfall amount, temperature, and wind data pertaining to the field plots.

A pond was constructed to collect runoff water from both field plots. Automated sampling equipment was installed at both the inflow and outflow ends of the pond to record/sample water for water quality analysis. Additionally, 20 metal posts were placed throughout the pond in a grid fashion to note temporal changes in plant species within the pond. Changes in sediment levels throughout the pond were also noted using the measuring scales attached to each metal post.

During the second year of the project, the two agricultural fields produced five runoff events that could be sampled. The bermudagrass field had only three runoff events. The first two events are temporally related. It was not possible to separate the two rain events for proper analysis since the first event had an impact on the runoff from the second event. The second runoff event contained elevated concentrations of sediment and nutrients compared to the first. As expected, there were additional runoff events from the cornfield. While all measures of N were low, measures of sediment and P from the cornfield were 2 to more than 6 times the concentration found in runoff from the bermudagrass field. When a runoff event occurred, both sediment and total P were of environmental concern. Sediment and total P from the corn/wheat rotation field was higher than that from the bermudagrass field. The corn/wheat rotation field produced more runoff events that the bermudagrass field.

The stilling pond provided little retention, and did nothing for water quality improvement, as operated. Retention time was too short to permit natural settling. The suspended clay solids in runoff waters, should they be released from impoundment basins, would be an environmental concern. Chemical treatment is likely to improve water quality for subsequent discharge. Three compounds were used: ferric chloride, ferric sulfate, and alum. All compounds were effective in TP removal below 1 ppm using basic chemical techniques. Alum was the most effective coagulant chemical. Pond design and operation should be explored for maximum improvement of water quality of runoff from phosphatic clay. Pond designs could be improved to reduce on-site channeling, and increase the pathlength for greater sedimentation and greater residence times.

This project focused on the agricultural aspects. Because of good landform design and proven crop production techniques upstream of the pond, runoff events were relatively few and low in volume. These conditions precluded exploration of pond management for improved water quality.

INTRODUCTION AND BACKGROUND

The project, *Managing Runoff Water Quality From Clay Settling Areas Used For Intensive Agricultural Production*, was based on work conducted by the Polk County Mined Lands Agricultural Research and Demonstration Project (1985-1995). Early in that project, water quality and nutrient losses due to erosion were identified as concerns as phosphatic clays were developed for intensive agriculture. The project presented here contained the elements originally proposed in the demonstration: a macrobed drainage system to prevent flooding of agricultural crops and a pond to retain runoff, allow eroded clays to settle, and serve as a potential watering source for agricultural operations with the field (Hanlon and others 1991).

STATEMENT OF SOURCE & MAGNITUDE OF PROBLEM

Phosphate mining in Florida has produced about 41,300 hectares (102,000 acres) of clay settling ponds with 9,300 hectares (23,000 acres) forecast to be constructed. Once waste clay is separated from the phosphatic ore matrix, clay is pumped to large impoundments (settling areas) as a 2% solid. With time, the clay settles out, and water is decanted for reuse in the mining process. After mining is complete, about 40% of the land surface is covered with clay settling areas. However, this percentage varies with the depth and thickness of the initial ore matrix, composition of the matrix, and constructed depth of the settling pond (Partney and Henderson 1992).

Approximately 24,280 hectares (60,000 acres) of the upper Peace River watershed is occupied by clay settling areas (S. Partney, Florida Department of Environmental Protection, Bureau of Mine Reclamation, personal communication, Oct. 27, 1994). The Peace River empties into Charlotte Harbor. Charlotte Harbor is a National Marine Estuary water body and is specifically under the auspices of SWIM (Surface Water Improvement and Management) planning (Livingston and others 1989). Additionally, the Southwest Florida Water Management District (SWFWMD) is developing plans to utilize the lower Peace River as a regional water supply for Sarasota and Charlotte Counties. Given these intentions and the high water quality standards required for environmental and human health, the quality of water runoff from clay settling areas is of great importance.

Presently, most reclaimed phosphatic clay sites are used for pasture, forestry, wildlife, or other low-intensity land uses. The Mined Lands Agricultural Research/Demonstration Project (MLAR/DP) is a jointly funded project of the Florida Institute of Phosphate Research, University of Florida, and the Polk County Board of Commissioners. The MLAR/DP has developed agriculturally intensive management strategies for reclaimed phosphatic clays (Peacock and Deck 1985; Hochmuth and others 1987; Baltensperger and others 1989; Hanlon and others 1991). While these clays are inherently fertile, have superior water holding characteristics compared to typical unmined sandy soils, and are agronomically productive, drainage has been identified as a constraint to their utilization (Hanlon and others 1993). The MLAR/DP has developed certain management strategies to reduce this problem. One strategy includes land forming through construction of macrobeds, which increases surface drainage and permits more timely field access after storm events (Hanlon and others 1991a and b). Macrobeds are formed by shaping the phosphatic clay surface into a corrugated form with 1 to 2% slopes. To minimize clay movement during construction, macrobeds are usually 30 to 60 meters (100 to 200 feet) from crest to crest.

Increased surface drainage will increase runoff water volume. Runoff water may be impounded within another portion of the site (Hanlon and others 1991a) or, more appropriately, discharged off-site to contribute to the watershed. An associated potential problem is the increased transport of soil sediment with increased runoff. For water that is discharged from phosphatic clay ponded areas, water quality may be adversely affected by sediment content and increased phosphorus (P) concentrations.

As much as 70% of the phosphatic clay consists of particles of less than 2 microns. These clays are calcium saturated, which enhances flocculation compared to similar clays containing sodium. However, these clays typically contain from 1 to 4% organic matter (Jerez 1994), contributing little to secondary soil structure. Removal of phosphatic clay from the water column through sedimentation processes requires extended time. Most P in these runoff waters should be associated with the sediment (i.e., particulate portion).

REVIEW OF PERTINENT LITERATURE AND RELATED WORK IN PROGRESS BY OTHERS

Effect of Agricultural Management Practices on Runoff Quality

The effect of agricultural management practices on soil erosion, water runoff, and water quality have been intensively studied due to national nonpoint pollution concerns (Edwards and others 1994, Mostaghimi and others 1992). As reported by Edwards and others (1994), greater runoff concentrations of nitrogen (N) and P were observed for the inorganic fertilizer than for the organic fertilizer application. The use of sludge on agricultural land under a no-till system is a viable alternative to chemical fertilizer use and control of N and P in runoff (Mostaghimi and others 1992).

Reduced tillage and other conservation tillage approaches have been shown effective in reducing nutrient losses due to subsequent reduction of erosion (McDowell and others 1980, McIsaac and others 1991). Additionally, sediment and nutrient concentrations in runoff waters can be reduced through the use of different vegetative covers (i.e., clover, ryegrass, and fescue) (Gross and others 1990, 1991; Croops and Bates 1993).

Model Application on Runoff and Water Quality

Modeling of agricultural conditions is an appropriate method for describing complex events and predicting the outcome given a much wider range of events with success. As with any stochastic or mechanistic model, there is an element of uncertainty with the prediction. Therefore, this project will try to verify a proven model, adapting this model to conditions found with crop production on phosphatic clays in Florida.

The curve number (CN) procedure was developed by the Soil Conservation Service to estimate direct runoff from storm rainfall. This information is needed for proper calculation of soil erosion, runoff water quality, and many other applications. The national database of curve numbers was built from runoff measurements (USDA-SCS 1972). Curve numbers represents soils, land use, antecedent soil moisture, and hydrologic conditions of a watershed (SCS TR-55 1986). Extrapolation of CN values from the national database to a specific field situation often causes errors in runoff volume estimates (Yoo and Touchton 1993). Therefore, the CN should be calibrated for phosphatic clay due to the special hydrologic conditions of clay settling ponds in Florida. The CN concept is used in several water quality models (e.g., GLEAMS, CREAMS, SWRRB, AGNPS, EPIC; Bingner and others 1989).

The CREAMS model (Chemical, Runoff, and Erosion from Agricultural Management Systems) has been widely used to evaluate runoff, sediment, pesticide, and nutrient losses for different soil and management conditions (Knisel 1993). Kenneth et al. (1990) studied nitrate concentrations in drainage waters from a potato production area on sandy loam soil by using the nutrient submodel of CREAMS in Quebec, Canada. They found that the CREAMS nutrient submodel over-predicted nitrate concentration in drainage water by 32 percent, but correctly predicted values in excess of the 10 mg NO_{3-}N/L standard in all cases when the hydrology submodel value was greater than 0. The authors attributed lack of model precision due to accumulated errors within submodels and the need for more precise estimates within the nutrient submodel.

Another study conducted in Vermont compared simulated and observed monthly runoff, sediment, and P exports (Jamieson and Clausen 1988). The CREAMS model over-predicted exports for low-flow months and under-predicted exports during high-flow months. In all cases, coefficients of determination values remained between 0.78 and 0.90 except for the sediment prediction from one field.

After comparing annual runoff from 46 sites in the southern and Midwestern U.S. to predicted values, Smith and Williams (1980) concluded that the hydrology submodel was satisfactory. A study comparing the simulated results from CREAMS, SWRRB, EPIC, ANSWERS and AGNPS (Bingner and others 1989) showed that CREAMS and SWRRB produced results close to the measured values more often than the other models. The GLEAMS model (Groundwater Loadings Effect of Agricultural Management Systems) was developed as an extension of CREAMS and incorporates a component for both horizontal (runoff) and vertical (leaching) flux of pesticides and nutrients (Knisel 1992). The usefulness of this model is expected to be high, but no information is available to verify the effectiveness of the nutrient component of this model for phosphatic clays in Florida.

Enumeration of the Specific Project Goals

The overall objective of this project was to enhance surface water quality discharged from agriculturally utilized phosphatic clay settling pond areas. Three specific objectives were:

To measure the effects of two selected soil management field-scale systems on runoff water quality as indicated by dissolved P, N, and sediment contents;

To determine the effectiveness of stormwater retention areas (stilling pond) for improvement of discharge water quality from phosphatic clay used for agricultural production;

To determine the effectiveness of chemical treatment of runoff waters before entering the stilling pond in enhancing sediment/nutrient retention and discharged water quality.

SMALL PLOT EXPERIMENT METHODS

Small Plot Experiment, Green Bay Site

Within phosphatic clay areas at the Green Bay site with established alfalfa, bermudagrass, or bare soil, 0.5- by 1-m plots were chosen with slopes ranging from 1 to 12%. Water was applied to each plot via a controlled droplet nozzle mounted vertically above the center of the plot at a constant height of 1.8 m. +/- 0.05 m. Pressure was maintained at 10 psi. +/- 1 psi. by regulated CO_2. No change in water pH was found due to interaction with the CO_2 propellant. All runoff and sediment were collected during the timed water addition, which approximated a rainfall event of 2 inches (equivalent to a 10-year storm event, based upon Bartow weather data).

Both statistical regressions and GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model predictions were used to compare observed values with modeling values. Bermudagrass plots with 2 or 8% slopes were used for this initial calibration of the GLEAMS model because the standard for erosion models is a grassed surface.

The second small plot experiment was completed in partial fulfillment for a Masters of Science by Mr. D. Gao (Gao 1996). This experiment used a split plot design with a factorial arrangement of treatments using four replications. The objective was to determine the magnitude of erosion and N and P concentrations with and without ryegrass cover at 2 or 8% slope. As with the initial small plot work, 0.5- by 1-m plots were chosen, and water was applied to each plot via a controlled droplet nozzle as described previously.

A sensitivity analysis of the GLEAMS model for N and P indicated that several parameters would require further investigation. Equations reported in the original literature concerning development of the GLEAMS model were used to predict mechanisms that might be changed to improve model prediction of some variables, such as P concentration in runoff from phosphatic clays.

Total runoff and sediment amounts were recorded, and N and P analyses (Figure 1) were performed on both sediment and runoff. Both statistical regressions and the calibrated GLEAMS model predictions were used to compare observed values with modeling values.

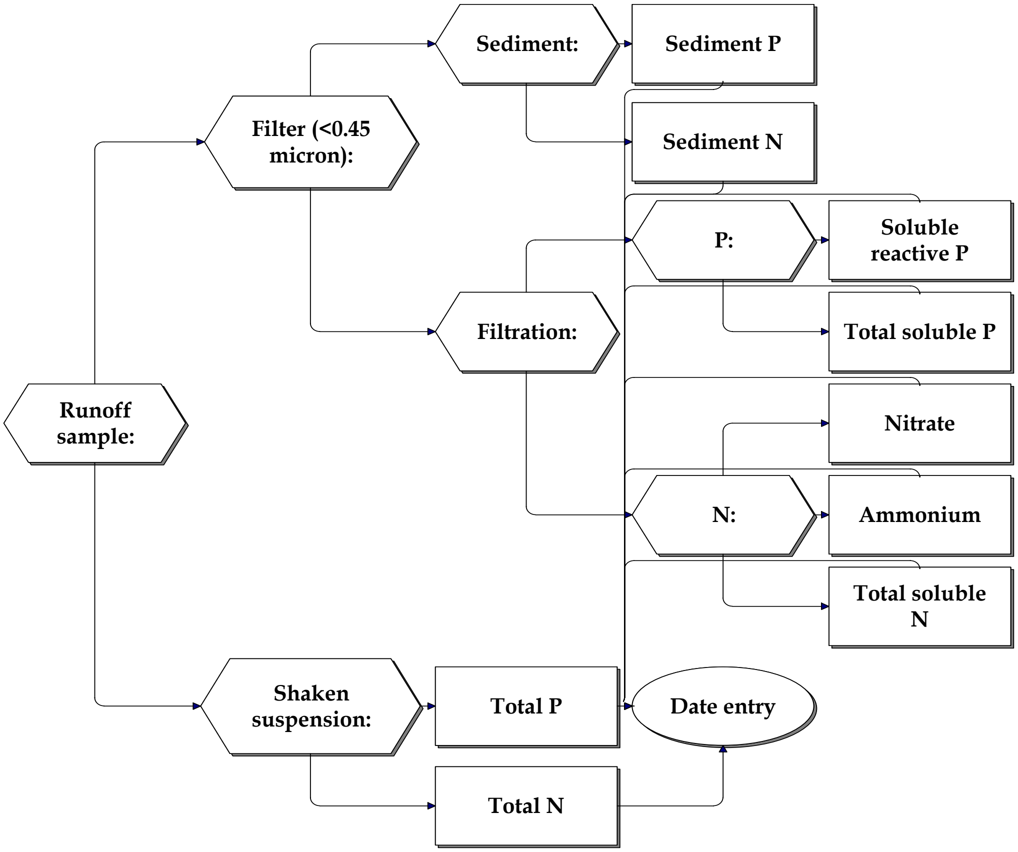


Figure 1. Analytical Pathway for Runoff Samples.

SMALL PLOT EXPERIMENT FINDINGS

SMALL PLOT EXPERIMENT, FT. GREEN SITE

Figure 2 shows that initial GLEAMS predictions were considerably higher than observed sediment values. As expected, the tabular values supplied with the GLEAMS model did not sufficiently represent erosion processes for phosphatic clay.

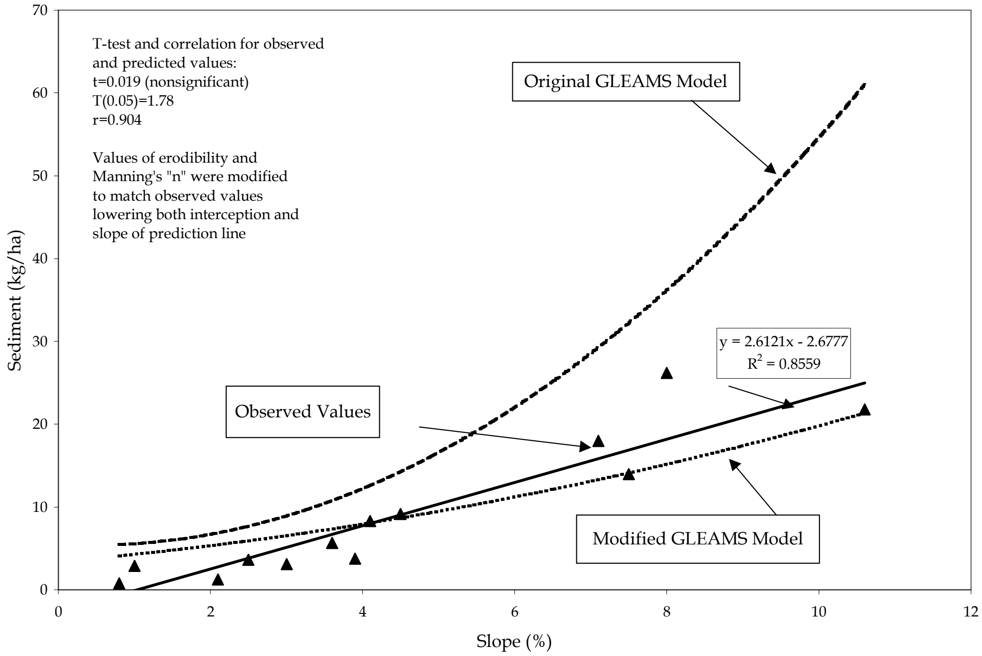


Figure 2. Initial and Calibrated GLEAMS Model Predictions with Observed Bermudagrass Sediment Values, Green Bay Site, 1995.

A sensitivity analysis of the model indicated that several parameters would require further investigation. Equations reported in the original literature concerning the development of the GLEAMS model were used to further highlight needed measurements of the phosphatic clay. This work produced a short list of parameters that were subsequently measured for phosphatic clay.

These measured parameters were entered into the GLEAMS model and compared to both observed small-plot values and linear regression (Figure 2). The calibrated GLEAMS model predicted sediment much better, and approximated the empirical linear regression.

The calibrated GLEAMS model was then used to predict sediment from both the bare soil (worst-case condition, Figure 3) and the alfalfa treatments (intermediate condition, Figure 4). The calibrated model did an excellent job of predicting sediment for the bare soil throughout the range of slopes. The GLEAMS model actually predicted sediment value more accurately than linear regression because the model is mechanistic in nature, taking into account both chemical and physical properties of the clay.

The calibrated GLEAMS model was then compared to observed erosion on all bare phosphatic clay plots (Figure 3). Despite the observed variability, the calibrated model agreed with the empirical regression acceptably.

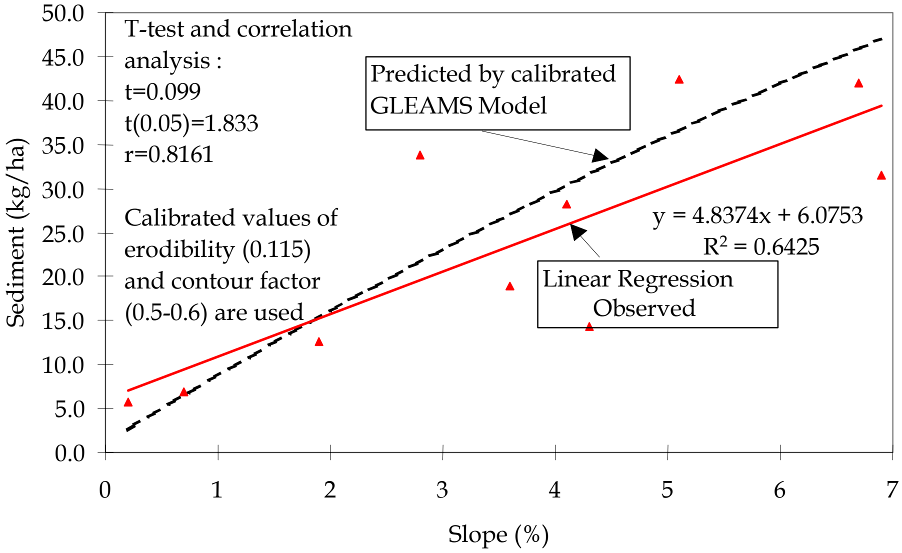


Figure 3. Predicted Bare Phosphatic Clay Sediment Values Using the Calibrated GLEAMS Model and Observed Values, Green Bay Site, 1995.

At the time of this small-plot work, the alfalfa stand was rapidly being replaced with the more aggressively growing bermudagrass. Only four satisfactory plots could be found with pure stands of alfalfa. The calibrated model predictably showed some deviation from these four points. The GLEAMS model is intended to estimate sediment and other runoff parameters using longer time periods than just one day and with more observations; however, the model did an acceptable job. These initial findings suggest that work with the model should continue.

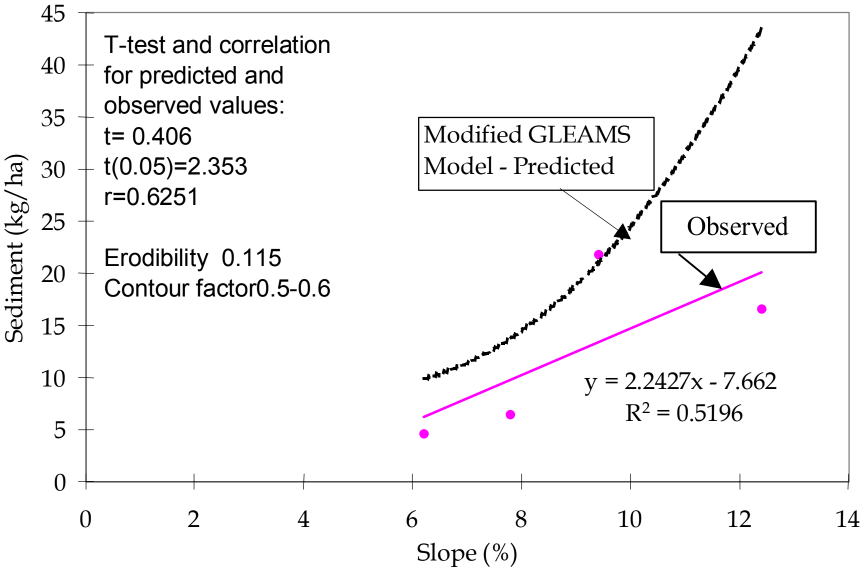


Figure 4. Predicted Sediment Values Using the Calibrated GLEAMS Model Compared to Observed Values from Phosphatic Clay with Alfalfa, Green Bay Site, 1995.

MODELING RUNOFF DATA FROM SMALL PLOT EXPERIMENT, FT. GREEN SITE

The calibration process, completed at the Green Bay site, improved GLEAMS-model predictions of both sediment (Figure 5) and runoff (Figure 6) at the Ft. Green site. While runoff predictions are considered adequate in the uncalibrated model, the calibrated model did better in predicting sediment at measured slopes with or without cover. However, initial calibration work did not address N and P concentrations in runoff or sediment.

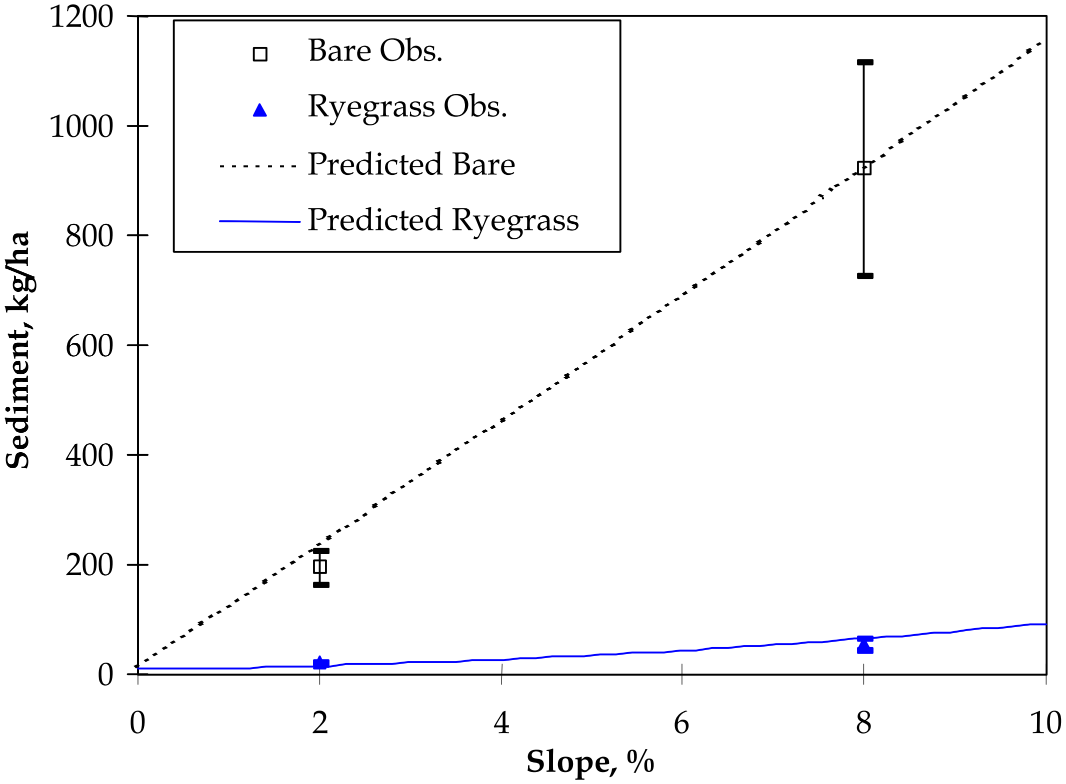


Figure 5. Predicted and Observed Sediment as a Function of Slope and Cover, Ft. Green Site, 1996. (Observed Data Presented with Standard Error Bars.)

Figure 6 demonstrates that the GLEAMS prediction for this single runoff event changed in magnitude as cover changed with selected slopes. However, the model did not produce predictions that fell within the variances observed from the small plots. It is important to consider that the model does best when predicting accumulated runoff, sediment, and other attributes with time. Therefore, this small plot work should be considered a challenging test of this semi-mechanistic model. In fact, the model did quite well. For example, the model predicted 1.2 cm of runoff from bare soil with changing slopes, and the observed value was 1.5 cm.

The apparent flat response (no y response to change in x value) of the model to increasing slope, regardless of cover, is a function of the fact that infiltration of water into this clay is very slow due to low measured saturated hydraulic conductivity. Therefore, water is modeled to produce equivalent amounts of runoff with a given cover regardless of slope. The model reflected observed measurements.

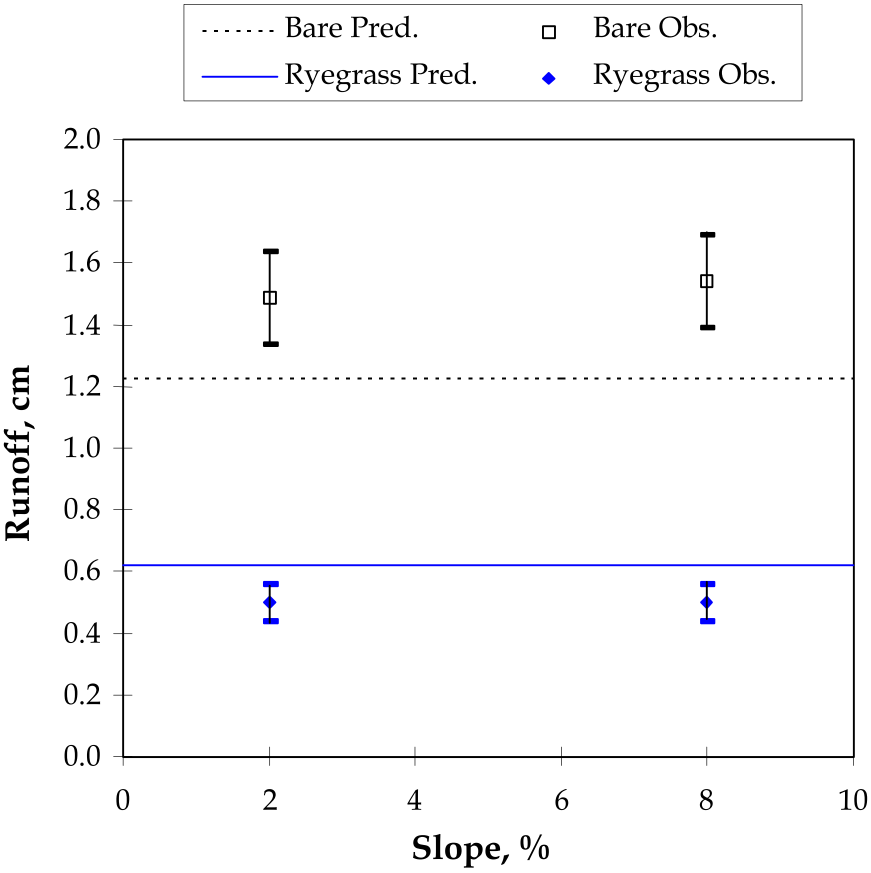


Figure 6. Predicted and Observed Runoff from Small Plots as a Function of Slope and Cover, Ft. Green Site, 1996. (Observed Data Presented with Standard Error Bars.)

The model was sensitive to changes in cover and slope when predicting N and P in sediment (Figures 7 and 8). Even in this rigorous evaluation, the calibrated model predicted N and P in sediment values that were quite close to observed values (within observed standard deviations for the most part).

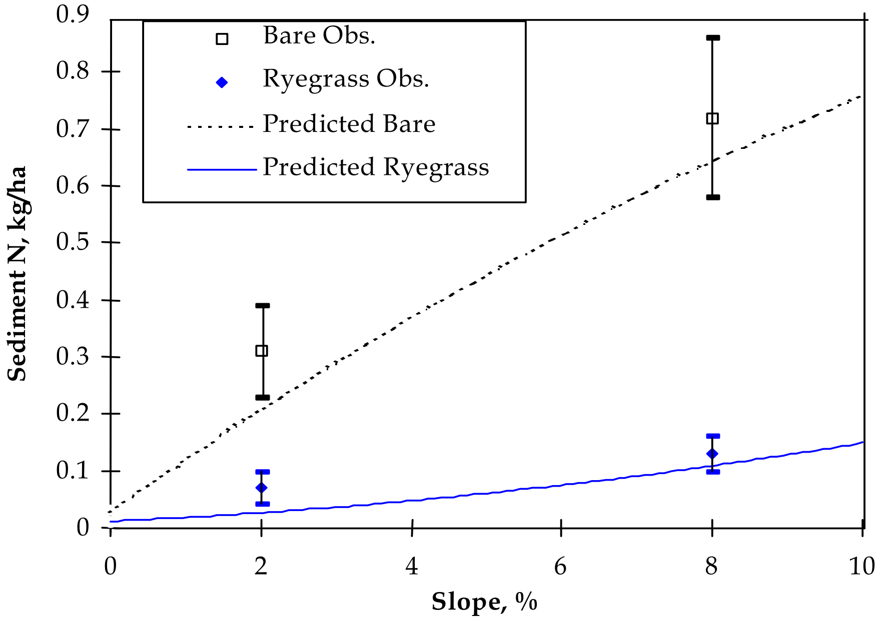


Figure 7. Predicted and Observed N in Sediment as a Function of Slope and Cover, Ft. Green Site, 1996.

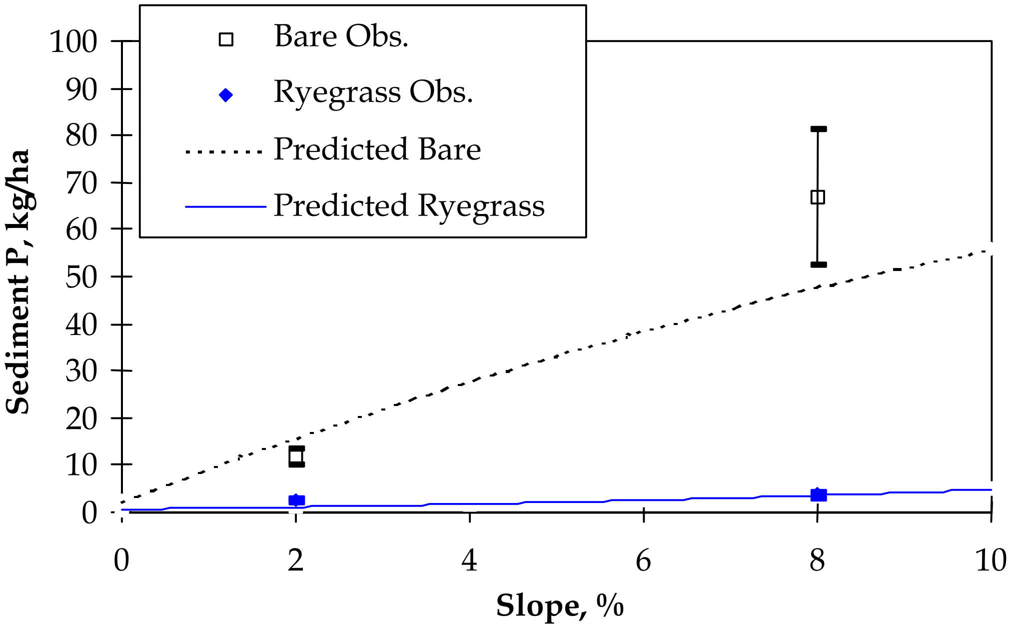


Figure 8. Predicted and Observed P in Sediment as a Function of Slope and Cover, Ft. Green Site, 1996. (Observed Data Presented with Standard Error Bars.)

However, predictions of N and P in runoff were not accurate, and in all cases were over-predicted. While it is interesting to note that observed runoff N and P values were considerably less than those predicted by the model, observed runoff-P values were quite high and of environmental concern. Recently, 0.015 ppm P has been identified as a concentration above which eutrophication becomes a concern. This concentration converts to 2 g ha^{-1} (0.002 kg ha^{-1}). Therefore, even at the 2% slope with ryegrass cover (best case scenario), soluble P in runoff (Figure 10) is a potential problem to oligotrophic environments.

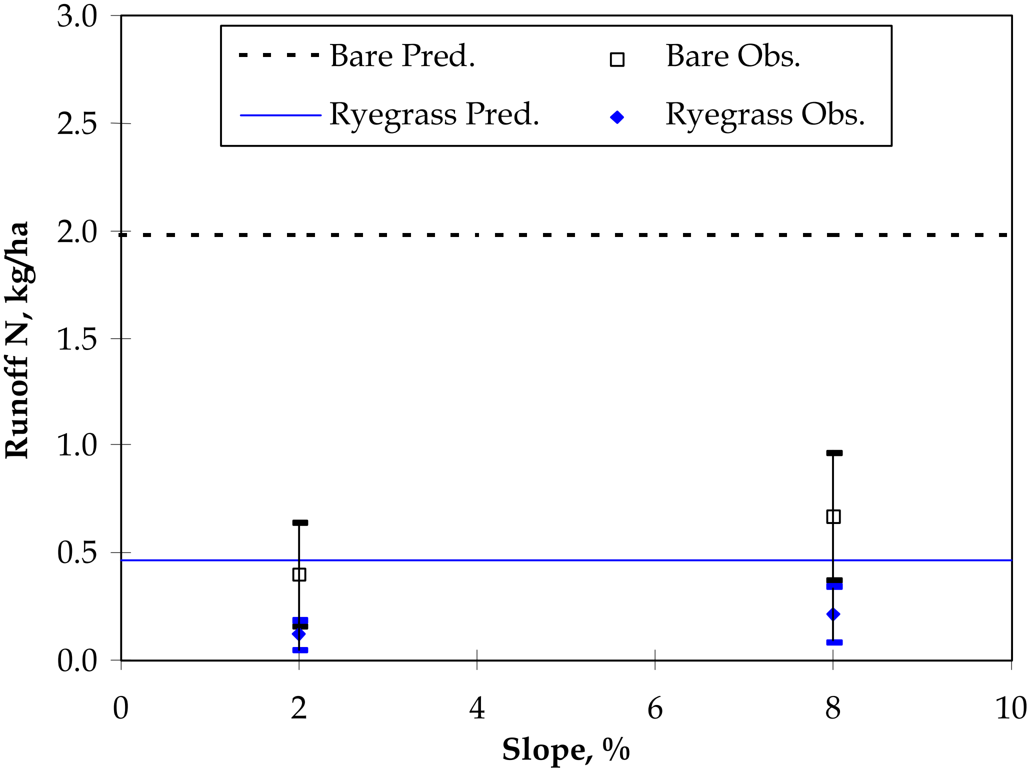


Figure 9. Predicted and Observed N in Runoff as a Function of Slope and Cover, Ft. Green Site, 1996. (Observed Data Presented with Standard Error Bars.)

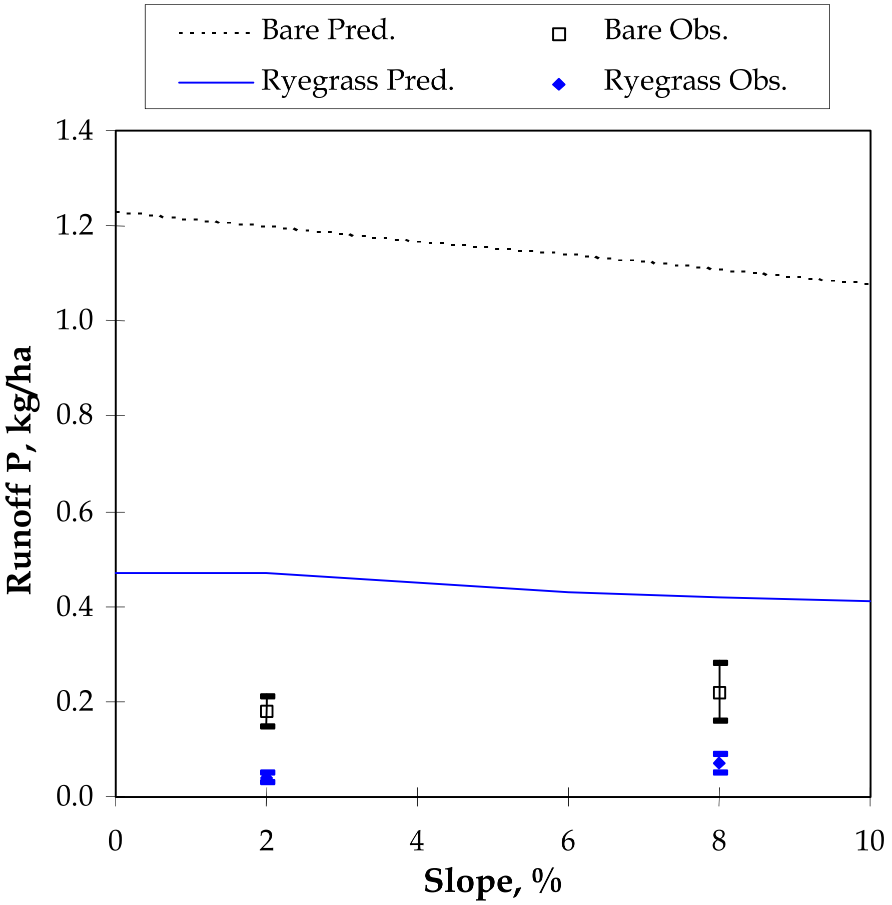


Figure 10. Predicted and Observed P in Runoff as a Function of Slope and Cover, Ft. Green Site, 1996. (Observed Data Presented with Standard Error Bars.)

Figure 11 shows the results of sensitivity tests on the calibrated GLEAMS model for N, and Figure 12 for P, in runoff. Each of these components has a major effect on predicted levels of N and P, and therefore indicate potential locations within the model to determine the cause for under- or over-prediction. For example, low estimates of porosity will lead to greatly over-predicted N in runoff. However, this model is designed to predict runoff and sediment values at the field scale.

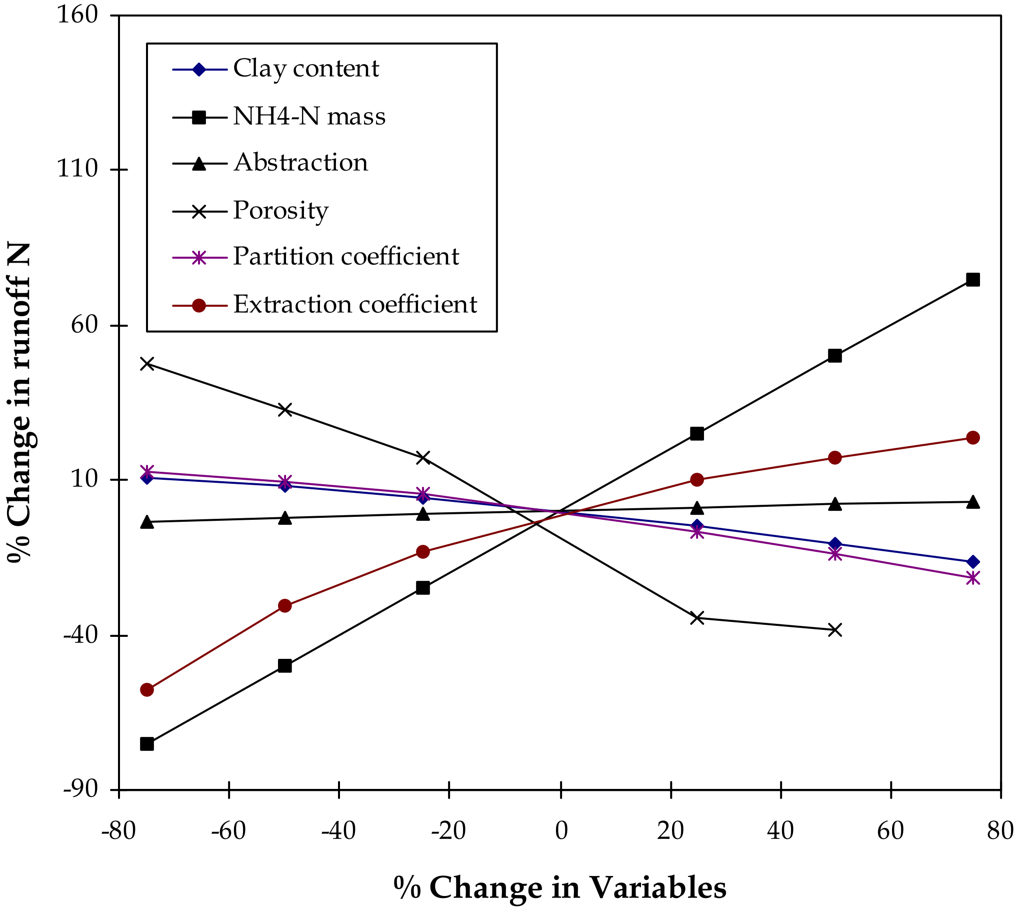


Figure 11. Sensitivity Analysis of GLEAMS Parameters for Prediction of N, Ft. Green Site, 1996.

The model should be expected to over-predict values within small plots, which is what was found concerning N and P in runoff. Exploration of the GLEAMS model mechanistic approach to runoff water quality is addressed in Mr. Gao's thesis (Gao 1996).

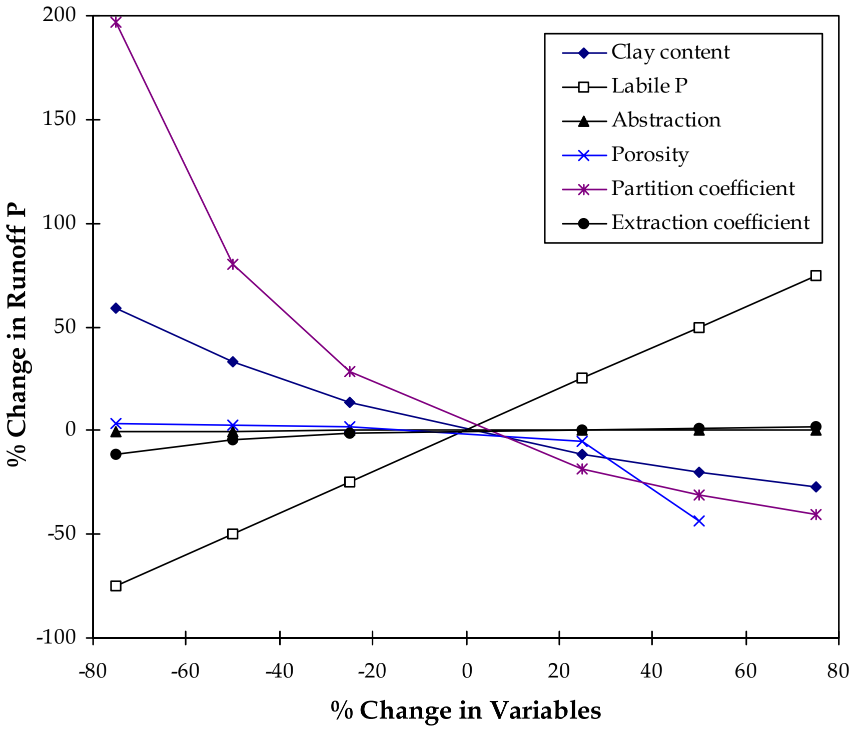


Figure 12. Sensitivity Analysis of GLEAMS Parameters for Prediction of P, Ft. Green Site, 1996.

LARGE FIELD MACROBED EXPERIMENT METHODS

MATERIALS AND METHODS

Two macrobeds, each approximately 1.2 ha in size and with slopes of 1-2%, were formed on a reclaimed clay settling pond at IMC-Agrico's Ft. Green Mine. Flumes with autosamplers and ultra-sonic distance sensors were installed at the drainage end of each macrobed. The eastern macrobed was planted to bermudagrass in May, 1996. The bermudagrass macrobed was mowed monthly to a 3-inch height to control weeds and promote grass growth. Bermudagrass was fertilized with 45 kg N ha^{-1} (50 pounds N per acre) at planting and 27 kg N ha^{-1} (30 pounds N per acre) in July, 1996. Fertilization was repeated in March, 1997 with 30 lbs/ac (pounds per acre) N as ammonium sulfate.

The second macrobed was clean tilled before planting temperate corn in July 1996. Plants were spaced to achieve about 54,000 plants ha^{-1} (22,000 plants per acre), and fertilized with 134 kg N ha^{-1} (150 pounds N per acre). Wheat was planted in rotation with the corn on December 13, 1996, with 54 kg N ha^{-1} (60 pounds N per acre) pre-plant fertilizer and an additional N application in March of 27 kg N ha^{-1} (30 pound per acre N). On April 11, 1997, wheat was harvested with the stover removed down to 3 inches. On June 4, 1997 the second crop of corn was planted (22,000 plants/acre). Fertilizer was incorporated at planting at the rate of 108 kg N ha^{-1} (120 pounds N per acre) as granular ammonium sulfate. The corn was harvested on September 15.

Rainfall was recorded using a Campbell Weather Station, in addition to temperature and wind speed. Programming automatically started and stopped the autosamplers based upon the depth of water in the flume (approximately 1 cm).

Soil samples were taken on a surveyed grid throughout each macrobed. Thirty samples were taken from each macrobed (0 to 5 cm depth) and analyzed for pH, and Mehlich-3 extractable Ca, Mg, K, and P. Both means and standard deviations were calculated.

Posts were surveyed on a 100-m grid throughout the pond, resulting in 20 locations. The posts were used as markers for monitoring plant colonization of the pond, and for determining sediment buildup. Two plant observations were taken – one in August 1996 and the second in April 1997.

A final survey of the macrobeds, connecting ditch, and pond inflow and outflow structures and pond was completed in June 1996 by NRCS personnel.

During the second year of the project the two agricultural fields produced five runoff events that could be sampled. While several samples were collected on July 3, 1997, the event was later determined to be a malfunction of the sensors and the data are not reported.

All runoff or discharge events were analyzed according to the flowchart presented in Figure 1. Results are reported in mg/L.

Filtration

A known quantity of sample is passed through a 0.45-µm filter. All P and N passing through the filter are in true solution. Material trapped on the filter is termed sediment.

Sediment

A known quantity of sample is passed through a 0.45-µm filter. The filter and trapped material is dried at 105° C, and weighed. The difference in weight before and after filtration is a measurement of the sediment load (mg/L) of the sample.

Sediment Phosphorus and Sediment Nitrogen

Due to the small amount of sediment obtained by this method, no attempt to analyze the sediment was made. These values can be approximated by subtracting all measurements conducted on the filtered portion of the sample from unfiltered TP and TN values. For purposes of this report, only Sediment P was calculated.

Soluble Reactive Phosphorus (SRP)

A subsample of the filtered samples was analyzed using an ascorbic acid phosphomolybdenum blue color complex. Due to turbidity of the filtered samples and the nature of this colorimetric process, we expected an over-estimation of SRP. This test was included in this report for completeness. Reports in the literature discuss many problems with turbid samples and use of activated charcoal or other clearing solutions have introduced considerable errors. No attempt to correct for turbidity was made in this project.

Total Soluble Phosphorus (TSP)

The same subsample used for SRP was also analyzed using inductively coupled argon plasma spectroscopy (ICP). This process is less sensitive to turbidity, and will result in the soluble inorganic and organic fractions found in the filtered samples.

Total Phosphorus (TP)

An unfiltered sub-sample was digested using a standard perchloric acid digestion procedure. The resulting solution was analyzed for P using ICP. This method results in an estimate of all P in the sample, including solid, solution, organic, and inorganic fractions.

Nitrate (NO_3– N)

Nitrate-N was determined in the filtered portion of the sample, and was analyzed for N using a standard colorimetric method.

Ammoniacal-N (NH_4^+-N)

Ammoniacal-N was determined in the filtered portion of the sample, and was analyzed for N using a standard colorimetric method.

Total Soluble Nitrogen (TKN)

A filtered subsample was digested using a standard Kjeldahl nitrogen procedure. This method is an estimate of all soluble N in the sample, including both organic and inorganic fractions. The soluble organic N fraction can be estimated by subtracting the sum of NH_4^+-N and NO_3^--N from TKN. This procedure was not done for this report due to low N values in the system.

Total Nitrogen (TN)

An unfiltered subsample was digested using a standard Kjeldahl nitrogen procedure. This method is an estimate of all N in the sample, including solid, solution, organic, and inorganic fractions.

Mehlich-3 Extraction

Soils were collected on a fixed-point basis with thirty sampling points located in each of the bermudagrass and corn/wheat rotation fields. Immediately following corn in both 1996 and 1997, six 2.5-cm by 15-cm soil cores were collected from within 1 m of each fixed point. Soil cores were air-dried, crushed using a stainless steel hammer mill, and screened to pass a 2-mm mesh opening. A soil volume of 2.5 cm^3 was extracted using Mehlich-3 solution and analyzed for Ca, Mg, K, and P by ICP (Hanlon and others 1998). Calculating the mean and sample standard deviation for each element within cropping system and year was used to summarize results.

Use of Chemical Precipitation and Coagulation Techniques

The use of chemical precipitation and coagulation techniques were investigated for the objective of reducing TP in mined-lands runoff waters. Three compounds were used: ferric chloride, ferric sulfate, and alum. After dosing, each compound acidified treatment waters. Calcium carbonate was used to readjust pH to initial water conditions (pH 7.2-8.0). The precipitant and coagulant compounds were allowed to settle by gravity and turbidities were measured. Total P and calcium were measured from water samples after settling.

LARGE FIELD MACROBED EXPERIMENT FINDINGS

Results of the Mehlich-3 extraction of soil samples (grid sampling, Table 1) revealed that there were no differences ($P>0.05$) between the samples in the two macrobeds. All samples were very high in Ca, Mg, K, and P. This uniformity was expected due to the use of this land for vegetable and agronomic crop production during the Polk County Mined Lands Agricultural Research and Demonstration Project (1985 through 1995). The high native fertility of the phosphatic clay is obvious.

Table 1. Results of Soil pH (1:2 Water) and Mehlich-3 Soil Tests from the Macrobed Grid Sampling.

Bermudagrass Macrobed					
	pH	Ca	Mg	K	P
		Ppm in the soil			
Mean	8.07	6059	2823	368	605
Std Dev[1]	0.06	196	111	45	48
Corn Macrobed					
	pH	Ca	Mg	K	P
		Ppm in the soil			
Mean	8.09	6060	2900	363	516
Std Dev	0.02	96	84	36	49

[1] Std Dev is the standard deviation of the 30 observations.

AGRONOMIC DATA

The first crop of corn was harvested in the middle of October, 1996. Wheat was planted in rotation with the corn on December 13, 1996. On April 11, 1997, wheat was harvested with the stover removed down to 3 inches. On June 4, 1997, the second crop of corn was planted. The second crop of corn was harvested in the middle of September, 1997. Respective yields are presented in Table 2.

Table 2. Corn and Wheat Yields Adjusted for Moisture (12%) from 5 Subplots. Stover is Reported on an Oven-Dry Weight Basis.

Crop	Subplot number	Stover (lb/ac)	Yield (bu/ac)
Corn 96	1	7,275	65
	2	5,807	62
	3	5,762	49
	4	6,013	77
	5	5,989	65
	Mean	6,169	64
Wheat 96/97	1	1,472	61
	2	1,481	59
	3	1,660	59
	4	1,043	60
	5	1,087	59
	Mean	1,349	60
Corn 97	1	6,219	45
	2	9,231	55
	3	6,638	43
	4	6,461	68
	5	7,797	66
	Mean	7,269	55

SEDIMENT ACCUMULATION IN THE POND

Twenty metal posts, placed throughout the pond in a grid fashion, were also used for monitoring of temporal changes in sediment accumulation in the pond. The elevations were taken at the beginning of the project in 1996 and at the end of 1997. Mean accumulation of sediment was 0.05 ft (0.6 inch).

WATER QUALITY

The Bermudagrass field had only three runoff events (Table 3). The first two events are temporally related. The second runoff event containing elevated concentrations of sediment and nutrients compared to the first event. Normally, a complete grass cover is quite stable and resists runoff or sediment transport. However, the soil surface was wetted completely by the July 14, 1997, event, directly affecting the runoff on July 16, 1997. Both unfiltered and filtered Total Kjeldahl Nitrogen (TKN-u, TKN-f) is quite low, as are ammoniacal- and nitrate-N concentrations. However, Soluble Reactive Phosphorus (SRP), Total Soluble Phosphorus (TSP), and Total Phosphorus (TP) reflect changes in sediment concentration with time. While the TSP and TP values agree with the proposed fractionation described previously, the SRP appears to over-estimate this portion due to the turbidity of the samples.

As expected, there were additional runoff events from the cornfield (Table 4). The literature reports significantly more runoff and sediment from corn, compared to grass surfaces. While all measures of N were low, measures of sediment and P were twice to more than 6 times higher than that found in runoff from the bermudagrass field.

Design of the surface drainage system (1.5 to 2 % slopes with approximately 30-m slope lengths), so-called macrobeds, has allowed considerable retention of precipitation. Evidence from small plot research (D. Gao, M.S. Thesis 1996) showed that precipitation events must exceed 50 mm before runoff occurs. This design also provided sufficient soil moisture for both the corn-wheat rotation and bermudagrass growth. Corn and wheat yields during this experiment are typical for production on phosphatic clay (MLAR/DP final report 1997). Yields are low compared to commercial production on undisturbed soils. However, input costs are considerably lower due to better N use efficiency and the inherent fertility of phosphatic clay compared to sandy soils in Florida.

Runoff from both the bermudagrass and corn/wheat rotation fields supplemented by additional runoff from adjacent phosphatic clay was sampled at the entrance to the stilling pond (Table 5). The conveyance ditch had a vegetative cover, mostly of Bermudagrass and weeds. However, the 1 to 2% slope of the channel was not expected to affect water quality. Only three measurable runoff events occurred at the inlet point to the stilling pond. As expected, the observed sediment and P fractions represent a composite of the concentrations reported on those dates for both fields (Table 3 and Table 4).

Table 3. Analyses of Runoff Water from Bermuda Grass Field, Bartow, FL, 1997, by Date.

		Sediment				SRP				TSP				TP			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
14-Jul-97	7	83.4	27.5	128.0	59.0	6.7	1.4	8.9	5.1	4.2	1.0	5.9	3.2	5.7	1.7	8.0	4.0
16-Jul-97	15	106.3	108.1	465.0	0.0	10.5	14.5	58.8	0.0	4.7	4.8	20.8	0.0	5.9	6.0	26.0	0.0
8-Aug-97	5	52.8	41.0	123.0	20.0	4.1	2.0	7.5	2.4	3.1	1.6	5.7	1.6	3.6	2.1	7.0	2.0

		TKN-f				Ammonium-N				Nitrate-N				TKN-u			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
14-Jul-97	7	1.7	2.5	7.3	0.7	0.2	0.1	0.4	0.0	0.8	0.3	1.3	0.5	1.8	0.6	3.1	1.4
16-Jul-97	15	0.4	0.2	1.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.5	0.0	1.3	0.8	3.7	0.3
8-Aug-97	5	0.6	0.1	0.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.4	2.1	1.0

Table 4. Analyses of Runoff Water from the Cornfield, Bartow, FL, 1997, by Date.

		Sediment				SRP				TSP				TP			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
7-Jul-97[1]	18	30.3	128.5	545.0	0.0	0.0	0.0	0.0	0.0								
14-Jul-97	6	218.7	294.0	706.0	0.0	16.5	17.1	35.1	0.0	12.9	13.6	28.4	0.1	17.3	18.6	40.0	0.0
16-Jul-97	8	698.0	325.5	1071.0	0.0	29.0	12.2	38.8	0.0	27.8	12.9	42.4	0.1	38.0	18.0	60.0	0.0
8-Aug-97	9	64.9	40.7	153.0	30.0	4.9	2.1	9.3	2.9	3.7	1.8	7.6	2.1	4.6	2.4	10.0	3.0
30-Sep-97	11	75.5	72.8	284.0	19.0	7.2	9.6	33.0	0.8	3.5	3.5	13.5	0.6	4.6	4.3	17.0	2.0

		TKN-f				Ammonium-N				Nitrate-N				TKN-u			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
7-Jul-97	18					0.2	0.1	0.5	0.0	0.8	0.7	2.3	0.0				
14-Jul-97	6	0.7	0.3	1.0	0.3	0.2	0.2	0.4	0.0	0.8	0.8	1.5	0.0	1.7	1.3	3.1	0.0
16-Jul-97	8	0.4	0.3	1.0	0.0	0.1	0.1	0.2	0.0	0.8	0.4	1.3	0.0	2.0	1.1	3.4	0.0
8-Aug-97	9	0.4	0.6	2.0	0.0	0.1	0.3	0.8	0.0	0.0	0.0	0.0	0.0	3.2	5.1	16.8	0.7
30-Sep-97	11	1.3	0.5	2.5	0.8	0.9	0.3	1.2	0.4	1.4	0.7	2.5	0.5	1.9	0.3	2.3	1.5

[1] Not all tests were completed due to low sample volumes.

Table 5. Analyses of Runoff Water at the Pond Inlet, Bartow, FL, 1997, by Date.

		Sediment				SRP				TSP				TP			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
7-Jul-97	9	27.2	81.7	245.0	0.0	0.0	0.0	0.0	0.0								
14-Jul-97	1	188.0	NA	188.0	188.0	11.7	NA	11.7	11.7	7.8	NA	7.8	7.8	11.0	NA	11.0	11.0
16-Jul-97	5	161.2	104.4	284.0	6.0	12.5	10.3	29.0	1.6	10.4	9.7	26.4	0.6	13.6	12.4	34.0	1.0

		TKN-f				Ammonium-N				Nitrate-N				TKN-u			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
7-Jul-97	9					0.0	0.1	0.4	0.0	0.2	0.1	0.2	0.0				
14-Jul-97	1	1.0	NA	1.0	1.0	0.2	NA	0.2	0.2	0.0	NA	0.0	0.0	1.4	NA	1.4	1.4
16-Jul-97	5	0.4	0.2	0.7	0.3	0.0	0.0	0.0	0.0	0.4	0.2	0.5	0.0	1.1	0.3	1.5	0.8

Table 6. Analyses of Discharge Water from Pond, Bartow, FL, 1997, by Date.

		Sediment				SRP				TSP				TP			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
14-Jul-97	10	322.6	159.0	538.0	0.0	18.5	7.7	27.4	0.0	14.3	6.8	22.8	0.0	18.5	8.9	30.0	0.0
16-Jul-97	17	292.4	102.8	460.0	115.0	15.1	4.7	22.3	6.7	12.7	4.5	20.3	5.1	16.1	5.6	26.0	7.0
8-Aug-97	2	63.0	73.5	115.0	11.0	4.2	4.6	7.4	0.9	2.9	3.4	5.3	0.5	3.0	4.2	6.0	0.0

		TKN-f				Ammonium-N				Nitrate-N				TKN-u			
Date	Obs.	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min	Mean	Std.	Max	Min
14-Jul-97	10	0.8	0.3	1.3	0.3	0.3	0.2	0.5	0.0	0.4	0.2	0.5	0.0	2.0	1.5	5.1	0.0
16-Jul-97	17	0.4	0.2	0.7	0.3	0.1	0.1	0.4	0.0	0.1	0.2	0.5	0.0	1.5	1.9	8.8	1.0
8-Aug-97	2	0.3	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.4	1.2	0.7

MODELING RUNOFF FROM LARGE MACROBEDS

The data set collected from the research sites for bermudagrass, corn/wheat rotation, inlet to pond and outlet from pond covered a period of time from June 1997 through September 1997. Very short time of data collection (4 months), limited number of rain events with runoff, and some unexpected problems with the instrumentation caused periods of missing or unreliable data during this time. An attempt was made to validate the GLEAMS model for clay settling areas used for agricultural production using the data for this time period. Although the data collected were not sufficient to say that the results are statistically sound, some trends found for the modeling effort are noted below.

Bermudagrass Macrobed

The data set obtained from the macrobed planted in bermudagrass seemed to be the most complete and the best for the GLEAMS modeling effort. On this type of soils a significantly reduced antecedent moisture Condition I curve number can be expected due to cracking and swelling properties. The clay settling area cracks during dry periods which raises the initial abstraction prior to runoff. Abstraction is usually defined as all losses before runoff begins. Abstraction is highly variable but generally is correlated with soil and cover parameters. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. As an example, on July 5, 1997, a rainfall of 1.47 inches produced only a 0.03 inch runoff. GLEAMS predicted a 0.29 inch runoff using a curve number of 86. On the following day, a 2.99 inch rainfall produced a 1.76 inch runoff, whereas GLEAMS predicted a 1.64 inch runoff. On the first day of rain, runoff water collects in the cracks and runoff is less than expected. On the following day, the clay is swelling shut and the storage in the cracks has been filled, thus runoff is at expected levels. GLEAMS does not model this initial abstraction on high shrink-swell clay soils. Care should be taken to include the initial moisture condition of the soils when modeling runoff.

Although individual runoff events are sometimes not well predicted by the model, due to shrink-swell proprieties of the soil, the model is much better predicting the overall runoff during the season. For the total period of data collection, from June 18, 1997, through August 8, 1997, the measured runoff was 3.24 inches and the GLEAMS predicted runoff was 3.31 inches. The graph of measured runoff versus GLEAMS predicted runoff shows that the daily-modeled runoff was not as close as the summed values for this period suggest.

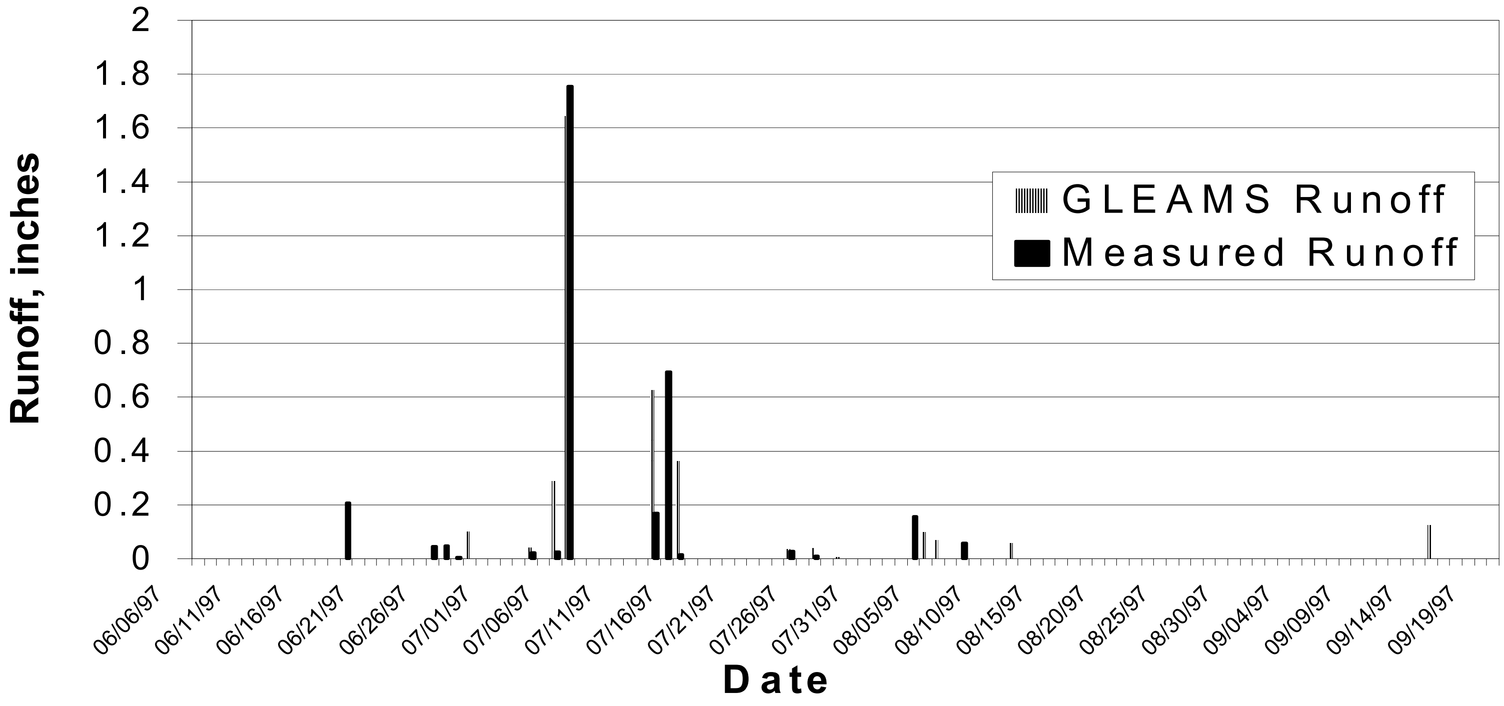


Figure 13. Predicted and Observed Runoff from Macrobed Planted in Bermudagrass.

Sediment yields for the bermudagrass covered bed were only measured and analyzed for three dates. On all three dates the measured sediment yield was larger than the sediment yield predicted by GLEAMS. The data are presented in Figure 14. On the only other date with sediment yield data, GLEAMS did not predict any runoff. Some other sediment data were taken, but the results were averaged across several days.

Nutrient data for these same dates were compared with predicted values from the GLEAMS model. The parameters compared were phosphate (PO_4), nitrate (NO_3), and ammonium (NH_4).

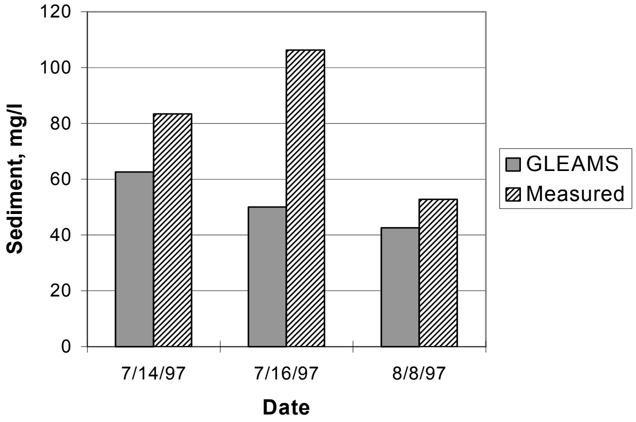


Figure 14. Predicted and Observed Sediment Concentration from Macrobed Planted in Bermudagrass.

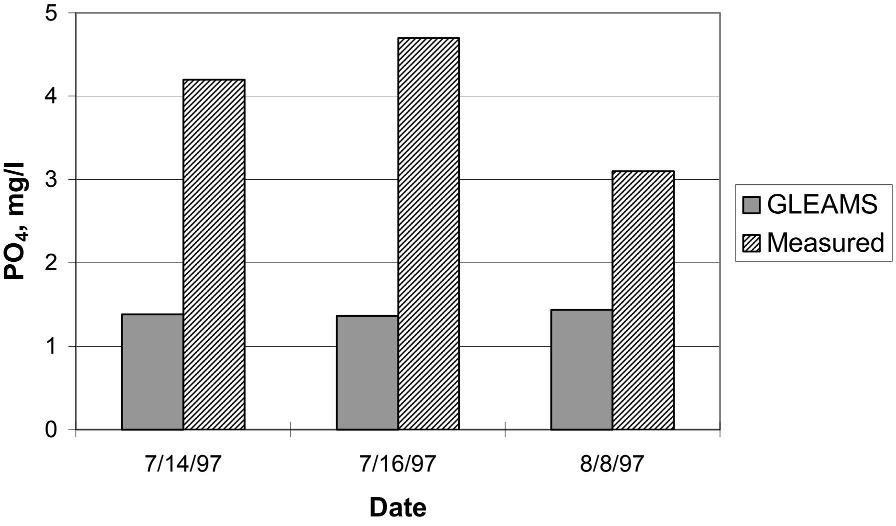


Figure 15. Predicted and Observed Phosphate (PO_4) from Macrobed Planted in Bermudagrass.

Figure 15 presents the results of phosphate (PO_4) analysis and modeling predictions. In all three events, the measured levels of PO_4 were higher than GLEAMS predicted values. As can be expected, PO_4 was mostly attached to the sediment particles (Figure 16). The amount of PO_4 was directly proportional to the amount of sediment present in the runoff from both fields.

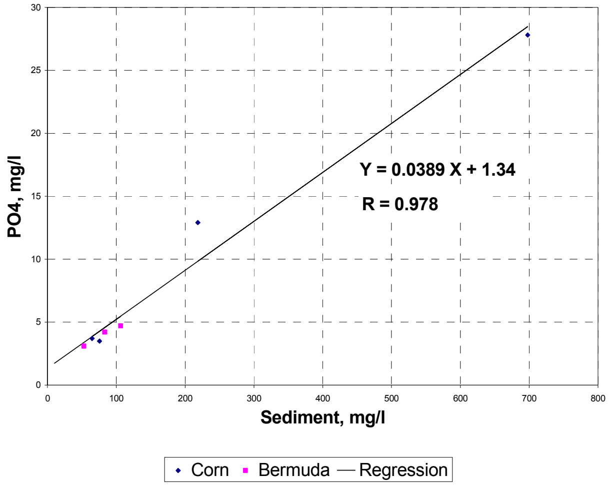


Figure 16. Phosphate Versus Sediment in the Runoff from All Experimental Plots.

Figure 17 presents the results of nitrate (NO_3) analysis in runoff samples and modeling predictions. In this case, GLEAMS predicted concentrations were much higher than concentrations detected in the actual field runoff. This may be due to a model limitation since 1 ppm of NO_3 is the lowest value predicted larger than zero.

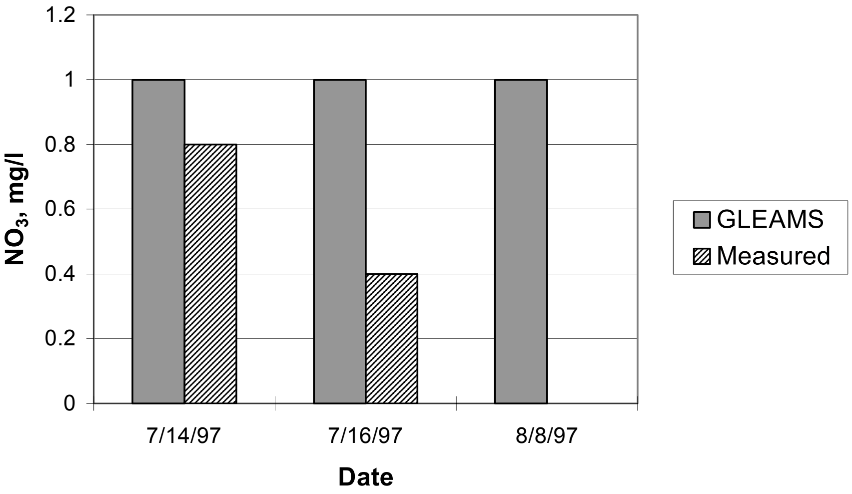


Figure 17. Predicted and Observed Nitrate (NO_3) in the Runoff from the Macrobed Planted in Bermudagrass.

Figure 18 presents the results of ammonium (NH_4) analysis in runoff samples and modeling predictions. Ammonium was detected in the water sample only during one of the runoff events at a very low level (0.2 mg/l). The GLEAMS model did not predict any ammonium in the runoff. The lowest level that can be predicted by the model is 1mg/l.

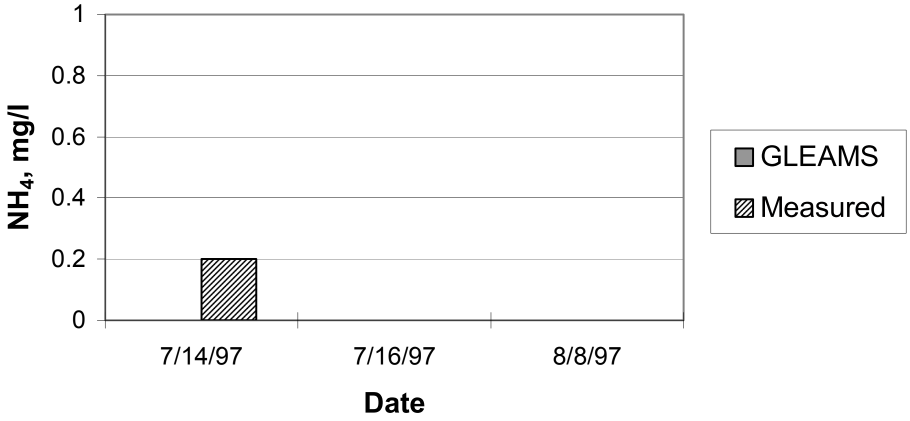


Figure 18. Predicted and Observed Ammonium (NH_4) in the Runoff from the Macrobed Planted in Bermudagrass.

Corn/Wheat Macrobed

This data set had several inconsistencies. There were two days when runoff was measured and rainfall was not. This type of error could be caused by instrument drift, debris being blown into the flume and giving a false reading, or instrument setup error. We attempted to account for this type of error, but the presence of this type of error leaves doubt as to the accuracy of the measured data on those dates. The graph of measured runoff vs. GLEAMS predicted runoff is shown below (Figure 19).

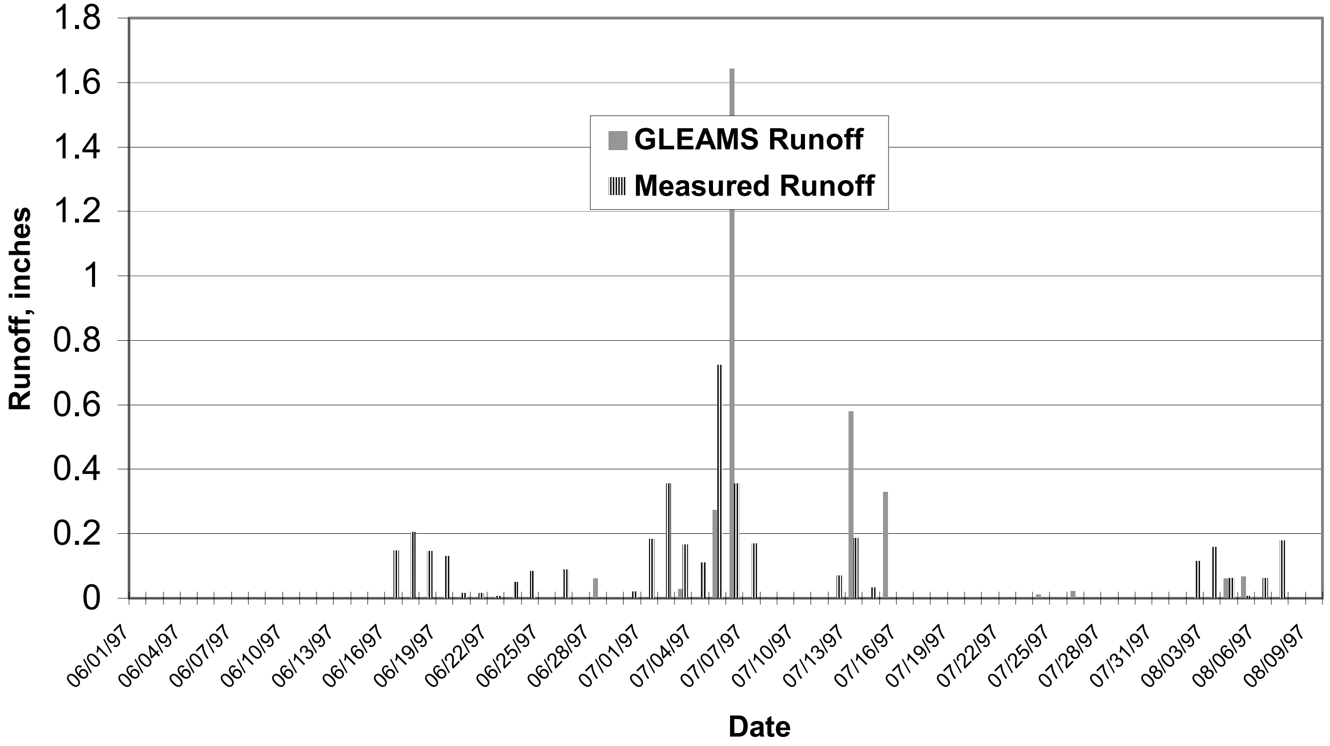
The GLEAMS runoff prediction was much higher, especially when rain events were closely spaced in time. Small rain events that followed longer dry periods (for example between July 19 and August 8) resulted in predicted runoff much lower than the measured runoff. It is unclear if this was caused by measurement error, modeling error, or initial abstraction estimation error. It may also be a function of rain intensity.

Sediment concentration in the runoff water was measured for five events during the summer of 1997 and compared to GLEAMS-predicted sediment concentrations (Figure 20). Out of five events, in three cases the model predicted higher sediment concentrations than those measured in the actual runoff. On July 16, the actual sediment was more than seven times greater than predicted. This event closely followed the event on July 14 and the soil was saturated and without cracks.

The three events with lower actual sediment concentrations were spaced farther apart in time. It can be speculated that some sediment was caught in the cracks and the runoff did not carry as many particles. The other possibility is that expanded, wet clay particles move easier. Further research would be necessary to investigate these hypotheses.

Nutrient data for these same dates were compared with predicted values by GLEAMS. The parameters compared were phosphate (PO_4), nitrate (NO_3), and ammonium (NH_4). The data are presented in Figures 21, 22, and 23 respectively. With the exception of the first measured event, all measured PO_4 concentrations were higher than the values predicted by GLEAMS model. On July 16, when sediment concentration was above the predicted value, the measured phosphate was also much higher than the predicted value as can be expected. Differences in soluble P between predicted and observed values can be traced back to weakness of the soluble nutrient components in the nutrient sub-model as acknowledged by the model developers (Frere and others 1980).

Figure 19. Predicted and Observed Runoff from Macrobed Planted with Corn/Wheat.



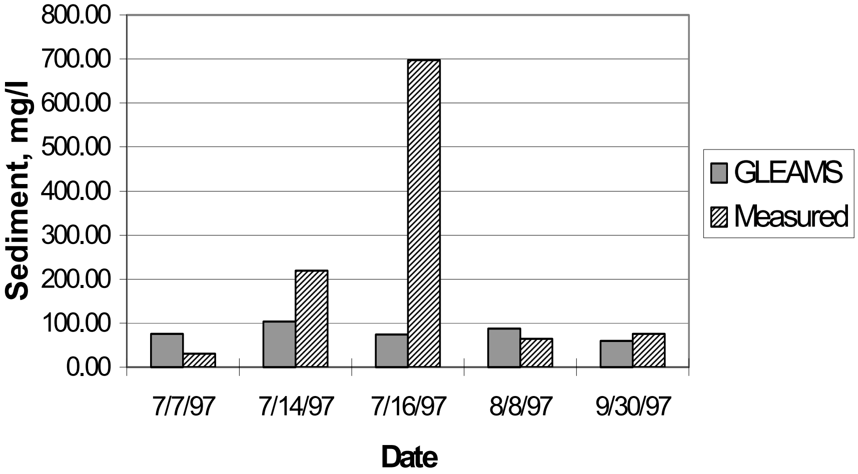


Figure 20. Predicted and Observed Sediment Concentrations from Macrobed Planted in Corn/Wheat.

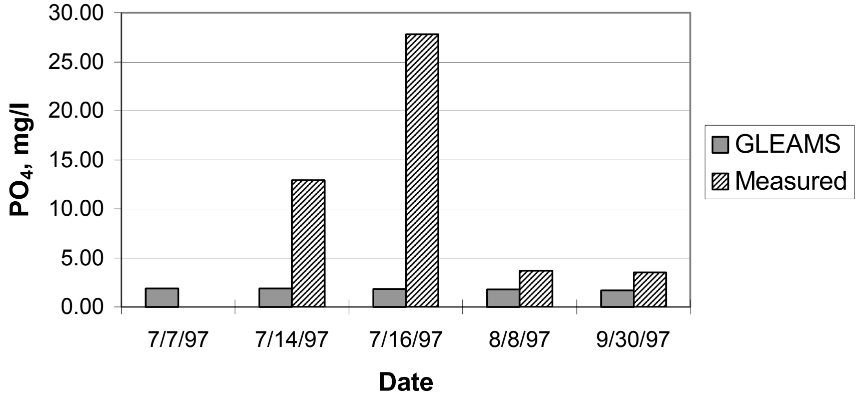


Figure 21. Predicted and Observed Phosphate (PO_4) Concentrations from Macrobed Planted in Corn/Wheat.

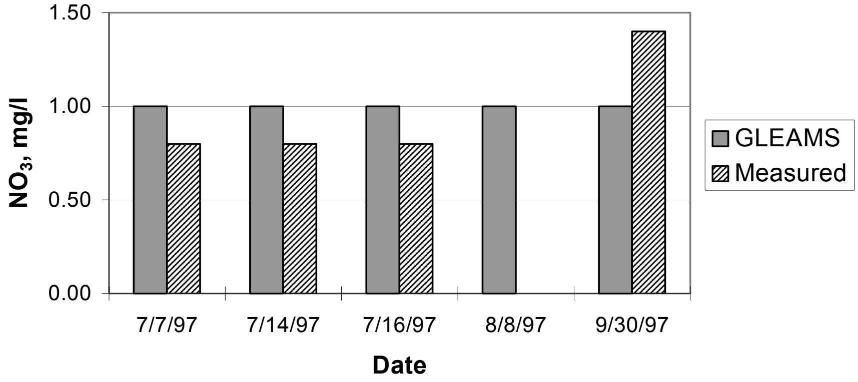


Figure 22. Predicted and Observed Nitrate (NO_3) Concentrations in the Runoff from the Macrobed Planted in Corn/Wheat.

The predicted values for nitrate (NO_3) concentrations in the runoff from corn/wheat covered macrobed were very close to the concentrations measured at the field (Figure 22). The model predicts concentrations to the nearest mg/liter (ppm). As a result, the concentrations predicted are 1 mg/l. These results are consistent with those for the bermudagrass-covered macrobed.

For the corn/wheat macrobed, the predicted concentrations of ammonium (NH_4) were much higher than the values detected in the runoff from the field, with the exception of the last event on September 30, when the observed concentration was higher than on any other event.

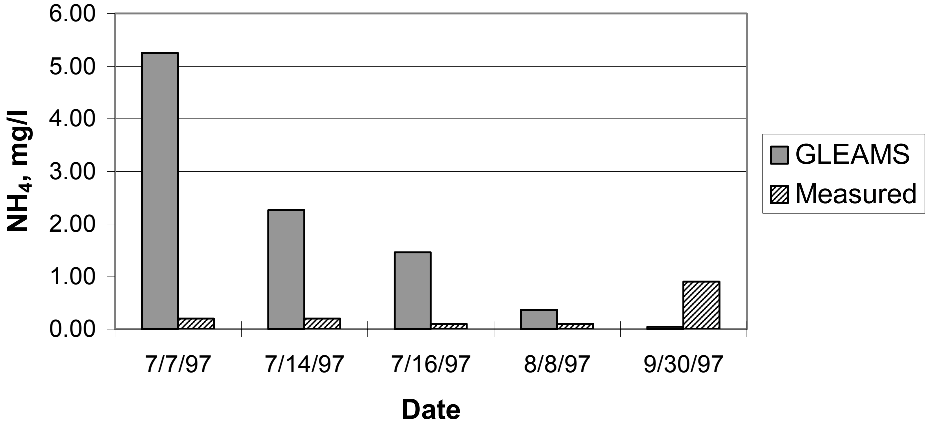


Figure 23. Predicted and Observed Ammonium (NH_4) Concentrations in the Runoff from the Macrobed Planted in Corn/Wheat.

Pond

GLEAMS can only model one homogenous land-use with up to two channels and a pond. Since the research site has two different land use types (bermudagrass and corn/wheat rotation), GLEAMS could not directly model the pond outflow. An analysis of the water budget was expected to show that the volume of runoff for the bermudagrass and corn/wheat added together would approximate the amount of water flowing into the settling pond. The outflow from the pond was affected by pond size and was not a direct function of the inflow. Figure 24 presents all the components of this flow budget. The outflow from the pond is indicated in the lighter gray dotted line.

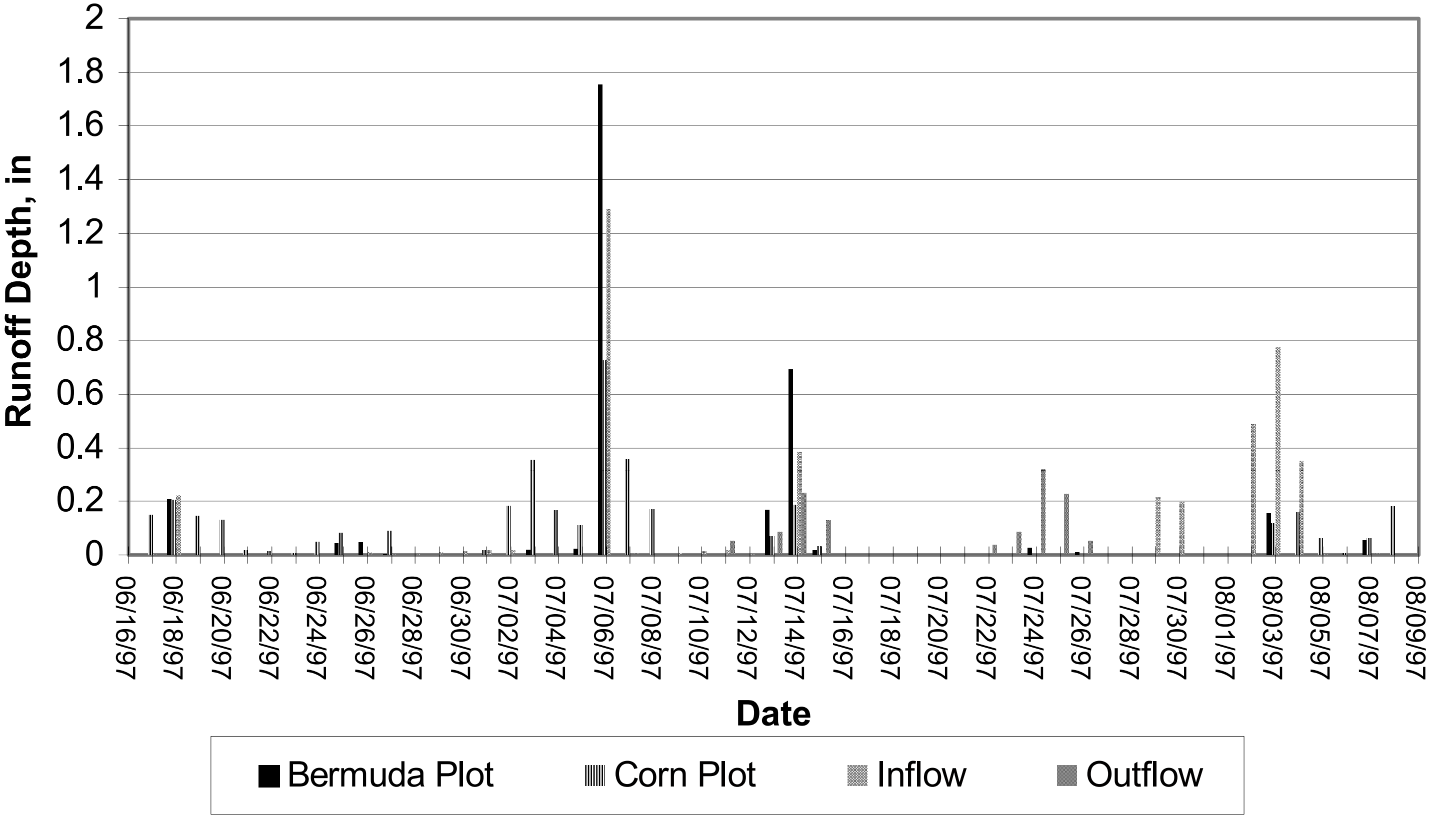


Figure 24. Measured Runoff from Both Macrobeds and Inflow and Outflow of the Pond.

CHEMICAL TREATMENT OF SUSPENDED CLAY SOLIDS IN MINED-LANDS RUNOFF WATERS

The use of chemical precipitation and coagulation techniques were investigated for the objective of reducing total phosphorus (TP) in runoff waters from a reclaimed clay settling area used for agriculture. Three compounds were used: ferric chloride, ferric sulfate, and alum. After dosing, each compound acidified treatment waters. Calcium carbonate was used to readjust pH to initial water conditions (pH 7.2-8.0). The precipitant and coagulant compounds were allowed to settle by gravity and turbidities were measured (see Figure 25). Total P and calcium were measured from water samples after settling.

In all cases TP was reduced below 1 ppm. All compounds were effective in TP removal below 1 ppm using basic chemical techniques. Preliminary results indicated that alum was more efficient in TP removal than either ferric source. The treatment protocols did not affect pH nor calcium concentrations in the waters. Settling times (gravitational) of 30 minutes or less were generally suitable for visual removal of suspended solids. Greater settling times further improved solids removal.

The particle size distribution was calculated as mean, median, and mode. The mean represents the arithmetical mean particle diameter in the entire distribution in the size range 0.1-900 µm. The median is defined as the particle diameter at which half of the distribution (50% percentile value) is larger and half is smaller. The mode is defined as the particle size that occupies the most volume in the distribution. Results are presented as volume percentages, which give a good interpretation of the space occupied by particles. Median data is often used to describe particle size distribution.

Suspended clay solids in clay settling area runoff waters contain high concentrations of phosphorus (P). Measurements of the turbidity (NTU) and particle size (mean or median) allow reasonable certainty in determining total P (TP):

$$\text{TP} = (0.197 \times \text{NTU} \times \text{Mean}) - (0.170 \times \text{NTU} \times \text{Median})$$

with 0.97 R^2 (R - linear correlation coefficient).

Turbidities of runoff samples ranged from 102 to 516 NTU. Mean particle sizes ranged from 0.846 to 2.945 µm and the median particle sizes ranged from 0.533 to 2.585 µm. Total phosphorus concentrations in these waters ranged from 9 to 56 ppm. These suspended clay solids in runoff waters, should they be released from impoundment basins, would be an environmental concern. For example, South Florida Water Management District established the Average Annual Concentration of Total P at the inflow structures to Lake Okeechobee not to exceed 0.18 mg/l (Lake Okeechobee SWIM Plan).

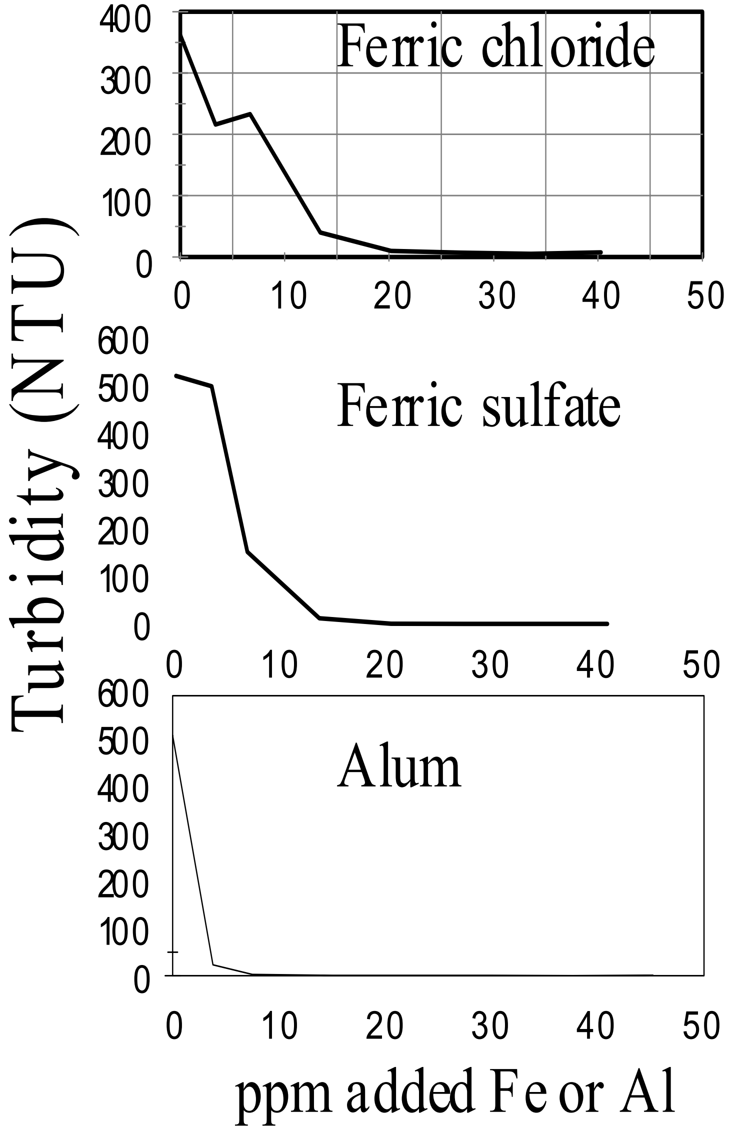


Figure 25. Turbidity Levels after Chemical Treatment.

SOIL PARTICLE SIZE AND DISTRIBUTION AT THE EXPERIMENTAL SITE

Objective

The objective was to determine the particle size and texture distribution of soils and sediments found in the growing areas and over-flow pond. Variations in particle size and texture may indicate the level or type of particle transport in the reclamation project.

Materials and Methods

Sixty soil core composites (5-6 cores, 0-6 inches deep) within the cropped reclamation project and twenty soil core composites within the over-flow pond were grid sampled. Samples (approximately 1000 g) were kept in field moisture conditions in plastic bags and sent to the laboratory within 72 hours.

In the laboratory, sub-samples of each core composite (approximately 400 g) were saturated with water and stirred until each sample had a liquefied paste consistency. This sample was used for particle size analysis. Particle size analysis was made on each sample in duplicate or until consistency in results (5%) was obtained.

1. The Coulter LS 130 particle sizing device was initialized and operated according to operating instructions (Coulter Corporation, 1994). The Fraunhofer model was used to calculate the particle size distribution (0.1 to 900 µm).

2. Prior to analyzing the samples, a control with a known particle size distribution (Alcoa silica material) was analyzed every 10th sample to verify the consistency of the instrument. A blank (distilled water without sample) was included in each batch run to insure instrument "zeroing." All samples were duplicated and checked for consistency in results. If sample result variation in particle size fraction differed by more than 5%, the samples were rerun.

3. All samples were run in the same manner as the control. Each sub-sample was blended to be a representative sample. Obscurations between 45 and 55 % were used for each run, with a target obscuration count of 50%. If the obscuration was too low, additional sample was added. If the obscuration was too high, the sample was diluted by adding distilled water to the Coulter chamber.

The plastic bagged samples (approximately 600 g each) and moist prepared sub-samples (250 ml vials) were frozen (-13°C) for storage. Moist sub-samples used for particle size analysis were composited for further testing and placed in storage (3°C).

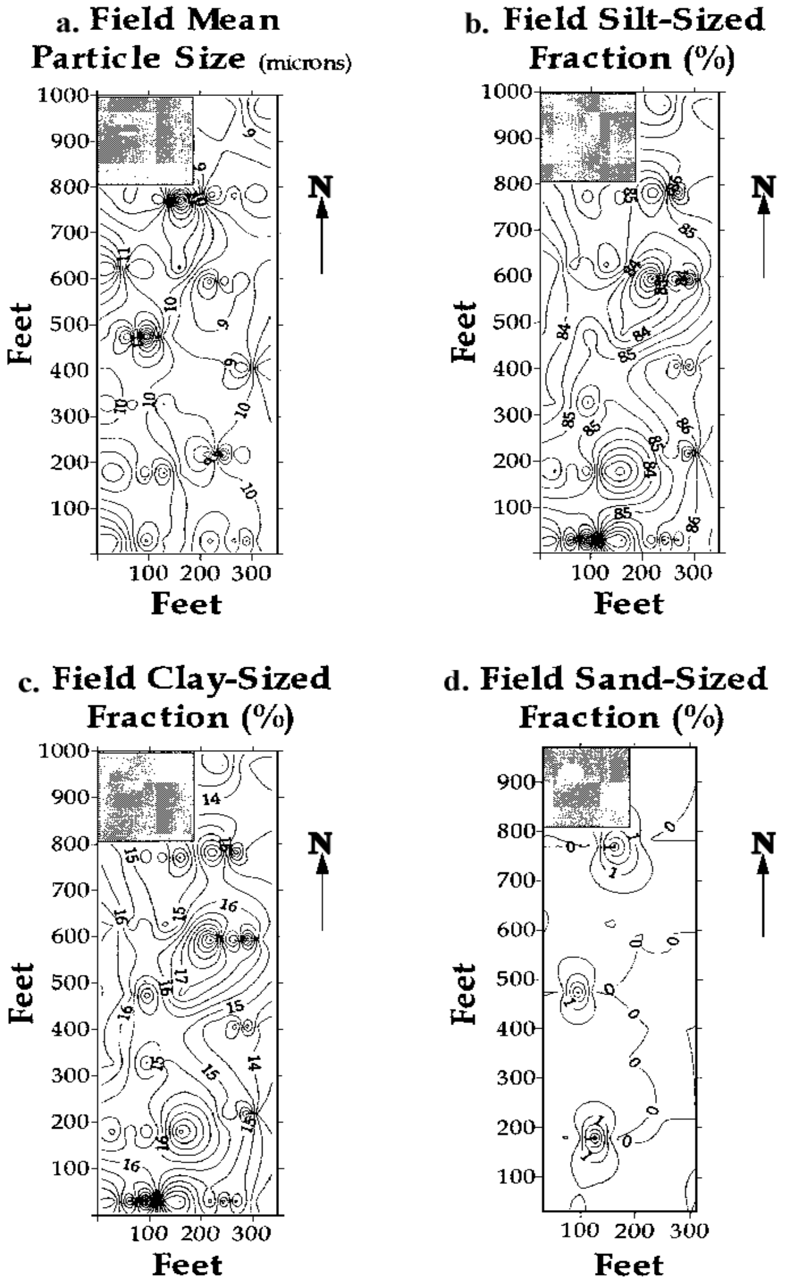
Reclamation Growing Area

The average soil particle size across the growing area was 9.3 microns. The clay content was 14.7%; the silt content was 85.1%; and there was only 0.2% sand. The smallest mean particle sizes (Figure 26a) only ranged from 6 to 12 microns, but overall were relatively uniform. Particle size distributions for sand, silts, and clays were also relatively uniform across the growing area.

Reclamation Overflow Pond

The average soil particle size across the over-flow pond was 11 microns. The clay content was 12.3%; the silt content was 87.1%; and there was only 0.6% sand. The smallest mean particle sizes (Figure 27a) observed in the over-flow pond were found at the end of the pond flow stream, where settling of clay sized particles occur more commonly. Higher silt and clay-sized fractions were found in these areas (Figures 27b and 27c). This was apparent in Figure 27d, which shows higher sand deposits where flows enter the pond. The larger particles settle faster and are thus found nearer to the inflow.

Runoff overflow ponds are currently used to capture sediments and nutrients. However, channeling within these ponds may lead to very short residence times, too short to remove P-bound sediments by gravity alone. The use of ferric compounds or alum to precipitate and coagulate solids and soluble phosphorus has merit if the over-flow ponds discharge waters to the outside.


a. Field Mean Particle Size (microns)

b. Field Silt-Sized Fraction (%)

c. Field Clay-Sized Fraction (%)

d. Field Sand-Sized Fraction (%)

Figure 26. a. Mean Particle Size, b. Silt (2-64 μm) Content, c. Clay (0-2 μm) Content, and d. Sand(>64 μm) Content of Sediments in the Reclamation Growing Area.

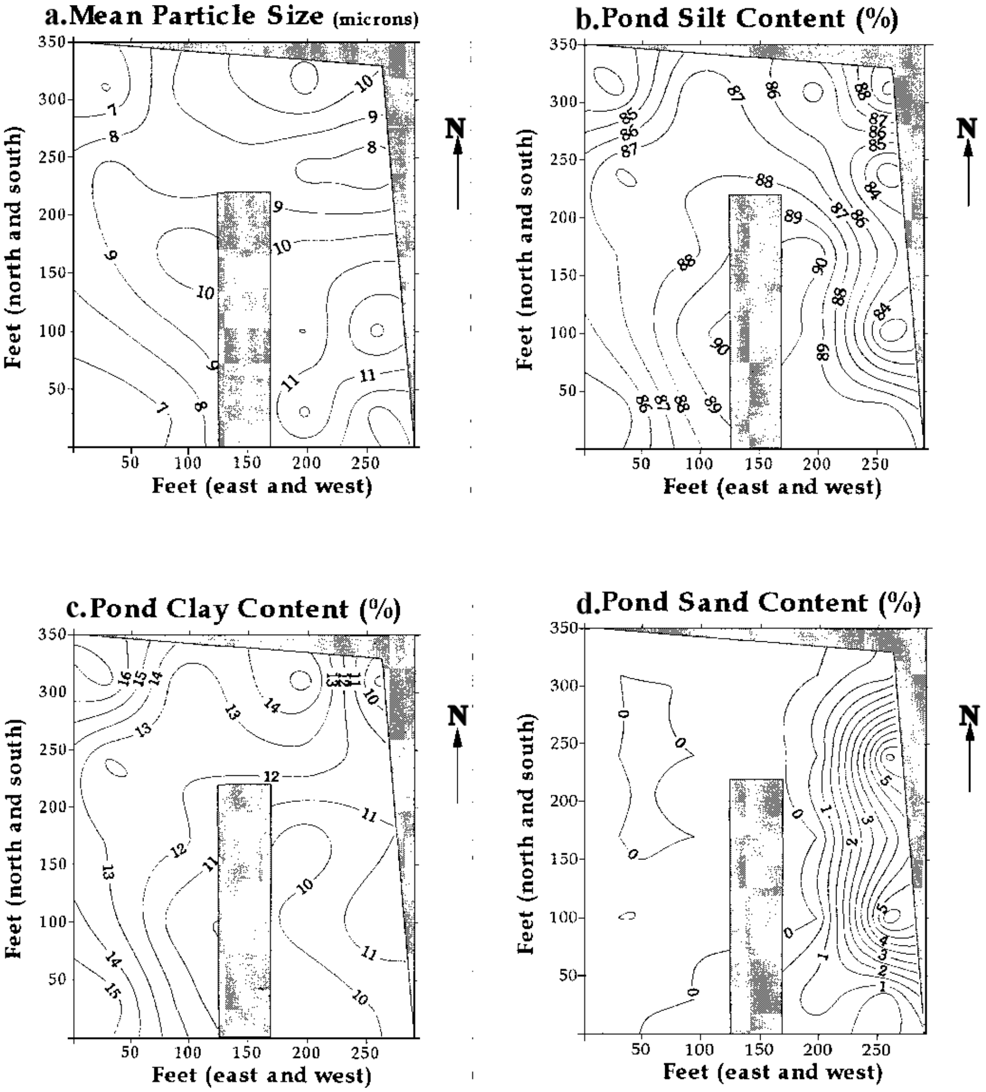


Figure 27. a. Mean Particle Size, b. Silt (2-64 μm) Content, c. Clay (0-2 μm) Content, and d. Sand (>64 μm) Content of Sediments in the Over-flow Pond.

CONCLUSIONS/RECOMMENDATIONS

The macrobed design worked well to permit intensive cropping (corn/wheat rotation) or pasture production (bermudagrass), and harvest most rainfall events for plant use.

While numerous precipitation events occurred in both years, most water was retained on site (no runoff).

Crop growth and yield were consistent with previous production on phosphatic clay, indicating that water supply was adequate.

When a runoff event occurred, N forms were below regulatory concern, and demonstrated that use of UF-IFAS fertilization recommendations will result in little loss of N from phosphatic clay.

When a runoff event occurred, both sediment and TP were of environmental concern.

Sediment and TP from the corn/wheat rotation field was higher than that from the bermudagrass field.

The corn/wheat rotation field produced more runoff events that the bermudagrass field.

The stilling pond provided little retention, and did nothing for water quality improvement, as operated.

Retention time was too short to permit natural settling. Chemical treatment is likely to improve water quality for subsequent discharge. Alum was the most effective coagulant chemical. The data indicate that small chemical additions of alum will remove >99% of the total P in the system. Field scale research on chemical treatment should be considered.

Pond design and operation should be explored for maximum improvement of water quality of runoff from phosphatic clay. Pond designs could be improved to reduce in-site channeling, and increase the pathlength for greater sedimentation and greater residence times. More research on various pond designs and their effectiveness in sediment removal is recommended.

This project focused on the agricultural aspects. Because of good landform design and proven crop production techniques upstream of the pond, runoff events were relatively few and low in volume. These conditions precluded exploration of pond management for improved water quality.

Findings related to water quality in the large field trial were consistent with the findings of small plot research conducted earlier.

REFERENCES

Agassi M, Shainberg I, Warrington D, Ben-Hur M. 1989. Runoff and erosion control in potato fields. Soil Science 148(2):149-154.

Ahuja LR, Sharpley AN, Lehman OR. 1982. Effect of soil slope and rainfall characteristics on phosphorus in runoff model. J. Environ. Qual. 11(1):9-13.

Alberts EE, Neibling WH, Moldenhaner WC. 1981. Transport of sediment nitrogen and phosphorus in runoff through cornstalk residue strips. Soil Sci. Soc. Am. J. 45:1177-1184.

Andraski BJ, Mueller DH, Daniel TC. 1985. Phosphorus losses in runoff as affected by tillage. Soil Sci. Soc. Am. J. 49:1523-1527.

Angle JS, McClung G, McIntoch MS, Thomas PM, Wolf DC. 1984. Nutrient losses in runoff from conventional and no-till corn watersheds. J. Environ. Qual. 13(3):431-435.

Ardaman & Associates, Inc. 1982. Evaluation of phosphatic clay disposal and reclamation methods, Volume 1: Index properties of phosphatic clays. Final Report, Research Project FIPR 80-02-002. FIPR Publication Nr 02-002-003. Bartow (FL): Florida Institute of Phosphate Research.

Baker JL, Laflen JM. 1982. Effect of corn residue and fertilizer management on soluble nutrient runoff losses. Trans. ASAE 25:344-348.

Baltensperger DD, Prine GM, Wofford DS. 1989. Phosphate settling pond clays as potential forage legume seed production site. In: Proceedings XVI International Grasslands Congress, Nice, France. p 1627-1628.

Barisas SG, Baker JL, Johnson HP, Laflen JM. 1978. Effects of tillage systems on runoff losses of nutrients, a rainfall simulation study. Trans. ASAE 21:893-897.

Barnett AP. 1965. Using perennial grasses and legumes to control runoff and erosion. J. Soil and Water Conservation. 20:212-215.

Barnett AP, Carreker JR, Abruna F, Jackson WA, Dooley AE, Holladay JH. 1972. Soil and nutrient losses in runoff with selected cropping treatments on tropical soils. Agron. J. 64:391-395.

Bingner RL, Murphree CE, Mutchler CK. 1989. Comparison of sediment yield models on watersheds in Mississippi. Transactions of the ASAE 32(2):529-534.

Blake GR. 1965. Bulk density. In: Methods of soil analysis. Black CA, Evans DD, White JL, Ensminger LE, Clark FE, editors. Agronomy nr 9. Madison (WI): American Society of Agronomy.

Bromwell Engineering, Inc. 1982. Physico-chemical properties of Florida phosphatic clays: final report. Publication nr 02-003-020. Bartow (FL): Florida Institute of Phosphate Research.

Burwell RE, Rimmons DR, Holt DF. 1975. Nutrient transport in surface runoff as influenced by soil cover and seasonal periods. Soil Sci. Soc. Amer. Proc. 39:523-528.

Branson FA, Owen JB. Plant cover, runoff, and sediment yield relationships on Mancos shale in western Colorado. Water Resour. Res. 6(3):783-790.

Chichester FW. 1977. Effects of increased fertilizer rates on nitrogen content of runoff and percolate from monolith lysimeters. J. Environ. Qual. 6(2):211-217.

Clesceri LS, Greenberg AE, Trussell RR, editors. 1989. Nitrogen. In: Standard methods for the examination of water and wastewater. New York: American Public Health Assoc. and American Water Works Association. p 4-110, 111

Clesceri LS, Greenberg AE, Trussell RR, editors. 1987. Phosphorus. In: Standard methods for the examination of water and wastewater. New York: American Public Health Association and American Water Works Association, New York. p 437-453

Coleman TL, Eke AU, Bishnoi UR, Sabota C. 1990. Nutrient losses in eroded sediment from a limited-resource farm. Field Crop Research 24:105-117.

Cropps RW, Bates HK. 1993. Effect of cover crops on soil erosion in nursery aisles. J. Environ. Hort. 11(1):5-8.

Dickens PS, Tschantz BA, Minear RA. 1985. Sediment yield and water quality from a steep-slope surface mine spoil. Trans. ASAE 28(6):1838-1845.

Dragoun FJ. 1969. Effect of cultivation and grass on surface runoff. Water Resour. Res. 5(5):1078-1083.

Dunigan EP, Phelan RA, Mondart CL Jr. 1976. Surface runoff losses of fertilizer elements. J. Environ. Qual. 5(3):339-342.

Dunigan EP, Dick RP. 1980. Nutrient and coliform losses in runoff from fertilized and sewage sludge-treated soil. J. Environ. Qual. 9:243-250.

Dunne T, Zhang W, Aubby BF. 1991. Effects of rainfall, vegetation, and microtopography on infiltration and runoff. Water Resour. Res. 27(9):2271-2285.

Edwards LM, Burney JR. 1991. Sediment concentration of interrill runoff under varying soil, ground cover, soil compaction, and freezing regimes. J. Environ. Qual. 20:403-407.

Edwards DR, Daniel TC. 1994. A comparison of runoff quality effects of organic and inorganic fertilizers applied to fescuegrass plots. Water Resour. Bulletin 30(1):35-41.

Emmerich EW, Cox JR. 1994. Changes in surface runoff and sediment production after repeated rangeland burns. Soil Sci. Soc. Am. J. 58:199-203.

Ewing LK. 1989. CREAMS representation for hydrology and sedimentology of central Illinois. Transactions of the ASAE 32(5):1599-1604.

Florida Phosphate Council. 1992. Phosphate feeds you. Lakeland (FL): Florida Phosphate Council.

Frere MH, Ross JD, Lane LJ. 1980. Chapter 4. The nutrient submodel. In: Knisel, WG, editor. CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Department of Agriculture, Conservation Research Report Nr 26, Washington: U.S. Government Printing Office. p 65-87.

Ford D. 1992. Evaluation of the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) Computer Model. SCS file code 460-7. South National Technical Center, Soil Conservation Service, USDA.

Gao D. 1996. Sediment, nitrogen, and phosphorus in runoff from reclaimed phosphatic clay. A thesis. University of Florida, Gainesville, FL 32611.

Gilbertson CB. 1970. The effect of animal density and surface slope on characteristics of runoff, solid wastes and nitrate movement on unpaved beef feedlots. University of Nebraska, Agricultural Experiment Station.

Gilley JE, Finkner SC, Varvel GE. 1986. Runoff and erosion as affected by sorghum and soybean residue. Transactions of the ASAE 29(6):1605-1610.

Grosh JL, Jarrett AR. 1994. Interrill erosion and runoff on very steep slopes. Transactions of the ASAE 37(4):1127-1133.

Gross CM, Angle JS, Welterlen MS. 1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19:663-668.

Gross CM, Angle JS, Hill RL, Welterlen MS. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual. 20:604-607.

Hanlon EA, Gonzalez JG, Bartos JM. 1994. IFAS Extension Soil Testing Laboratory Chemical Procedures and Training Manual. Circular 812. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Hanlon EA, Kananen HW, French EC. 1991. Guidelines for reclaiming phosphatic clay ponds for intensive agricultural uses. Gainesville (FL): Florida Cooperative Extension Service, IFAS, University of Florida. SS-MLR-01. 12 p.

Hanlon EA. 1991. Summary of the proceedings from the national symposium on radionuclides in agricultural products. Mined Lands Agricultural Research/Demonstration Project. Gainesville (FL): Florida Cooperative Extension Service, IFAS, University of Florida. 4 p.

Hanlon EA, editor. 1991. Symposium proceedings of naturally occurring radionuclides in agricultural products. p 317.

Hanlon EA, Hochmuth GJ, Shaw L, Riddle C. 1993. Tillage for vegetable-crop production on phosphatic clays. Mined Lands Agricultural Research/Demonstration Project. Production Guide SS-MLR-4. 6 p.

Hanlon EA, Jerez RA, Stricker JA, editors. 1996. The Mined Lands Agricultural Research and Demonstration Project. Bartow (FL): Florida Institute of Phosphate Research. Pub. nr 03-093-128. p 115.

Hays OE, McCall AG, Bell FG. 1949. Investigations in erosion control and the reclamation of eroded land at the upper Mississippi valley conservation experiment station near LaCrosse, Wisconsin, 1933-1943. USDA Tech. Bull. 973.

Hochmuth GJ, Hanlon EA, Stricker JA. 1987. Crop production on reclaimed phosphate-mined soils in Florida. HortScience 22:189-191.

Hubbard RK, Williams RG, Erdman MD. 1989. Chemical transport from coastal plain soils under simulated rainfall: I. Surface runoff, percolation, nitrate, and phosphate movement. Transactions of the ASAE 32(4):1239-1249.

Jackson WL, Asmussen LE, Hauser EW, White AW. 1973. Nitrate in surface and subsurface flow from a small agricultural watershed. J. Environ. Qual. 2:480-482.

Jamieson CA, Clausen JC. 1988. Test of the CREAMS model on agricultural fields in Vermont. Water Resour. Bull. 24(6):1219-1226.

Jerez RA. 1994. Soil management for vegetable production on reclaimed phosphatic clays. Ph.D. Dissertation. University of Florida, Gainesville, FL 32611

Johnson HP. 1979. Tillage system effects on sediment and nutrients in runoff from small watersheds. J.ASAE 22:1110-1114.

Kilmer VJ, Gilliam JW, Lutz JF, Joyce RT, Eklund CD. 1974. Nutrient losses from fertilized grassed watersheds in western North Carolina. J. Environ. Qual. 3:214-219.

Kissel DE, Richardson CW, Burnett E. 1976. Losses of nitrogen in surface runoff in the blackland prairie of Texas. J. Environ. Qual. 5(3):288-293.

Knisel WG, editor. 1993. GLEAMS: Groundwater loading effects of agricultural management systems (version 2.10). University of Georgia, USDA-ARS, UGA-CPES-BAED Publication Nr 5.

Kramer LA, Meyer LD. 1969. Small amounts of surface mulch reduce soil erosion and runoff velocity. Transactions of the ASAE 12:638-641.

Lal R. 1976. Soil erosion problems on an alfisol in western Nigeria and their control. IITA Monograph 1.

Lane LJ, Ferreira VA. 1980. Sensitivity analysis. In: Knisel WG, editor. CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Department of Agriculture, Conservation Research Report Nr 26. Washington: U.S. Government Printing Office. p 113-158.

Langdale GW, Leonard RA, Fleming WG, Jackson WA. 1979. Nitrogen and chloride movement in small upland piedmont watersheds: II. Nitrogen and chloride transport in runoff. J. Environ. Qual. 8:57-63.

Langdale GW, Perkins HF, Bernett AP, Reardon JC, Willson RL Jr. 1983. Soil and nutrient runoff losses with in-row, chisel-planted soybeans. J. Soil Water Conserv. 38:297-301.

Lui BY, Nearing MA, Risse LM. 1994. Slope gradient effects on soil loss for steep slopes. Trans. ASAE 37(6):1835-1842.

Mah MGC, Douglas LA, Ringrose-Voase AJ. 1992. Effects of crust development and surface slope on erosion by rainfall. Soil Science 154(1):37-43.

McDowell LL, McGregor KC. 1980. Nitrogen and phosphorus losses in runoff from no-till soybeans. Trans. ASAE 23:643-648.

McIsaac GF, Hirschi MC, Mitchell JK. 1991. Nitrogen and phosphorus in eroded sediment from corn and soybean tillage systems. J. Environ. Qual. 20:663-670.

McLeod RV, Hegg RO. 1984. Pasture runoff water quality from application of inorganic and organic nitrogen sources. J. Environ. Qual. 13(1):122-126.

Meek BD, Rechel ER, Carter LM, DeTar WR, Urie AL. 1992. Infiltration rate of a sandy loam soil: effects of traffic, tillage, and plant roots. Soil Sc. Soc. Am. J. 56:908-913.

Milos H, editor. 1980. Erosion and environment, Chapter 3. Pergamon Press.

Mislevy P, Blue WG, Roessler CE. 1989. Productivity of clay tailings from phosphate mining: I. Biomass crops. J. Environ. Qual. 18:95-100.

Moe PG, Mannering JV, Johnson CB. 1967. Loss of fertilizer nitrogen in surface runoff water. Soil Sci. 104:389-394.

Moe PG, Mannering JV, Johnson CB. 1968. A comparison of nitrogen losses from urea and ammonium nitrate in surface runoff water. Soil Sci. 105:428-433.

Morgan RPC, editor. 1986. Soil erosion and conservation. New York: Longman Scientific & Technical, and John Wiley & Sons.

Mostaghimi S, Flagg JM, Dillaha TA, Shanholtz VO. 1988. Phosphorus losses from cropland as affected by tillage system and fertilizer application method. Water Resour. Bull. 24(4):735-742.

Mostaghimi S, Younos TM, Tim US. 1992. Effects of sludge and chemical fertilizer application on runoff water quality. Water Resour. Bulletin 28(3):545-552.

Naslas GD, Miller WW, Gifford GF, Fernandez GCJ. 1994. Effects of soil type, plot condition, and slope on runoff and interrill erosion of two soils in the Lake Tahoe Basin. Water Resour. Bull. 30(2):319-328.

Neal JH. 1938. The effect of the degree of slope and rainfall characteristics on runoff and soil erosion. University of Missouri, College of Agriculture, Agricultural Experiment Station.

Nelson DW. 1973. Losses of fertilizer nutrients in surface runoff. Fert. Solutions 17(3):10-11, 13.

Nicholaichuk W, Read DWL. 1978. Nutrient runoff from fertilized and unfertilized fields in western Canada. J. Environ. Qual. 7(4):542-544.

Olsen SR, Khasawneh FE. 1980. Use and limitations of physical-chemical criteria for assessing the status of phosphorus in soils. Chapter 14. In: Khasawneh FE, Sample EC, Kamprath EJ, editors. The role of phosphorus in agriculture. ASA, CSSA, and SSSA.

Osborn B. 1950. Range cover tames the raindrop-A summary of range cover evaluations. U.S.D.A., SCS, Fort Worth, Texas. mimeo.

Owens LB, Edwards WM, Van Keuren RW. 1989. Sediment and nutrient losses from an unimproved, all-year grazed watershed. J. Environ. Qual. 18:232-238.

Peacock CH, Dudeck AE. 1985. A comparison of sod-type and fertilization during turf establishment. HortScience 20(1):108-109.

Quinn NW, Morgan RPC, Smith AJ. 1980. Simulation of soil erosion induced by human trampling. J. Environmental Management 10:155-165.

Reddy GY, McLean EO, Hoyt GD, Logan TJ. 1978. Effect of soil, cover crop, and nutrient source on amounts and forms of phosphorus movement under simulated rainfall conditions. J. Environ. Qual. 7:50-54.

Rose CW. 1985. Developments in soil erosion and deposition models. In: Stewart BA, editor. Advances in Soil Science 2:1-63. New York: Springer Verlag.

Rudra RP, Dickinson WT, Wall GJ. 1985. Application of the CREAMS model in southern Ontario conditions. Transactions of the ASAE. 28)4):1233-1240.

SAS Institute Inc. 1988. SAS/STAT user's guide (release 6.03 edition). Cary (NC): SAS Institute Inc., Cary, NC.

Schreiber JD, Duffy PD, McClurkin DC. 1976. Dissolved nutrient losses in storm runoff from five southern pine watersheds. J. Environ. Qual. 5(2):201-204.

Schuman GE, Burewell RE, Piest RF, Spomer RG. 1973. Nitrogen losses in surface runoff from agricultural watersheds on Missouri valley loess. J. Environ. Qual. 2(2):299-302.

Schuman GE, Spomer RG, Piest RF. 1973. Phosphorus losses from four agricultural watersheds on Missouri valley loess. Soil Sci. Soc. Amer. Proc. 37:424-427.

Sharpley AN, Jones CA, Gray C, Cole CV. 1984. A simplified soil and plant phosphorus model: Prediction of labile, organic, and sorbed phosphorus. Soil Sci. Soc. Am. J. 48(4):805-809.

Sharpley AN, Smith SJ, Williams JR, Jones OR, Coleman GA. 1991. Water quality impacts associated with sorghum culture in the southern plains. J. Environ. Qual. 20:239-244.

Sharpley AN. 1980. The enrichment of soil phosphorus in runoff sediments. J. Environ. Qual. 9:521-526.

Sharpley AN, Menzel RG, Smith SJ, Rhoades ED, Olness AE. 1981. The sorption of soluble phosphorus by soil material during transport in runoff from cropped and grassed watersheds. J. Environ. Qual. 10:211-215.

Sharpley AN, Syers JK. 1983. Transport of phosphorus in surface runoff as influenced by liquid and solid fertilizer phosphate addition. Water, Air, and Soil Pollution. 19:321-326.

Shibles DB, editor. 1994. Polk County Mined Lands Agricultural Research Demonstration Project final report (March 1, 1989 through February 29, 1992). FIPR publication Nr 03-088-107. Bartow (FL): Florida Institute of Phosphate Research.

Smajstrla AG, Boman BJ, Clark GA, Haman DZ, Pitts DJ, Zazueta FS. 1990. Field evaluations of irrigation systems: solid set or portable sprinkler systems. Bulletin 266. Gainesville (FL): Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Smith RE, Williams JR. 1980. Simulation of the surface water hydrology. In: Knisel WG, editor. CREAMS: a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. U.S. Department of Agriculture, Conservation Research Report Nr 26. Washington: U.S. Government Printing Office. p 13-35.

South Florida Water Management District. 1989. Interim Surface Water Improvement and Management (SWIM) Plan for Lake Okeechobee.

Stall JB. 1972. Effects of sediment on water quality. J. Environ. Qual. 1:353-360.

Sur HS, Mastana PS, Hadda MS. 1992. Effect of rates and modes of mulch application on runoff, sediment and nitrogen loss on cropped and uncropped fields. Trop. Agric. (Trinidad) 69(4):319-321.

Taylor AW, Kilmer VJ. 1980. Agricultural phosphorus in the environment. In: Khasawneh FE, Sample EC, Kamprath EJ, editors. The role of phosphorus in agriculture. Madison (WI): Am. Soc. of Agronomy, Crop Sci. Soc. Am., Soil Sci. Soc. Am.

Timmons DR, Holt RF. 1977. Nutrient losses in surface runoff from a native prairie. J. Environ. Qual. 6(4):369-373.

Timmons DR, Burwell RE, Holt RF. 1973. Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer. Water Resour. Res. 9(3):658-667.

Timmons DR, Verry ES, Burwell RE, Holt RF. 1977. Nutrient transport in surface runoff and interflow from an aspen-birch forest. J. Environ. Qual. 6:188-192.

Waldron LJ. 1977. Shear resistance of root-permeated homogeneous and stratified soil. Soil Sci. Soc. Am. J. 41:843-849.

Walker PH, Hutka J, Moss AJ, Kinnel PIA. 1977. Use of versatile experimental system for soil erosion studies. Soil Sci. Soc. Am. J. 41:610-612.

Warrington D, Shainberg I, Agassi M, Morin J. 1989. Slope and phosphogypsum's effects on runoff and erosion. Soil Sci. Soc. Am. J. 53:1201-1205.

White EM, Williamson EJ. 1973. Plant nutrient concentrations in runoff from fertilized cultivated erosion plots and prairie in eastern South Dakota. J. Environ. Qual. 2(4):453-455.

Wiyo K, Madramootoo CA, Enright P, Bastien C. 1990. Modeling nutrients in runoff from potato fields using CREAMS. ASAE meeting presentation, paper nr 90-2505.

Yoo KH, Touchton JT. 1988. Surface runoff and sediment yield from various tillage systems of cotton. Transactions of the ASAE 31(4):1154-1158.

Yoon KS, Yoo KH, Wood CW, Hall BM. 1994. Application of GLEAMS to predict nutrient losses from land application of poultry litter. Transaction of the ASAE 37(2):453-459.

Zhu JC, Gantzer CJ, Anderson SH, Alberts EE, Beuselinck PR. 1989. Runoff, soil, and dissolved nutrient losses from no-till soybean with winter cover crops. Soil Sci. Soc. Am. J. 53:1210-1214.

Appendix A

POND SURVEY DATA

Table A-1. Results of First Survey of Colonizing Plants in the Pond, Ft. Green, August, 1996.

Pin #	Water Depth	Common Name	Height	Clock Loc.	Distance from Pin
	inches		inches		inches
1	.5	Sesbania	48	12:00	24
		2 dogfennell	12	2:00	6
		1 dogfennell	12	4:00	18
		1 vaseygrass	9	3:00	12
		30 willows	6-9	all over	
		1 bahia	12	3:00	36
		1 bahia	12	10:30	12
2	3.5	1 vaseygrass	36	11:00	24
		2 willows	12	12:00,12:30	24
		1 willow	18	9:00	12
		1 willow	6	3:00	16
3		1 dogfennell	18	9:30	24
		1 vaseygrass	36	5:00	6
		1 marshepper smartweed	10	5:00	16
		1 hyssop spurge	10	1:00	8
4		8 vaseygrass	12	3:00	1,8
				4:00	16
				5:00	18
				9:00	14
				10:00	6
				11:00	12
				1:30	12

		1 southern crabgrass	8	4:30	6
5		1 vaseygrass	48	3:00	24
		1 vaseygrass	18	4:00	24
		3 vaseygrass	36,24,36	6:00	12,24,36
		1 vaseygrass	12	9:00	18
		1 vaseygrass	36	10:00	18
		1 vaseygrass	36	12:00	24
		2 vaseygrass	36,12	1:00	12,36
6		7 sesbania	24	9:00	24
		1 vaseygrass	36	10:00	24
		1 vaseygrass	12	10:00	4
		4 vaseygrass	36	12:00	6,12,18,24
		1 vaseygrass	60	3:00	36
		1 vaseygrass	60	4:00	36
		1 vaseygrass	48	4:00	12
		2 vaseygrass	48	6:00	24,36
		1 vaseygrass	48	8:00	24
7		1 crabgrass photo/3	12	1:00	24
		1 vaseygrass	8	5:00	12
		2 vaseygrass	8	7:00	12,18
		1 vaseygrass	6	8:00	6
8		1 sesbania	50	4:00	24
		1 vaseygrass	30	12:00	16
		1 willow	12	6:00	16
		1 vaseygrass	16	10:00	18
9	8	No weeds			
10	10	No weeds			

11		1 willow	6	4:00	6
		1 sesbania	36	5:00	36
		2 vaseygrass	6,8	6:00	24,36
		1 vaseygrass	36	7:30	18
		2 willows	8,4	10:00	6,12
		1 vaseygrass	12	10:00	24
		1 vaseygrass	12	12:00	30
		1 vaseygrass	36	1:00	24
		1 aeschynomone	8	2:00	18
		1 vaseygrass	36	3:00	30
12		1 vaseygrass	36	12:30	6
		1 vaseygrass	6	3:00	12
13		1 spurge	8	12:00	12,16
		3 spurge	6	1:00	12,18,24
		1 sesbania	30	1:30	40
		5 vaseygrass	4,8,6,12,16	3:00	4,12,18,24,36
		4 vaseygrass	8	4:00-5:00	16-32
		1 vaseygrass	8	6:00	14
		1 vaseygrass	6	7:00	12
		1 vaseygrass	6	8:30	6
		1 vaseygrass	8	3:30	18
		1 vaseygrass	6	11:00	12
		1 vaseygrass	16	12:00	18
		2 spurge	4	3:00	8,12
14		1 sesbania	72	6:30	30
		1 sesbamoa	50	10:00	30
		2 vaseygrass	12,36	1:00	8,12

		1 vaseygrass	16	3:00	24
		1 vaseygrass	20	4:30	16
		3 vaseygrass	12,12,24	6:00	8,16,24
		1 vaseygrass	16	8:00	18
		1 vaseygrass	16	8:30	8
		1 vaseygrass	16	10:00	4
15		bare spot		12:00-1:00	
		bare spot		3:30-4:30	
		rest-vaseygrass			
16		3 sesbania	84	6:00	36
				8:00	24
				9:30	24
		1 sesbania	54	1:00	24
		understory of crabgrass			
		1 dogfennell	12	6:00	24
17		2 crabgrass	6	1:00	12,18
		1 crabgrass	6	9:00	4
		1 crabgrass	6	6:00	12
		1 crabgrass	6	4:00	24
		1 crabgrass	6	5:00	18
		1 vaseygrass	8	1:00	8
		1 vaseygrass	10	2:30	12
		4 vaseygrass	6	4:00	4,8,16,21
		1 vaseygrass	8	6:00	24
		3 vaseygrass	6	7:00	8,12,24
		1 vaseygrass	24	8:00	30

		1 vaseygrass	8	8:30	12
		1 vaseygrass	24	9:00	36
18		1 vaseygrass	40	12:00	24
		1 vaseygrass	40	1:00	30
		1 vaseygrass	8	1:30	18
		1 vaseygrass	12	2:00	16
		1 vaseygrass	40	2:30	12
		1 vaseygrass	24	3:00	10
		1 crabgrass	10	4:00	24
		1 vaseygrass	16	3:30	30
		1 vaseygrass	24	5:00	12
		1 vaseygrass	16	5:30	16
		1 vaseygrass	48	8:30	30
		2 vaseygrass	8	10:30	12,16
		1 vaseygrass	10	11:00	24
		1 vaseygrass	24	11:30	30
19		1 sesbania	12	1:00	10
		1 vaseygrass	36	2:00	8
		1 vaseygrass	12	4:30	12
		1 vaseygrass	12	6:00	36
		1 vaseygrass	24	8:00	24
		1 sesbania	24	9:00	30
		1 crabgrass	16	9:00	12
20		1 dogfennell	20	3:00	4
		1 vaseygrass	24	4:30	12

Table A-2. Results of Second Survey of Colonizing Plants in the Pond, Ft. Green, April, 1997.

Pin #	Weed Common Name	Weed Ht. in In.	Clock Loc.	Distance from Pin in In.
1	mock Bishop's weed	8,4,4	7:00	27,27,33
		6	4:00	33
		8	1:00	32
1	dog fennell	14	5:00	29
		10	11:00	12
		10	12:00	5,12
		21,26,32	9:00	3,9,12
		10	8:00	30
		14	4:00	16
	willows	14,14,11,14,14,14	2:00	3,13,16,16,22,26
		9-14	11:00	9,11,14,14,16,16,17,17,17,17,20,21,22,23,23,23,23,25,26,26,26,28,29,30,30,30,31,31,32,32,33,33,33,33,33,35,35,35
		5,5,7,5,8,12,7,7,11,7,12,5,4,6,6,14	10:00	10,11,14,15,17,18,20,20,21,21,27,31,31,33,35,35
		20	12:00	2-36
		18	6:00	1-27
		8,10,5,14,16,11,9,16	3:00	4,7,8,15,16,20,.23,24
		8,18,9,8,13,12,8,2	9:00	3,3.5,6.5,17,20,22,25,27
		14,13,14,14,11,13,14,8,14,4,16	8:00	10,10,13,13,16,18,21,21,21,23,25
		9,11,12,12,9,7,7,7,7,9,7,7,8,4,4	7:00	11,12,13,16,17,22,23,24,25,26,27,27,33,33,33
		8,8,8,8,4,4,7,7,8,7,8,5,4,10,4,5,4,7,8	5:00	10,12,14,15,17,21,23,23,24,25,25,26,27,27,27,31,

		4,10,4,5,4,7,8		21,31,35
	marsh aster	6	5:00	9,20
		4,4,4,8,4,4	12:00	15,18,24,25,26,31
		6	4:00	16
	vaseygrass	9,6,	3:00	10.5
		20,10	3:00	35
		10,8	3:00	18
		8,6	7:00	30
	ragweed	6	6:00	28
		4	7:00	22
		5	4:00	31
	spurge	6	7:00	3
	peppergrass	11	12:00	22
		8	4:00	21
2	dogfennell	14	12:00	27
	mock Bishop's weed	8	12:00	1
		9	6:00	3
		6,6	9:00	24,2
		8	1:00	25
		4,5,3,13,8	12:00	10,23,26,34
		10,5,12	3:00	27,28,30
		3,4,3	2:00	13,24
	willow	16,17,18,13	12:00	19,20,23,27
		11,15,16,17,9,9,9,11,9,6,9,9,11,17,9,9,6,9,11	6:00	22,22,24,28,30,30,30,31,31,31,32,32,32,32,34,34,34,34,34
		14	1:00	16
		32,5	9:00	11,17

		12-18	5:00	28,30,30,30,31,31,32,32,32,32,33,33,34,34,35,36
	marsh aster	7	12:00	31
		5	9:00	25
		6,10,16	7:00	21,21,33
		4,6,3	8:00	24,28,35
		4,7	1:00	30,33
	vaseygrass	4	9:00	33
		10	11:00	22
3	dog fennell	34	9:00	25
	vaseygrass	6	5:00	4
		8	9:00	20
		6	2:00	19
	marsh aster	5	5:00	10
4	vaseygrass	4,6,5	6:00	18,26,36
		4	7:00	25
		2	8:00	25
		5	9:00	13
		57	10:00	16
		7	11:00	11
		6,10	2:00	21,24
		4	2:00	12
		4,4	4:00	9,20
		4,4,4	5:00	18,26,33
	bermuda	6	7:00	25
		6	8:00	33
		4	9:00	13-25

		6	10:00	10-26
		12	11:00	19-25
		10	12:00	16-20
		10	1:00	8-18,26-35
		8	3:00	10-20
		8	3:00	28,32-36
		10	4:00	18-36
		8	5:00	26-36
5	dogfennell	11,10	6:00	9,20
		14,16	2:00	15,29
		10	1:00	32
		7,8	4:00	13,23
		9	5:00	10
	cogongrass	15,22,22	6:00	16,22,27
		12	8:00	25
		14	10:00	13
		16,12,14,14	11:00	14,27,29
		14	12:00	16-29
		16-22	2:00	13-30
		30	3:00	21-36
		16,16,17	5:00	20,23,33
	bushy bluestem	14	6:00	4
		13,13	7:00	22,34
		10,10	9:00	25,13
		12	12:00	34
		10,8	2:00	6,31
		10	3:00	4

		22	4:00	33
		10	5:00	19
	vaseygrass	6,4,12	6:00	12,21,36
		8	8:00	25
		7	9:00	14
		12	10:00	32
		8,10	11:00	14,32
		10	3:00	18-27
	primrose willow	3	9:00	34
	phasey bean	10	6:00	5
	bermuda	8	10:00	16
		12	11:00	15
6	dogfennell	15	12:00	16
	vaseygrass	15	12:	1-30
		7	12:00	25
		9	3:00	28
		18,18	4:00	9-16,26-35
		13,16	5:00	31,17
		19	6:00	13-36
		17	7:00	24-36
		7,9	8:00	25,33
		17,13	9:00	31,6
		21,12	10:00	26,31
	bushy bluestem	10	1:00	8
		11	3:00	7
	bermuda	13	3:00	17-24

		14	4:00	22-29
		8	9:00	7
	phasy bean	5	3:00	14
		10	4:00	33
		12	5:00	33
		4,6	6:00	23-25
7	vaseygrass	6,4	12:00	33,23
		5	1:00	6
		4,4	2:00	14,32
		4,6	4:00	20,27
		6	5:00	33
		6,7,9	6:00	9,24,32
		4,5,9,7	7:00	9,19,30,33
		7,9,7	8:00	13,21,34
		6,5	10:00	22,32
		6,6	11:00	22,34
	bermuda	9	1:00	11-21
		10	10:00	22-29
	phasey bean	4	7:00	26
8	vaseygrass	8	12:00	19
		6	11:00	33
		8-4	10:00	17-36
		6	6:00	33
		4,5,15	6:00	17,30,36
		4	2:00	28
	willow	10	6:00	6
9	marsh aster	16	9:00	20

		6,26	4:00	14,27
		10,8	3:00	15,25
		10,8,18	2:00	14,25,34
	horse weed	16	12:00	15
		18	1:00	22
		21	6:00	20
	mock Bishop’s weed	10,10,10	12:00	18,18,22
		10	9:00	5
		6	2:00	10
	Florida beggar weed	10,8,25	3:00	23
		28	11:00	16
	vaseygrass	3,6,4	9:00	9,14,27
		2	6:00	8
		4	2:00	20
		5	1:00	23
		11	1:00	27
	dogfennel	4	6:00	21
		6,6,7	3:00	11,18,23
10	marsh aster	20,4,20	12:00	12,18,36
		12,16	1:00	28,29
		13,7,6	2:00	24,28,34
		12,7,2,4,2,3,4,4,15,6	3:00	10,12,15,17,19,22,23,28,30,33
		9,5,4,4	4:00	15,19,28,31
		10	5:00	34
		12,16,3,16,12,25,9	6:00	11,19,19,24,28,33,35
		5,14,15	7:00	11,24,33

		16,14,11	9:00	20,24,28
		10,18,15,13,14	10:00	14,25,25,33,33,
		13,16,19	11:00	8,21,32
	vaseygrass	7	7:00	34
	marshpepper smartweed	10	10:00	13
11	vaseygrass	5,3,9	6:00	20,33,33
		28	12:00	30
		12	3:00	26
		8	2:00	33
		8	1:00	21
		10,5	8:00	18,28
		6	11:00	21
	sea myrtle	16	6:00	22
	willow	7	12:00	34
		15	2:00	3
		9	5:00	5
		13,5	11:00	6,12
	marsh aster	3,3,5	2:00	5,13,23
12	vaseygrass	10	12:00	
		35	1:00	
		4	3:00	
		3	7:00	
		4	12:00	
13	vaseygrass	4	6:00	
		6,4	11:00	15,28
		4,4	10:00	20,29
		4,4	9:00	19,31

		4,4	8:00	7,33
		4,6,4,4,4	7:00	12,21,24,29,34
		15	5:00	33
		4,4,4	4:00	16,19,26
		4,4		14,33
14	vaseygrass	10,14	7:00	30,21
		14,9,9	5:00	15,27,29
		6,6	3:00	20,31
		6,6	2:00	30,35
		6,6	1:00	28,28
		9,13	9:00	20,33
		10	10:00	32
		10,6	11:00	25,33
		7	12:00	26
	bushy bluestem	6	12:00	20
15	bushy bluestem	12,12	12:00	6,30
		12,12	1:00	25,31
		8,11	2:00	12,25
		12,14,14	3:00	18,22,30
		18,18	4:00	14,27
		16	5:00	32
		15,15	6:00	19,32
		10	8:00	26
		10	9:00	4-19
		10	10:00	33
		12	11:00	10-23
	vaseygrass	25	10:00	28

		9	8:00	29
		9	12:00	16
		19	11:00	33
16	vaseygrass	12	6:00	9-30
		12	7:00	10-36
		12	8:00	9-36
		12	9:00	8-36
		12	10:00	8-36
		12	11:00	7-36
		7,8,8	5:00	4,26,31
		11	4:00	23-36
		15	3:00	7-36
		11,15,15,17	2:00	9,23,29,34
		14,10	1:00	19,34
		8,14	12:00	3,24-36
	caesar weed	6	10:00	31
		4	11:00	18
	dog fennel	21	6:00	27
17	vaseygrass	5,5,7,10,10,4	6:00	8,8,12,16,19,28
		10,4,4,4,4	7:00	7,11,19,25,30
		8,6	8:00	11,23
		7,6	9:00	12,26
		5,3	10:00	29,35
		6,4	12:00	12-31
		9,6,3	1:00	13,19.29
		7,4,4	2:00	6,10,12
		5,5,	3:00	9,28,32

		6,5,4,3	4:00	4,22,25,33
		9,5,4	5:00	10,15,13
	bermuda	6	7:00	21
		3		
		5,6,5	1:00	16,23,29
18	vaseygrass	14,14	12:00	24,24
		7	6:00	24
		18	8:00	32
		10	10:00	10,15,22,25,28,33
		10	5:00	13,25
		7,13	4:00	19,27
		12	3:00	14
		7,12	1:00	17,34
		9	11:00	27
	phasey bean	8	11:00	27,16
19	vaseygrass	6,5	5:00	12,30
		5,5,6	1:00	8,17,26
		26	6:00	27
		9	3:00	21
20	dog fennel	31	3:00	6
	vaseygrass	10	12:00	33
		10	2:00	33
		15	3:30	33
		10	5:00	8
		8	7:00	30

Table A-3. Initial (May 24, 1996) and Final (Oct. 16, 1997) Elevations in the Sedimentation Pond.

Pin #	Initial Elevation (ft)	Final Elevation (ft)	Elevation difference (ft)
1	41.24	41.26	-0.02
2	41.14	41.20	-0.06
3	41.36	41,52	-0.16
4	42.14	42.22	-0.08
5	42.84	42.94	-0.10
6	42.83	42.92	-0.09
7	41.74	41.61	0.13
8	41.54	41.50	0.04
9	40.79	40.90	-0.11
10	40.48	40.64	-0.16
11	40.33	40.29	0.04
12	40.64	40.74	-0.10
13	41.98	41.97	0.01
14	41.04	41.15	-0.11
15	42.28	42.43	-0.15
16	40.83	40.87	-0.04
17	41.17	41.20	-0.03
18	41.24	41.13	0.11
19	40.59	40.57	0.02
20	39.64	39.71	-0.07

Table A-4. Soil Particle Size Data and Sampling Coordinates from the Field Reclamation Site.

	x	y	Average Values (µm)				Clay	Silt
Sample	(ft)	(ft)	mean	median	node	<2µm	2-64µm	>64µm
1	220	30	7.79	5.08	4.39	15.32	84.36	0.31
2	243	30	8.87	5.77	4.58	12.56	87.37	0.08
3	266	30	9.76	5.26	4.58	15.27	84.72	0.01
4	289	30	7.86	5.14	4.18	13.91	86.08	0.00
5	312	30	9.82	5.53	4.38	12.70	86.37	0.93
6	220	218	7.17	26.25	4.18	15.70	84.3	0.00
7	243	218	12.05	6.01	4.79	14.29	85.71	0.00
8	266	218	9.20	6.06	6.53	14.11	85.89	0.00
9	289	218	9.37	5.23	4.38	16.32	83.68	0.00
10	312	218	9.79	6.21	4.58	12.70	87.30	0.00
11	220	406	9.19	5.88	4.58	13.67	86.33	0.00
12	243	406	9.31	5.67	4.79	13.83	86.17	0.00
13	266	406	7.96	5.65	5.25	12.61	87.39	0.00
14	289	406	7.58	4.91	4.18	15.41	84.59	0.00
15	312	406	10.82	6.32	4.75	13.27	86.73	0.00
16	220	594	6.55	4.38	3.99	19.86	80.14	0.00
17	243	594	9.68	5.37	4.38	15.58	84.32	0.10
18	266	594	8.21	5.44	5.02	14.28	85.72	0.00
19	289	594	8.19	4.88	4.38	18.62	81.38	0.00
20	312	594	9.47	5.34	4.38	15.08	84.92	0.00
21	220	782	6.58	4.38	3.99	17.04	82.96	0.00
22	243	782	7.67	4.92	4.58	15.84	84.16	0.00

	x	y	Average Values (µm)				Clay	Silt
23	266	782	8.82	5.66	4.79	11.84	88.16	0.00
24	289	782	7.29	4.96	4.38	14.36	85.64	0.00
25	312	782	7.28	4.84	4.38	14.17	85.83	0.00
26	220	970	7.73	5.08	4.18	12.34	87.66	0.00
27	243	970	7.66	5.10	4.38	11.96	88.04	0.00
28	266	970	7.90	5.36	5.02	13.26	86.74	0.00
29	289	970	8.86	5.54	4.58	13.96	86.04	0.00
30	312	970	9.86	5.83	4.38	14.14	85.85	0.00
31	30	30	7.50	4.87	3.99	17.77	82.22	0.00
32	62.5	30	9.38	5.76	4.38	14.04	85.96	0.00
33	95	30	11.72	5.30	4.38	19.53	79.93	0.54
34	127.5	30	9.89	6.15	4.58	12.36	87.64	0.00
35	160	30	9.87	5.88	4.38	11.96	88.04	0.00
36	30	178	11.43	6.35	4.38	13.79	86.12	0.09
37	62.5	178	10.80	6.18	4.79	15.58	84.42	0.00
38	95	178	8.86	5.85	4.38	13.92	86.08	0.00
39	127.5	178	11.80	6.13	4.38	15.61	82.34	2.05
40	160	178	8.97	5.58	4.38	18.26	81.74	0.00
41	30	326	8.63	5.51	4.38	16.04	83.96	0.00
42	62.5	326	10.24	6.12	4.38	14.96	85.04	0.00
43	95	326	9.70	6.34	6.93	13.40	86.60	0.00
44	127.5	326	8.40	5.48	4.38	15.13	84.87	0.00
45	160	326	9.23	5.80	4.38	14.93	85.07	0.00
46	30	474	9.91	5.88	4.38	16.38	83.62	0.00
47	62.5	474	7.77	5.22	4.38	15.74	84.26	0.00
48	95	474	14.35	6.83	5.02	13.07	85.29	1.64

	x	y	Average Values (µm)				Clay	Silt
49	127.5	474	9.41	5.92	4.58	15.31	84.69	0.00
50	160	474	8.74	5.44	4.38	16.59	83.41	0.00
51	30	622	13.01	6.57	4.38	16.52	83.04	0.45
52	62.5	622	9.03	5.83	4.58	14.68	85.32	0.00
53	95	622	9.29	5.85	4.86	15.48	84.52	0.00
54	127.5	622	9.75	5.89	4.79	13.84	86.16	0.00
55	160	6.22	11.20	6.29	4.18	14.64	85.36	0.00
56	30	770	9.50	5.80	4.38	15.26	84.74	0.00
57	62.5	770	8.82	5.78	4.58	14.66	85.34	0.00
58	95	770	9.45	6.18	4.79	13.63	86.37	0.00
59	127.5	770	8.43	5.58	4.58	14.99	85.01	0.00
60	160	770	14.74	7.15	7.36	12.32	85.86	1.83
Average			9.30	5.99	4.61	14.74	85.13	0.134

Table A-5. Particle Size Data and Sampling Coordinates from the Overflow Pond Reclamation Site.

Sample	x (ft)	y (ft)	Average Values (µm)			<2µm	Clay 2-64µm	Silt >64µm
			mean	median	mode			
1	258	30	8.60	6.52	9.50	10.06	89.88	0.06
2	258	100	6.96	5.60	7.92	14.25	85.75	0.00
3	258	170	10.69	6.73	7.92	10.91	85.58	3.51
4	258	240	7.27	5.13	5.02	11.66	82.19	6.16
5	258	310	9.75	6.59	7.36	8.80	90.40	0.80
6	198	310	51.18	5.72	4.38	16.62	83.38	0.00
7	198	240	7.68	5.45	5.02	12.61	86.89	0.50
8	198	170	10.33	7.17	9.06	9.20	90.80	0.01
9	198	100	9.97	6.79	6.76	10.35	89.65	0.00
10	198	30	12.22	7.02	8.28	9.07	89.62	1.31
11	95	30	7.09	5.74	8.28	13.58	86.42	0.00
12	95	100	9.03	6.48	8.67	10.09	89.92	0.00
13	95	170	10.74	6.76	4.79	12.18	87.82	0.00
14	95	240	7.99	5.56	5.02	12.12	87.88	0.00
15	95	310	9.51	6.29	4.79	12.16	87.84	0.00
16	30	310	7.08	4.91	4.80	19.08	80.93	0.00
17	30	240	9.34	6.31	8.67	11.88	88.12	0.00
18	30	170	8.98	5.98	4.79	12.94	87.06	0.00
19	30	100	7.75	5.82	7.92	13.35	86.65	0.00
20	30	30	6.30	4.85	5.27	15.78	84.22	0.00
Average			10.92	6.07	6.71	12.33	87.05	0.62

Appendix B

LAYOUT AND CONSTRUCTION DETAILS FOR MACROBED EXPERIMENT

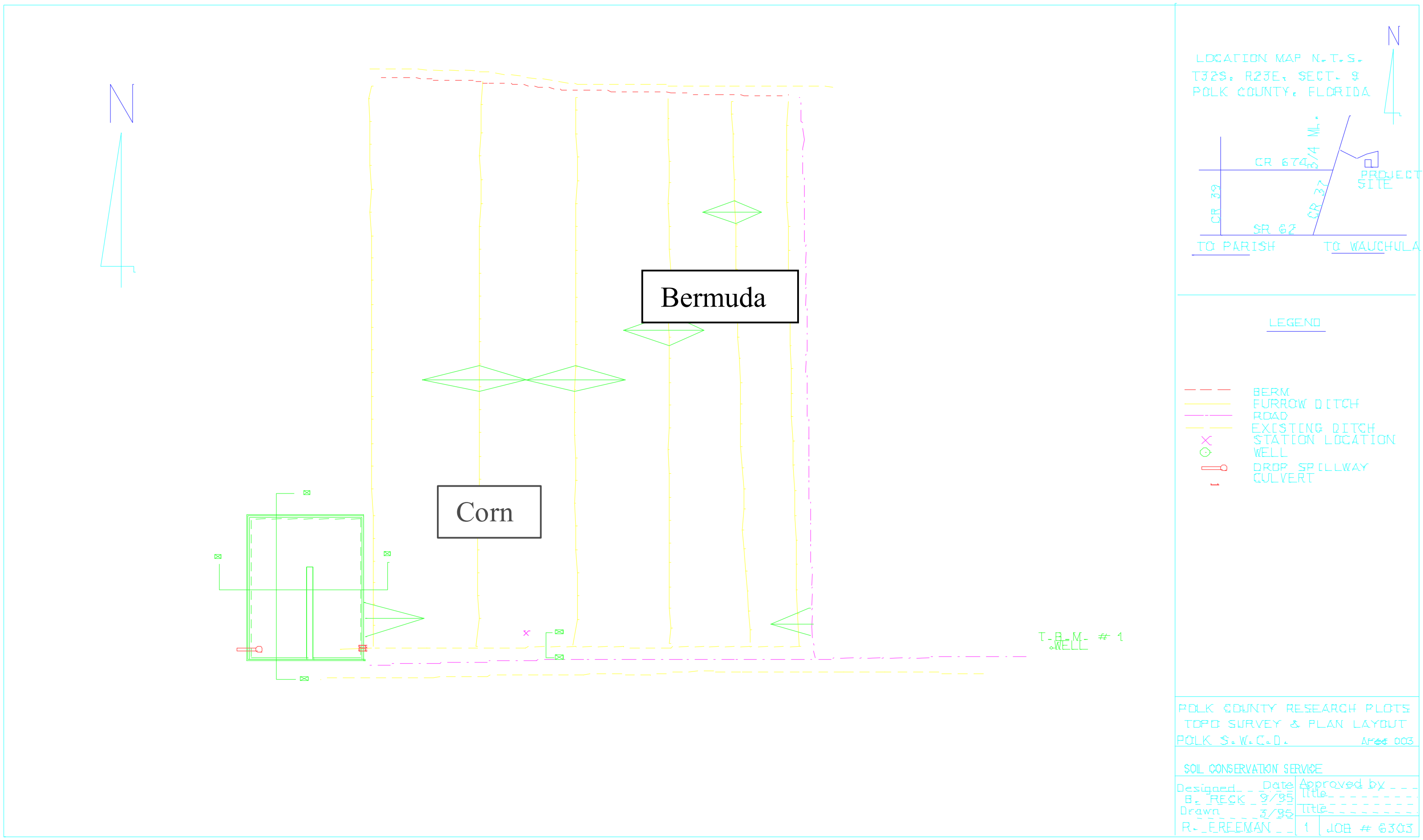


Figure B-1. Layout of Macrobeds and Pond, Ft. Green Site.

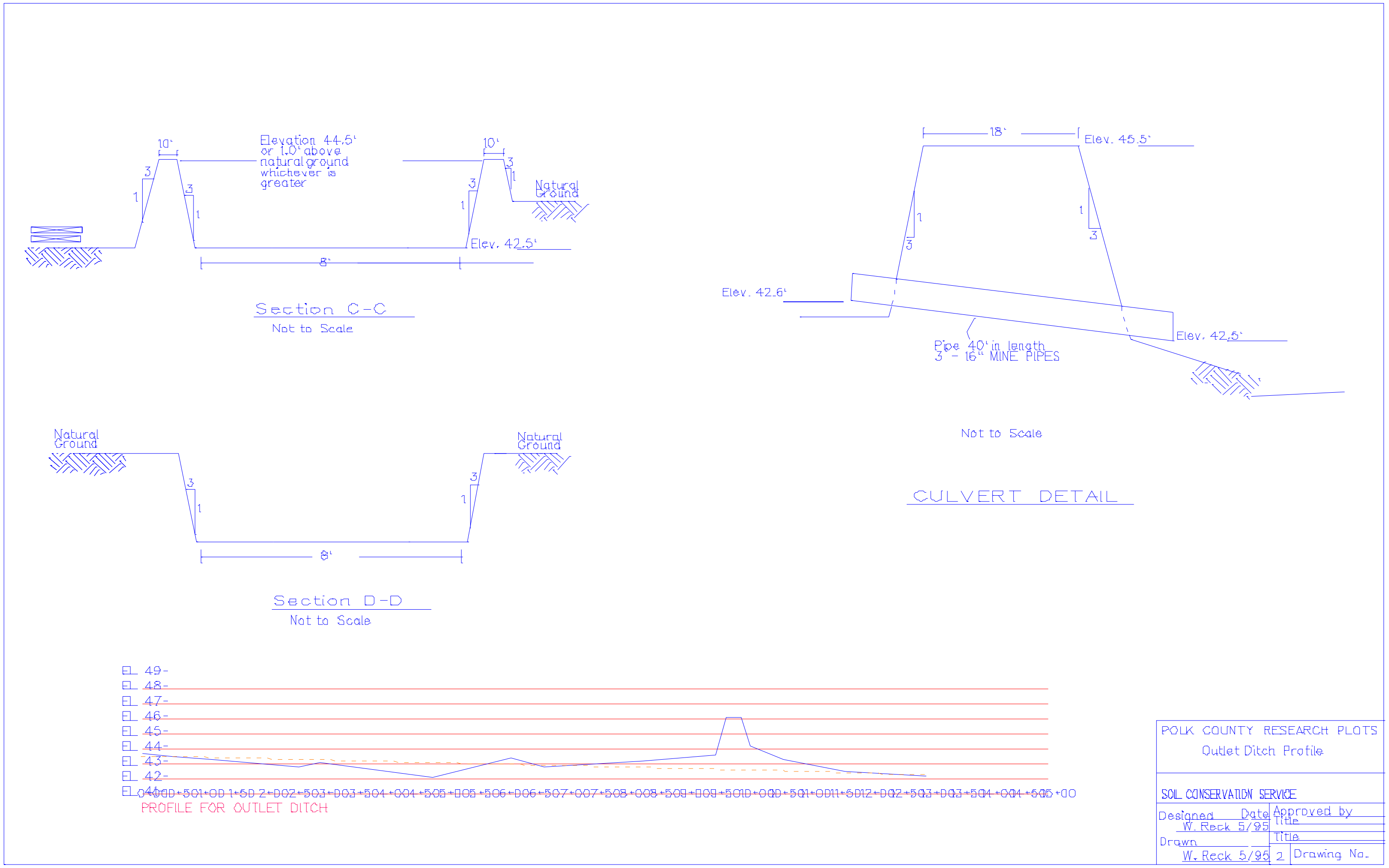
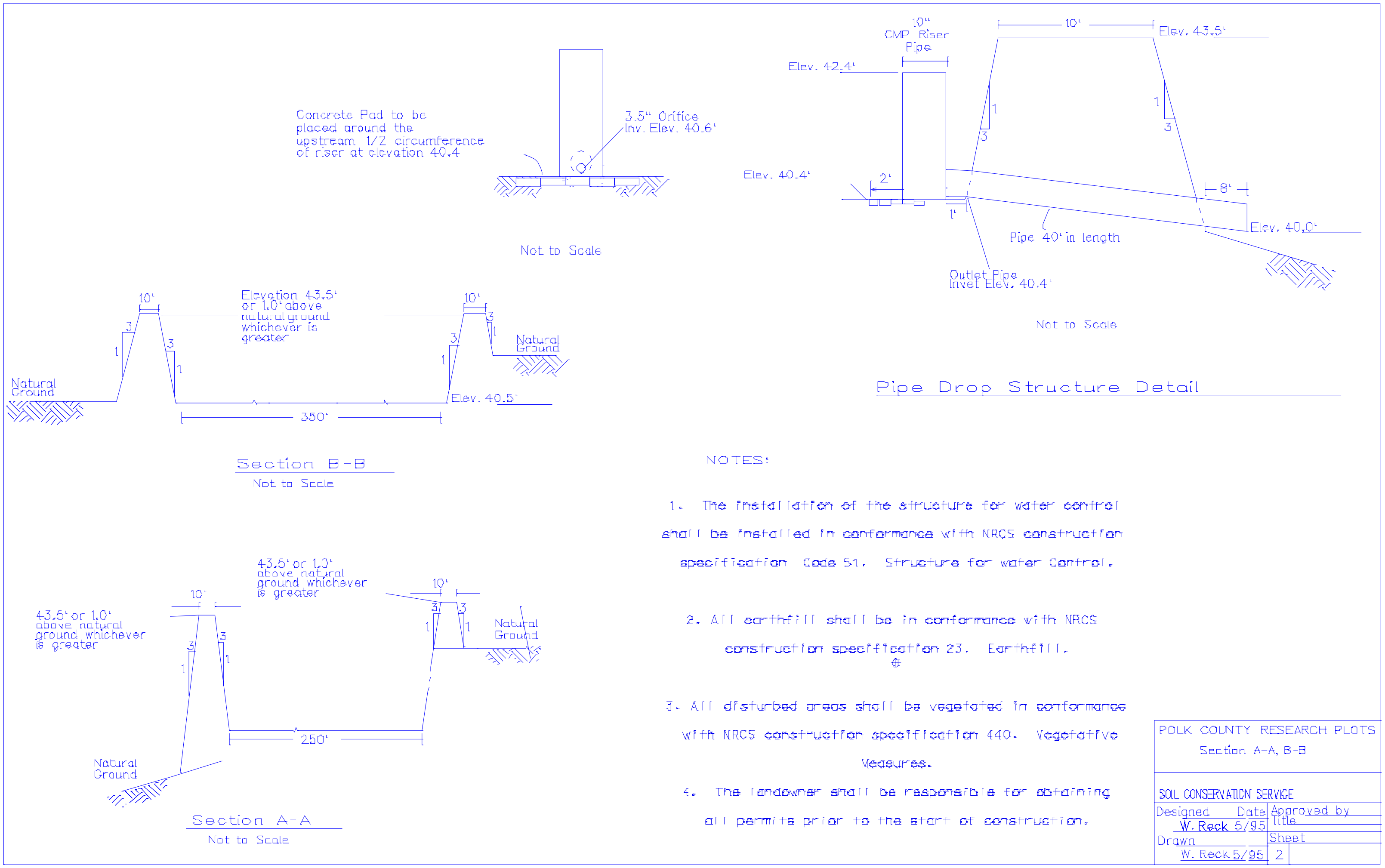


Figure B-2. Layout of Macrobed and Pond, Ft. Green Site.



NOTES:

1. The installation of the structure for water control shall be installed in conformance with NRCS construction specification Code 51. Structure for water Control.

2. All earthfill shall be in conformance with NRCS construction specification 23. Earthfill.

3. All disturbed areas shall be vegetated in conformance with NRCS construction specification 440. Vegetative Measures.

4. The landowner shall be responsible for obtaining all permits prior to the start of construction.

Figure B-3. Construction Details for Outlet Structure from the Pond, Ft. Green Site.

Appendix C

CHEMICAL TREATMENT OF SUSPENDED SOLIDS IN MINED-LANDS RUNOFF WATERS

LABORATORY DATA

FIPR Project, 1997

Total P (perchloric digestion) and Ca from same digestion

10 mL of shaken sample to a final solution after digestion of 100 mL.

Setno Adcode	Reported	Labno	ID#	Sample#	Starting Turbidity (NTU)	Initial pH	Dosing Compound	ppm Fe/Al	after pH	pH adjusted	Settling ime (min	Final Turbidity NTU	Ca	P	
6200	18-Jun-97	130376	1	1	242	7.44	FeCl3	3.4	6.43	7.00	30	232.00	127	24	
6200	18-Jun-97	130377	2	2	242	7.44	FeCl3	6.7	6.00	8.02	30	255.00	116	22	
6200	18-Jun-97	130378	3	3	242	7.44	FeCl3	13.4	3.80	7.20	30	29.20	124	3	
6200	18-Jun-97	130379	4	4	242	7.44	FeCl3	20.2	3.51	7.00	30	12.50	100	1	
6200	18-Jun-97	130380	5	5	242	7.44	FeCl3	26.9	3.24	7.60	30	8.40	113	1	
6200	18-Jun-97	130381	6	6	242	7.44	FeCl3	33.6	3.25	7.00	30	15.60	122	1	
6200	18-Jun-97	130382	7	7	242	7.44	FeCl3	40.3	2.19	7.00	30	8.10	129	1	
6200	18-Jun-97	130383	8	8	242	7.44	FeCl3	13.4	4.62	7.15	30	377.00	117	22	?? very high end turbidity
6200	18-Jun-97	130384	9	9	267	7.26	FeCl3	3.4	5.41	7.35	30	474.00	137	39	
6200	18-Jun-97	130385	10	10	267	7.49	FeCl3	6.7	4.30	7.50	30	472.00	143	36	
6200	18-Jun-97	130386	11	11	267	7.45	FeCl3	13.4	3.77	7.20	30	186.70	110	7	
6200	18-Jun-97	130387	12	12	267	7.55	FeCl3	20.2	3.44	7.25	30	45.20	93	2	
6200	18-Jun-97	130388	13	13	267	7.38	FeCl3	26.9	3.28	7.30	30	18.10	109	2	
6200	18-Jun-97	130389	14	14	267	7.73	FeCl3	33.6	3.23	7.05	30	27.40	118	1	
6200	18-Jun-97	130390	15	15	267	7.81	FeCl3	40.3	3.18	7.65	30	13.80	143	1	
6200	18-Jun-97	130391	16	16	267	7.67	FeCl3	26.9	3.33	7.16	30	58.20	108	3	
6200	18-Jun-97	130392	17	17	105	7.40	FeCl3	3.4	4.38	8.00	30	216.00	96	13	
6200	18-Jun-97	130393	18	18	105	8.00	FeCl3	6.7	3.78	6.98	30	233.00	105	14	
6200	18-Jun-97	130394	19	19	105	7.78	FeCl3	13.4	3.52	7.00	30	40.00	88	2	
6200	18-Jun-97	130395	20	20	105	7.82	FeCl3	20.2	3.35	7.00	30	9.70	104	1	
6200	18-Jun-97	130396	21	21	105	7.70	FeCl3	26.9	3.35	7.25	30	7.24	55	1	
6200	18-Jun-97	130397	22	22	105	7.83	FeCl3	33.6	3.34	8.00	30	5.31	69	0	
6200	18-Jun-97	130398	23	23	105	7.83	FeCl3	40.3	3.25	7.30	30	7.60	77	0	
6200	18-Jun-97	130399	24	24	105	7.90	FeCl3	26.9	3.43	8.75	30	13.74	53	0	
6200	18-Jun-97	130400	25	25	267	7.26	FeCl3	3.4	5.41	7.35	450	155.80	29	8	
6200	18-Jun-97	130401	26	26	267	7.49	FeCl3	6.7	4.30	7.50	450	52.60	20	2	
6200	18-Jun-97	130402	27	27	267	7.45	FeCl3	13.4	3.77	7.20	450	2.28	27	0	
6200	18-Jun-97	130403	28	28	267	7.55	FeCl3	20.2	3.44	7.25	450	0.86	39	0	
6200	18-Jun-97	130404	29	29	267	7.38	FeCl3	26.9	3.28	7.30	450	0.70	65	0	
6200	18-Jun-97	130405	30	30	267	7.73	FeCl3	33.6	3.23	7.05	450	0.64	68	0	
6200	18-Jun-97	130406	31	31	267	7.81	FeCl3	40.3	3.18	7.65	450	0.77	80	0	
6200	18-Jun-97	130407	32	32	267	7.67	FeCl3	26.9	3.33	7.16	450	0.97	54	0	
6200	18-Jun-97	130408	33	33	105	7.40	FeCl3	3.4	4.38	8.00	450	428.00	92	36	
6200	18-Jun-97	130409	34	34	105	8.00	FeCl3	6.7	3.78	6.98	450	57.10	22	4	
6200	18-Jun-97	130410	35	35	105	7.78	FeCl3	13.4	3.52	7.00	450	8.87	24	1	
6200	18-Jun-97	130411	36	36	105	7.82	FeCl3	20.2	3.35	7.00	450	2.80	37	0	
6200	18-Jun-97	130412	37	37	105	7.70	FeCl3	26.9	3.35	7.25	450	2.25	49	0	
6200	18-Jun-97	130413	38	38	105	7.83	FeCl3	33.6	3.34	8.00	450	1.92	60	0	
6200	18-Jun-97	130414	39	39	105	7.83	FeCl3	40.3	3.25	7.30	450	1.79	75	1	
6200	18-Jun-97	130415	40	40	105	7.90	FeCl3	26.9	3.43	8.75	450	2.34	46	0	

FIPR Project, 1997

Total P (perchloric digestion) and Ca from same digestion

10 mL of shaken sample to a final solution after digestion of 100 mL.

Setno	Reported	Labno	ID#	Sample#	Starting Turbidity (NTU)	Initial pH	Dosing Compound	ppm Fe/Al	after pH	pH adjusted	Settling ime (min	Final Turbidity NTU	Ca	P
Adcode														
6200	18-Jun-97	130416	41	41	361	7.70	e2(SO4)	3.4	6.71	7.33	95	414.00	235	89
6200	18-Jun-97	130417	42	42	361	7.86	e2(SO4)	6.8	6.32	7.71	90	467.00	246	93
6200	18-Jun-97	130418	43	43	361	7.90	e2(SO4)	13.6	5.04	7.49	85	215.00	51	11
6200	18-Jun-97	130419	44	44	361	7.92	e2(SO4)	20.4	4.20	7.44	80	48.00	50	3
6200	18-Jun-97	130420	45	45	361	7.93	e2(SO4)	27.3	3.65	7.55	75	26.30	71	2
6200	18-Jun-97	130421	46	46	361	7.86	e2(SO4)	34.1	3.35	7.70	70	15.70	94	1
6200	18-Jun-97	130422	47	47	361	7.98	e2(SO4)	40.9	3.24	7.56	65	16.30	120	2
6200	18-Jun-97	130423	48	48	361	7.98	e2(SO4)	27.3	4.20	8.23	60	39.50	55	3
6200	18-Jun-97	130424	49	49	539	7.85	e2(SO4)	3.4	6.65	7.80	100	547.00	135	50
6200	18-Jun-97	130425	50	50	543	7.70	e2(SO4)	6.8	5.80	7.20	100	536.00	155	57
6200	18-Jun-97	130426	51	51	520	7.60	e2(SO4)	13.6	3.81	7.50	90	47.80	54	10
6200	18-Jun-97	130427	52	52	535	7.60	e2(SO4)	20.4	3.35	7.75	85	20.40	92	2
6200	18-Jun-97	130428	53	53	545	7.65	e2(SO4)	27.3	3.31	7.90	80	14.30	127	1
6200	18-Jun-97	130429	54	54	533	7.80	e2(SO4)	34.1	3.10	8.50	75	6.44	159	3
6200	18-Jun-97	130430	55	55	534	7.80	e2(SO4)	40.9	3.05	7.80	70	12.10	162	1
6200	18-Jun-97	130431	56	56	535	7.80	e2(SO4)	27.3	3.40	8.50	65	21.50	86	2
6200	18-Jun-97	130432	57	57	361	7.70	e2(SO4)	3.4	6.71	7.33	1350	499.00	158	44
6200	18-Jun-97	130433	58	58	361	7.86	e2(SO4)	6.8	6.32	7.71	1350	152.40	82	13
6200	18-Jun-97	130434	59	59	361	7.90	e2(SO4)	13.6	5.04	7.49	1350	13.14	62	1
6200	18-Jun-97	130435	60	60	361	7.92	e2(SO4)	20.4	4.20	7.44	1350	1.40	143	0
6200	18-Jun-97	130436	61	61	361	7.93	e2(SO4)	27.3	3.65	7.55	1350	1.16	120	0
6200	18-Jun-97	130437	62	62	361	7.86	e2(SO4)	34.1	3.35	7.70	1350	1.21	147	0
6200	18-Jun-97	130438	63	63	361	7.98	e2(SO4)	40.9	3.24	7.56	1350	1.06	172	0
6200	18-Jun-97	130439	64	64	361	7.98	e2(SO4)	27.3	4.20	8.23	1350	1.60	94	0
6200	18-Jun-97	130440	65	65	539	7.85	e2(SO4)	3.4	6.65	7.80	1450	406.00	172	43
6200	18-Jun-97	130441	66	66	543	7.70	e2(SO4)	6.8	5.80	7.20	1450	133.60	103	12
6200	18-Jun-97	130442	67	67	520	7.60	e2(SO4)	13.6	3.81	7.50	1450	2.97	63	0
6200	18-Jun-97	130443	68	68	535	7.60	e2(SO4)	20.4	3.35	7.75	1450	1.12	89	0
6200	18-Jun-97	130444	69	69	545	7.65	e2(SO4)	27.3	3.31	7.90	1450	1.21	115	0
6200	18-Jun-97	130445	70	70	533	7.80	e2(SO4)	34.1	3.10	8.50	1450	1.20	86	0
6200	18-Jun-97	130446	71	71	534	7.80	e2(SO4)	40.9	3.05	7.80	1450	1.39	172	0
6200	18-Jun-97	130447	72	72	535	7.80	e2(SO4)	27.3	3.40	8.50	1450	1.57	103	0

FIPR Project, 1997

Total P (perchloric digestion) and Ca from same digestion

10 mL of shaken sample to a final solution after digestion of 100 mL.

					Starting							Final		
Setno	Reported	Labno	ID#	Sample#	Turbidity (NTU)	Initial pH	Dosing Compound	ppm Fe/Al	after pH	pH adjusted	Settling ime (min	Turbidity NTU	Ca	P
Adcode														
6200	18-Jun-97	130448	73	73	201	7.35	Alum	3.8	4.52	7.65	30	19.59	160	1
6200	18-Jun-97	130449	74	74	198	8.05	Alum	7.5	4.19	9.00	30	18.60	113	1
6200	18-Jun-97	130450	75	75	202	8.10	Alum	15.1	4.08	7.20	30	6.55	108	1
6200	18-Jun-97	130451	76	76	203	7.65	Alum	22.6	3.99	7.25	30	1.81	74	0
6200	18-Jun-97	130452	77	77	221	7.40	Alum	30.1	3.90	7.30	30	1.71	102	0
6200	18-Jun-97	130453	78	78	224	8.00	Alum	37.7	3.85	7.20	30	1.07	126	0
6200	18-Jun-97	130454	79	79	221	8.10	Alum	45.2	3.99	7.28	30	1.13	229	0
6200	18-Jun-97	130455	80	80	368	8.30	Alum	30.1	4.00	7.38	30	3.18	97	0
6200	18-Jun-97	130456	81	81	553	7.25	Alum	3.8	5.00	7.90	30	392.00	137	33
6200	18-Jun-97	130457	82	82	548	7.60	Alum	7.5	4.40	10.00	30	8.25	132	1
6200	18-Jun-97	130458	83	83	545	7.90	Alum	15.1	4.05	7.40	30	12.38	90	1
6200	18-Jun-97	130459	84	84	549	7.65	Alum	22.6	4.00	7.30	30	8.09	126	1
6200	18-Jun-97	130460	85	85	553	7.75	Alum	30.1	3.97	7.60	30	6.24	152	1
6200	18-Jun-97	130461	86	86	551	7.95	Alum	37.7	3.92	7.35	30	6.73	179	1
6200	18-Jun-97	130462	87	87	562	7.95	Alum	45.2	3.86	7.70	30	5.87	216	8
6200	18-Jun-97	130463	88	88	560	8.10	Alum	30.1	4.00	7.50	30	13.60	156	2
6200	18-Jun-97	130464	89	89	329	7.45	Alum	3.8	4.44	7.60	900	23.60	73	2
6200	18-Jun-97	130465	90	90	332	7.65	Alum	7.5	4.25	7.50	900	2.62	89	1
6200	18-Jun-97	130466	91	91	335	7.80	Alum	15.1	4.15	7.40	900	0.84	104	0
6200	18-Jun-97	130467	92	92	328	7.80	Alum	22.6	4.00	7.45	900	0.76	131	0
6200	18-Jun-97	130468	93	93	355	7.90	Alum	30.1	3.98	7.24	900	0.58	148	0
6200	18-Jun-97	130469	94	94	369	8.00	Alum	37.7	3.89	7.20	900	0.45	172	0
6200	18-Jun-97	130470	95	95	360	7.95	Alum	45.2	3.85	7.31	900	0.94	193	0
6200	18-Jun-97	130471	96	96	366	8.00	Alum	30.1	3.99	7.40	900	1.46	124	0

FIPR Project, 1997

Total P (perchloric digestion) and Ca from same digestion

10 mL of shaken sample to a final solution after digestion of 100 mL.

Setno	Reported	Labno	ID#	Sample#	Starting Turbidity (NTU)	Initial pH	Dosing Compound	ppm Fe/Al	after pH	pH adjusted	Settling ime (min	Final Turbidity NTU	Ca	P
Adcode														
					Turbidity (NTU)	Mean (microns	Median (microns	Ca	P	P and Ca correlations with NTUxMean, NTU x Median				
6200	18-Jun-97	130472	97	101	360	1.138	0.627	138	37		and NTU with a 0.97 Rsq. (No intercept)			
6200	18-Jun-97	130473	98	102	515	0.864	0.752	190	56					
6200	18-Jun-97	130474	99	103	211	1.556	1.750	98	16	TP= (0.197xNTUxMean) - (0.170xNTUxMedian) 0.97 Rsq				
6200	18-Jun-97	130475	100	104	158	1.256	0.896	80	12					
6200	18-Jun-97	130476	101	105	521	5.031	3.697	528	193	TCa= (0.252xNTU) - (0.481xNTUxMedian) + (0.495xNTUxMean) 0.97 Rsq				
6200	18-Jun-97	130477	102	106	516	2.945	2.585	190	56					
6200	18-Jun-97	130478	103	107	362	2.525	2.314	114	26	TP = (0.404xTCa) - 20.348 0.999 Rsq				
6200	18-Jun-97	130479	104	108	290	1.647	1.587	111	26					
6200	18-Jun-97	130480	105	109	102	0.846	0.566	71	9	* computed with SAS (9/18/97)				
6200	18-Jun-97	130481	106	STD150P				58	148					
6200	18-Jun-97	130482	107	STD150P				54	136					

55.847	Fe	287.7526	Fe2(SO4)3	0.38816	FE : Fe2(SO4)3
32.064	S	162.206	FeCl3	0.344297	FE : FeCl3
15.9994	O	101.9612	Al2O3	0.52925	AL : Al2O3
35.453	Cl				
26.9815	Al				
74.09	Ca(OH)2	(1.85 g/L solubility)			

12/18/96

	FERRIC SULFATE		FERRIC CHLORIDE		ALUM
1.467	specifc gravity (g/cc)	1.488	specifc gravity (g/cc)	1.327	specifc gravity (g/cc)
25.2	% Fe2(SO4)3	44.3	% FeCl3	8.04	Al2O3
9.8	% Fe (III)	15.252	% Fe (III)	4.26	% Al
98,000	ppm Fe	152,523	ppm Fe	42,552	ppm Al

For a 1 ml to 1000 ml addition to make 1 ppm addition of Fe, the following is calculated:
Need a 1000 ppm solution for each chemical. Make a 10,000 ppm first, then the 1,000 ppm second.

7

10,000 ppm =	102.041	weigh out into 1000 ml		65.564	weigh out into 1000 ml		235.008	weigh out into 1000 ml	
	6817	ppm Fe		6720	ppm Fe		7536	ppm Al	
	ppm Fe	Dilution	mL to 1000 ml	ppm Fe	Dilution	mL to 1000 ml	ppm Fe	Dilution	mL to 1000 ml
1	3.4	2000	0.5	3.4	2000	0.5	3.8	2000	0.5
2	6.8	1000	1	6.7	1000	1	7.5	1000	1
3	13.6	500	2	13.4	500	2	15.1	500	2
4	20.4	333	3	20.2	333	3	22.6	333	3
5	27.3	250	4	26.9	250	4	30.1	250	4
6	34.1	200	5	33.6	200	5	37.7	200	5
7	40.9	167	6	40.3	167	6	45.2	167	6
8	27.3	250	4	26.9	250	4	30.1	250	4