DETERMINATION OF INDICATORS OF ECOLOGICAL CHANGE

Third Annual Progress Report

Project Year 2001-2002 (FY02)

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EXECUTIVE SUMMARY

Introduction:

The goal of this research is to develop indicators of ecosystem integrity and impending ecological change that include natural variation and human disturbance. We are evaluating parameters related to properties and processes in the understory vegetation, soil and surface hydrology as potentially sensitive indicators of ecosystem integrity and ecological response to natural and anthropogenic factors. The basic premise is that soil serves as the central ecosystem component that links the quality of the terrestrial habitats (by influencing vegetation and its stability) and the aquatic habitats (via control of soil erosion and overland runoff). Our research and monitoring plan addresses the following objectives:

- Identification of physical, chemical and biological variables of soil, surface hydrology and vegetation that may be used as indicators of ecological change.
- Evaluation of potential ecological indicators for sensitivity, selectivity, ease of measurement and cost effectiveness.
- Selection of indicators that 1) show a high correlation with ecosystem state, 2) provide early warning of impending change and 3) differentiate between natural ecological variation and anthropogenic negative impacts.
- Determination of the range of natural variation for indicator variables, and comparison with the range of values under anthropogenic, especially mission-related, influences.

FY00-01 Summary:

In Phase 1 approximately 300 sites within six watersheds were categorized as low, moderate or severe disturbance, based on visual assessment of vegetation and soil disturbance in the immediate vicinity. Comparison of soil total carbon (TC) and microbial biomass C from these sites supports field observations that the primary impact of intensive military training on soil quality is soil erosion in uplands and associated sedimentation in wetlands. Topsoil loss in disturbed upland sites results in decreased soil organic matter content in upland sites and concomitant deposition of silt and clay in downslope and downstream wetlands. In general, for both wetlands and uplands, soil chemical and biological parameters correlated with soil organic matter tend to decrease with increasing site disturbance. The ratio MBC:TC tends to increase with increasing soil disturbance, which may relate to the relative availability of organic C to heterotrophic microorganisms in the soil. It appears that the loss of soil organic matter near the soil surface through topsoil erosion in uplands or sedimentation in wetlands results in a higher proportion of freshly-deposited organic material in the soil organic matter pool, thus stimulating microbial growth.

Multivariate statistical analyses were performed on the Phase 1 soil biogeochemical data set. Cannonical Discriminant Analysis was used as to reduce the dimensionality of the multivariate data set while maximizing the separation between specific categories of data. Discriminant Function Analysis was used to classify observations into groups on the basis of the biogeochemical data set. Results indicate that canonical variable 1 provides relatively good separation among sites designated as low and moderate, while canonical variable 2 primarily provides separation of severe-disturbance sites from those with low to moderate disturbance.

Results of Discriminant Function Analysis indicate that the Phase 1 soil biogeochemistry data "predict", to a large extent the degree of site disturbance.

Structural and compositional parameters of vegetation were measured at the Phase I soil biogeochemical sites. A total of 113 woody and 110 herbaceous species were encountered. Cannonical Correspondence Analysis (CCA) of relative woody plant cover with environmental variables indicates a separation of low disturbance sites from moderate and severe sites, but no marked separation between moderate and severe disturbance sites. There appears to be a relationship between the cover of a subset of the herbaceous species and sites of severe disturbance.

Distributed soil moisture content was sampled in June and August 2001. Analysis indicated relatively dry upland soils with increasing water content on the hill slopes. The majority of the water storage is confined to the areas immediately adjacent to the stream channel. Stream flow, stage, rainfall and throughfall data collection were initiated in FY 2000 and expanded during FY2001. Initial results of the throughfall study indicate a distinct signature among the 5 vegetation categories into five different groups: wetland, pine plantation, hard wood, mixed, and pine. A spatially distributed hydrological input model was developed, including a Gash throughfall model coupled to a GIS system which uses landuse coverages. A preliminary hydrologic model for Bonham-2 using TOPMODEL was run with reasonable results.

FY2002 Summary:

Soil sampling for biogeochemical analyses was continued along disturbance gradient transects and at vegetation study sites investigating recovery from clearcutting. Multivariate data analyses were completed on Phase I and II biogeochemical data. Hyperspectral analysis was conducted on soil samples taken from the Ft. Benning Installation in Phase I in order to determine whether soil sample spectral signatures can be used to discriminate ecological impact, and to determine the relationship between biogeochemistry and spectral reflectance for soil samples. The reflectance signatures of soil samples were analyzed using multivariate statistical methods. Principal Components Analysis was performed to achieve reduction of the dimensionality of data (2000+ variables of wavelengths) into a few important variables. Canonical Discrimination and Discriminant Function Analysis were conducted to determine whether spectral signatures can be used to discriminate soils taken from bottomlands and uplands and also from low, medium and highly disturbed sites. Canonical Correlation and Partial Least Squares were carried out to relate spectral signatures to soil biogeochemistry.

Discrimination on the basis of landscape position using hyperspectral data was successful using one canonical variable, and results were comparable to Cannonical Discrimination Analysis results found using biogeochemistry data directly. Cannonical Discrimination on the basis on disturbance was not as successful as that obtained using 20 biogeochemical variables, but comparable to that obtained using 4 variables.Results of the Discriminant Function Analysis for landscape position based on the reflectance data are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables. Results of the Discriminant Function Analysis for disturbance based on reflectance data are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables.

A chronosequence study focusing on recovery of ground cover vegetation after clear cutting was conducted. Ground cover vegetation was assessed within two major soil groups (loamy vs. sandy soils) and four time intervals (0-3, 8-10, 18-20, and >30 years) after logging for a total of 32 sites. Identification of pattern and rate of ground cover recovery following clear cutting will aid in identification of sensitivity and return rate for herbaceous species following low to moderate levels of disturbance, and help to separate natural variation from anthropogenic disturbance. Results indicate that percent clay and sand contributed significantly to variation in vegetation, and CCA produced a weak separation of species based on age classes. Increase Bulk Density was associated with sandy soil in 0-3 year post-clearcut sites, and increased overstory density was associated with 15-20 and >30 year age classes.

Soil water content measurements were obtained every two months in the Bonham-1 watershed using 50-meter contour lines as references. Measurements were used to estimate the total water storage and spatial moments of water content within the catchment. When compared to volumes estimated from precipitation and hydrograph data, our estimated soil-water storage appear to account for the expected volume of precipitation minus hydrograph volume.

Watershed hydrologic monitoring activities continued, including precipitation monitoring, stream flow gaging, throughfall measurements, water content sampling, and soil water, groundwater and stream water sampling. Hydrological sampling occurred approximately 2 times per month during FY2002. The impact of vegetation community and dynamics on water input were characterized by the throughfall study, and results suggest that forests comprised of multiple species may require species-based corrections to model parameters. Water quality measurements revealed low levels of most nutrients, but significantly higher levels of some nutrients (TKN, sulfate, DOC, TOC, NH_3, Cl) were observed in throughfall and stemflow than in soil and stream waters. A seasonal increase in stream water nitrogen was observed during the winter months. This increase coincided with the decreased canopy cover in the wetland and hardwood communities. Preliminary modeling results suggest that an understanding of hydrologic pathways is necessary to link excess nitrogen to stream water chemistry. A joint effort between UF (Jacobs) and ORNL (Garten and Ashwood) was established to generate a distributed, regional model of excess nitrogen at Fort Benning and to develop a hydrologic modeling framework that links the nitrogen model to the stream water chemistry. This effort will be continued during FY2003.

General Conclusions:

1. Approximately 2-15% of throughfall shows up as stream flow. Median value is approximately 6%. Time to peak discharge is approximately 3 hours.
2. Storm intensities are usually $<K_{sat}$ at most places, except severely disturbed areas.
3. Soil cover plays an important role in determining the potential runoff. More important than K_{sat} of surface soil.
4. Biogeochemical cycling in soils and vegetation are influenced by soil-water content.
5. Soil organic matter and its cycling is an important biogeochemical indicator.
6. Spectral analysis shows excellent promise to determine soil nutrient status.

7. Understory vegetation species diversity correlates with disturbance. Clear indicators generally observed only at heavily impacted sites.
8. Nutrient and sediment loads in “low” and “medium” impact sites are not too large. Sediment may be the most important water quality attribute for “severe” impact sites.
9. Water quality measurements revealed low levels of most nutrients.
10. Decreased canopy cover in wetlands and hardwood communities increased the nutrient load to streams.
11. Riparian zones may be the most important determinants of water quality.
12. Multivariate Analysis, Principal Component Analysis, and Canonical Correspondence Analysis yielded combination of factors that were useful in identifying spectrum of impacts.

1.0 INTRODUCTION

Our research seeks to develop suitable indicators of ecosystem integrity and impending ecological change resulting from both natural variation and anthropogenic activities. We will use a multidisciplinary and multi-scale approach, which will result in robust techniques for ecosystem monitoring and evaluation. Results of the study will enhance the ability to minimize, mitigate or remove major negative environmental impacts on DoD's ability to conduct the military mission. Through the proposed research plan, we will address the SEMP objective of identifying indicators that signal ecological change in intensively and/or lightly used ecological systems on military installations. These indicators will provide early indications of change associated with (1) natural ecosystem variability and (2) military activities, including training and testing, as well as other land management practices. Early indications of change, and an understanding of the likely causes, will improve installation managers' ability to manage activities that are shown to be damaging, and prevent long-term, negative effects.

The concept of ecosystem integrity, or "health", in the context of the military installation, encompasses not only the sustainability of the "natural" biota in the system, but also the sustainability of human activities at the installation, namely the military mission. Thus, changes in ecological condition are of great concern to both resource managers and military trainers. A suite of variables is needed to measure changes in ecological condition. Two types of indicators that may be useful are (1) variables that inform managers about ecosystem status and (2) variables that signal impending change. In many cases, these indicators may be the same. Both types are needed, but variables that serve as early warnings of impending changes outside the natural range of variation, and variables that are shown to be related to activities affecting the military mission, may be especially valuable.

2.0 TECHNICAL OBJECTIVES

We will evaluate a suite of parameters related to properties and processes in the understory vegetation, soil and surface hydrology as potentially sensitive indicators of ecosystem integrity and ecological response to natural and anthropogenic factors. In general, the soil hydrologic and biogeochemical parameters to be examined relate to changes in soil physical and chemical characteristics, and the response of soil microbial population and plant communities. To the greatest extent possible, cause and effect relationships will be developed between environmental changes, due to both natural variability and anthropogenic perturbation, and soil and vegetation responses, primarily as they relate to nutrient storage, nutrient turnover and population dynamics.

Our basic premise is that soil serves as the central ecosystem component that links the quality of the terrestrial habitats (by influencing the vegetation and its stability) and the aquatic habitats (via control of soil erosion and overland runoff). Thus, a careful study of soil parameters and processes and linking them to impacts on terrestrial/aquatic habitats is the basis for our experimental approach. Furthermore, we aim to establish a sound scientific basis for the empirical parameters that might be used as ecological indicators.

Our proposed research and monitoring plan will address the following objectives:

- Identify physical, chemical and biological variables (properties and processes) associated with soil, surface hydrology and vegetation that may be used as indicators of ecological change.

- Evaluate potential ecological indicators based on sensitivity, selectivity, ease of measurement and cost effectiveness.
- Select indicators that most effectively 1) show a high correlation with a certain state in a specific ecosystem, 2) provide early warning of impending change and 3) differentiate between natural ecological variation and anthropogenic negative impacts.
- Determine the likely range of natural variation for indicator variables, and compare with the range of values under anthropogenic, especially mission-related, influences.

3.0 SUMMARY OF PREVIOUS RESULTS (FY00-01)

3.1 SOIL BIOGEOCHEMISTRY

The Phase 1 objectives were to characterize the distributions (range, central tendency) of indicator variables at a regional scale and to determine the response of variables to impacts related to military training and other land uses and management practices. Sampling for Phase 1 of the soil biogeochemistry component was completed during FY2000. FY2000 sampling and monitoring was conducted within 6 watersheds of order 3 or 4, which had been proposed and/or selected as ECMI long-term monitoring units. These watersheds, associated with Sally Branch, Bonham, Halloca, Randall, Wolf and Shell Creeks, represent a wide range of military and non-military land uses and anthropogenic disturbance regimes (type and intensity of disturbance). Analysis of Phase 1 data was performed during FY2001.

FY2001 sampling was conducted for a comparative study of soil and vegetation-based indicators in both wetland and upland regions of highly-disturbed (D-15 compartment) and minimally-disturbed (D-4) areas. These areas were sampled both in December 2000 and August 2001 in order to examine temporal or seasonal variability in soil indicators. Soil cores were taken at 21 points along a 400 m transect in each upland site (high and low disturbance) and at 18 points along 3 transects across each wetland site. Each soil sample consisted of a composite of five 20-cm deep sub-samples taken by 1-inch diameter soil probe within a 1 m^2 quadrat. Riparian wetland transects, 80 m in length, were located on either side of the stream (paired transects) and sampled at 20 m intervals. Wetland soils were sampled to a depth of 10 cm, using a 6.5-cm diameter polycarbonate corer. Each sample represented a composite of three subsamples taken within a 1 m^2 quadrat. The transect-based sampling layout facilitates both comparison of indicator response in high and low disturbance areas and, simultaneously, an evaluation of local, within-site variability. The soil characteristics and properties evaluated for this study were total C, N and P, pH, organic matter, exchangeable NH_4^+, potentially mineralizable N, microbial biomass C and N, soil respiration, Mehlich 1 and 3 extractable P, HCl and ammonium oxalate extractable P, Fe and Al, and microbial enzyme activity (acid phosphatase, beta glucosidase and dehydrogenase).

Additional soil and vegetation monitoring transects were established at 4 upland and 3 wetland sites in D12, D13 and O3 during June 2001. Upland transects were sampled in areas of high military disturbance (Rowan Hill – D12), low disturbance (D13), and planted pines (2 stands in O3 – ca. 5 years and 12 years). Wetland transects were sampled in watersheds with low (D13) and moderate military impact (D12), and a watershed dominated by managed timber land. Soils sampled along the upland and wetland transects were analyzed for total and extractable nutrients and microbial activity, as previously indicated. The upland transects, all of which are underlain by Troup loamy fine sands, were 200 m total length, and were sampled for soil biogeochemical characterization at 20 m intervals. Sampling procedures were modified slightly for wetland sites during this sampling event, i.e., the sampling depth was decreased from 10 to 5 cm. It was concluded that sampling only the upper 5 cm of wetland soils provided greater sensitivity and resolution for comparing soil biogeochemical processes among sites. To accommodate this change, the previously sampled wetland transects were resampled using a soil depth of 5 cm. Analysis was completed for soil samples during FY2001-2002.

3.1.1 Soil Biogeochemical Analyses

The 300 Phase 1 sites were categorized as low, moderate or severe disturbance, based on visual assessment of vegetation and soil disturbance in the immediate vicinity (ca. 0.1 ha area surrounding the sampling point). Such an initial characterization, albeit a rough estimate, of site disturbance was considered to be necessary component of the evaluation process for soil variables as potential indicators of ecological condition.

A summary comparison of soil total carbon (TC) and microbial biomass C (expressed as a proportion of total C {MBC:TC}) among low-, moderate- and severe-disturbance sites grouped by landscape position (uplands and bottomlands / wetlands) is presented in Fig. 1. These data support field observations that the primary manifestation of intensive military training, with respect to soil quality, is soil erosion in uplands and associated sedimentation in wetlands. Loss of topsoil in disturbed upland sites has resulted in decreased soil organic matter content, shown here as total C. While much of the soil organic matter lost from upland sites is apparently flushed into streams, a significant proportion of the mineral or inorganic component, primarily silt and clay, but also sand in extreme cases, tends to settle out in downslope and downstream wetlands. Thus, a decrease in organic content of disturbed wetland soils occurs as a result of “dilution” by inorganic soil material. In general, for both wetlands and uplands, soil chemical and biological parameters typically correlated with soil organic matter also tend to decrease with increasing site disturbance.

Among the soil parameters that typically decrease with increasing site disturbance is soil microbial biomass C (data not shown), which is primarily a function of decreasing soil organic matter. However, when MBC is expressed as a proportion of total soil C, the MBC:TC tends to increase with increasing levels of soil disturbance. We believe that this phenomenon relates to the relative availability of organic C to heterotrophic microorganisms in the soil. It appears that the loss of “stable” soil organic matter, e.g. humus, near the soil surface through topsoil erosion in uplands or sedimentation in wetlands results in a higher proportion of freshly-deposited organic material, e.g. leaf fragments, in the soil organic matter pool, thus stimulating microbial growth within the organic material. The availability of nutrients such as N, P or K may also be a factor, but this has not been clearly indicated by our data thus far. The relationships between soil organic matter and microbial biomass, activity and diversity will be examined in greater detail, along with implications to soil quality and ecological stability (and change), during FY 2002.

Phase 2 data, which is relatively site-specific compared to Phase 1 data, revealed similar trends in soil C and microbial biomass in response to site disturbance (Figs. 2 and 3). Analysis of within-site spatial and temporal variability along upland and wetlands transects will continue during FY2002, and will be reported in subsequent reports.

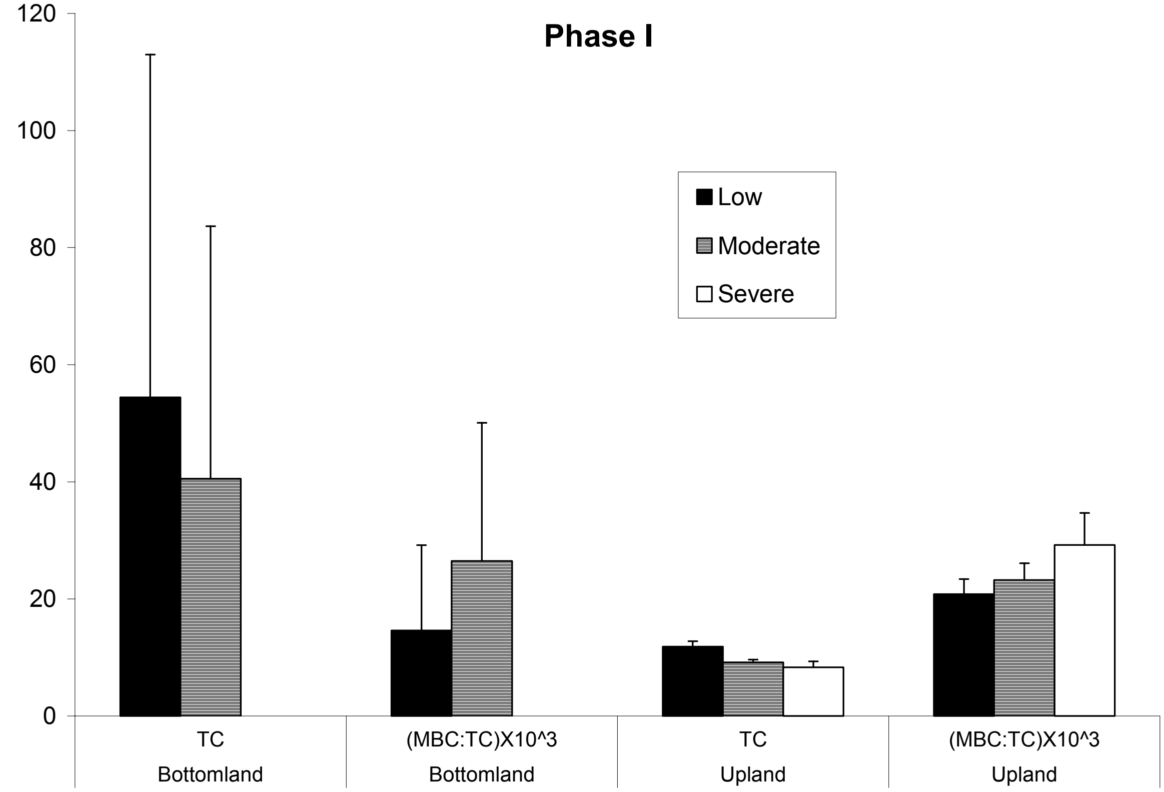


Figure 1. Summary of Phase 1 soil analysis (300 sites) for total carbon and microbial biomass C (as proportion of total soil C) at low-, moderate- and severe-disturbance sites in uplands and bottomlands (wetlands). Data points are mean values, with standard deviation denoted by error bars. All wetland sites sampled during Phase 1 were classified as either "low" or "moderate" disturbance, hence there is no "severe" class shown for wetlands.

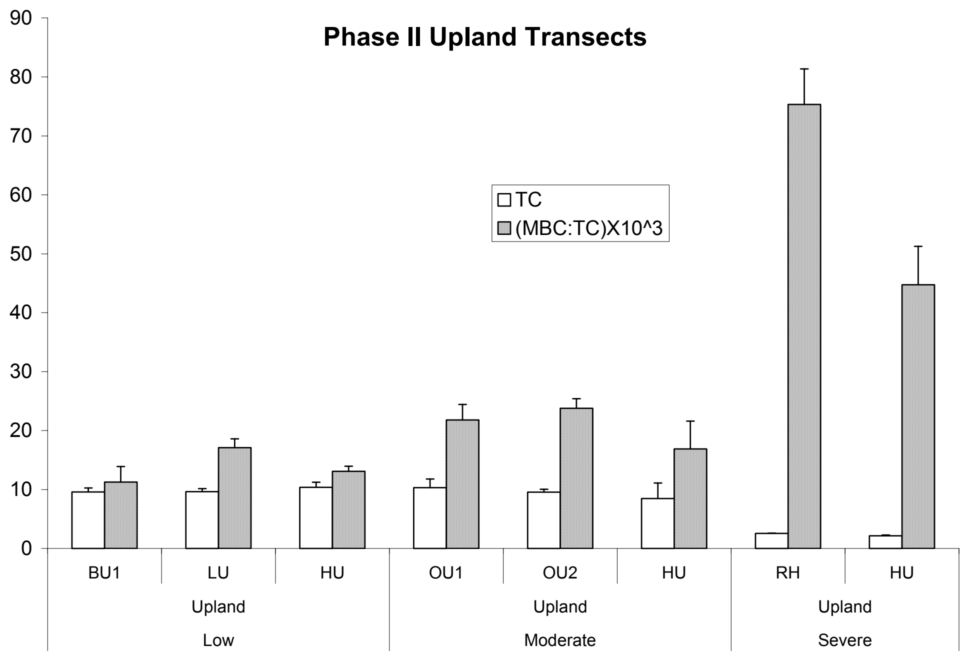


Figure 2. Summary of Phase 2 (transects) soil analysis for total C and microbial biomass C (proportion of total soil C) at low-, moderate- and severe-disturbance sites in uplands. Data points are mean values, with standard deviation denoted by error bars.

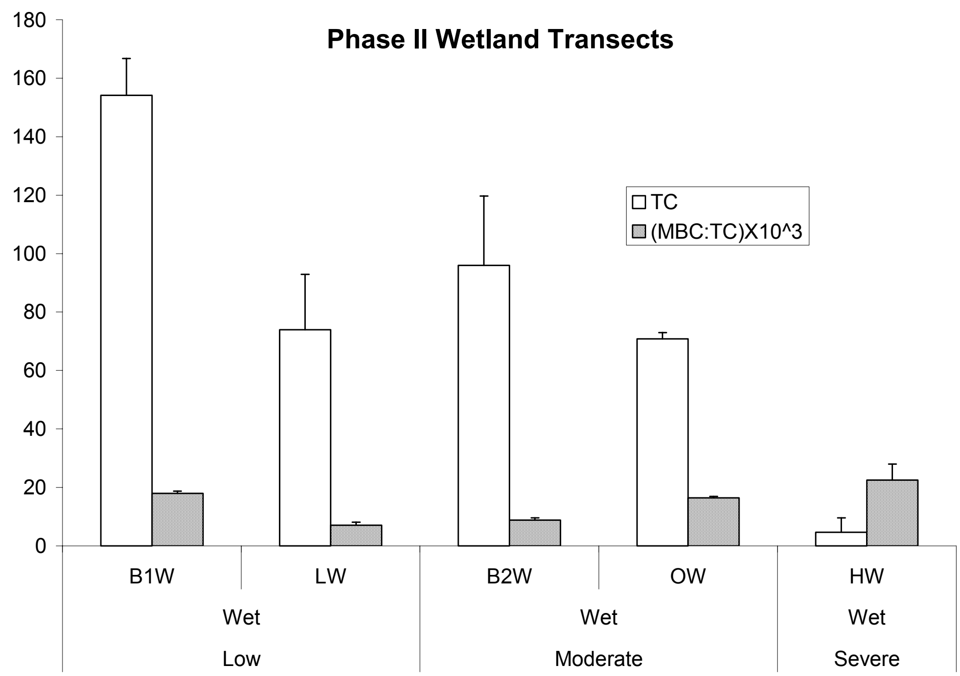


Figure 3. Summary of Phase 2 (transects) soil analysis for total C and microbial biomass C (proportion of total soil C) at low-, moderate- and severe-disturbance sites in wetlands. Data points are mean values, with standard deviation denoted by error bars.

3.1.2 Multivariate analyses

Multivariate statistical analyses were performed on the Phase 1 soil biogeochemical data set, using the most-commonly analyzed parameters: pH, organic matter content, total phosphorus, water extractable P, oxalate extractable P, Mehlich-1 P, microbial P, total carbon, total nitrogen, water extractable C, microbial C, exchangeable ammonium, microbial N, Mehlich-1 Fe, Al, Ca, Mg and K, oxalate extractable Fe and Al. All parameters except for pH were log-transformed prior to analysis, due to the log-normal distributions of these variables.

Cannonical Discriminant Analysis was used as a visualization technique to reduce the dimensionality of the multivariate data set while maximizing the separation between specific categories of data. This was accomplished by developing a smaller set of cannonical variables (which are a weighted linear sum of the original variables), that preserve the maximum variability of the original data set that can be attributed particular data classes. For the Phase 1 soil biogeochemistry data set Cannonical Discriminant Analysis was conducted to provide maximum discrimination among pre-determined site disturbance classes (low, moderate and severe). Results in Fig. 4 show that the canonical variable 1 provides relatively good separation among sites designated as low and moderate, while canonical variable 2 primarily provides separation of severe-disturbance sites from those with low to moderate disturbance. Thus, canonical variable 1 represents a simple combination of soil biogeochemical characteristics that may provide a useful indicator of ecological change, especially where differences or changes in site condition are not easily discernable by observation.

Discriminant Function Analysis is a procedure for classifying observations into two or more groups on the basis of one or more quantitative measurements. To develop the discriminant function, prior knowledge of the classes from which each observation is taken is required, unlike cluster analysis. Quadratic discriminant function analysis was conducted on the Phase 1 soil biogeochemistry data set. The degree to which the a priori site disturbance classification is supported by the soils data is shown in Table 1 as the proportion of the sites assigned to each disturbance class (low, moderate and severe) that fall into the assigned class, based on discriminant function analysis, as compared to the other 2 disturbance classes. Results indicate that the Phase 1 soil biogeochemistry data "predict", to a large extent the degree of site disturbance.

Table 1. Results of discriminant function analysis of Phase 1 soil biogeochemistry data. Values in "low", "moderate" and "severe" columns indicate frequency of statistical grouping of sites in each class, for each pre-determined disturbance group (rows).

From Disturbance	Low	Moderate	Severe	Total
Low	89	16	3	108
Moderate	15	68	5	88
Severe	2	11	13	26

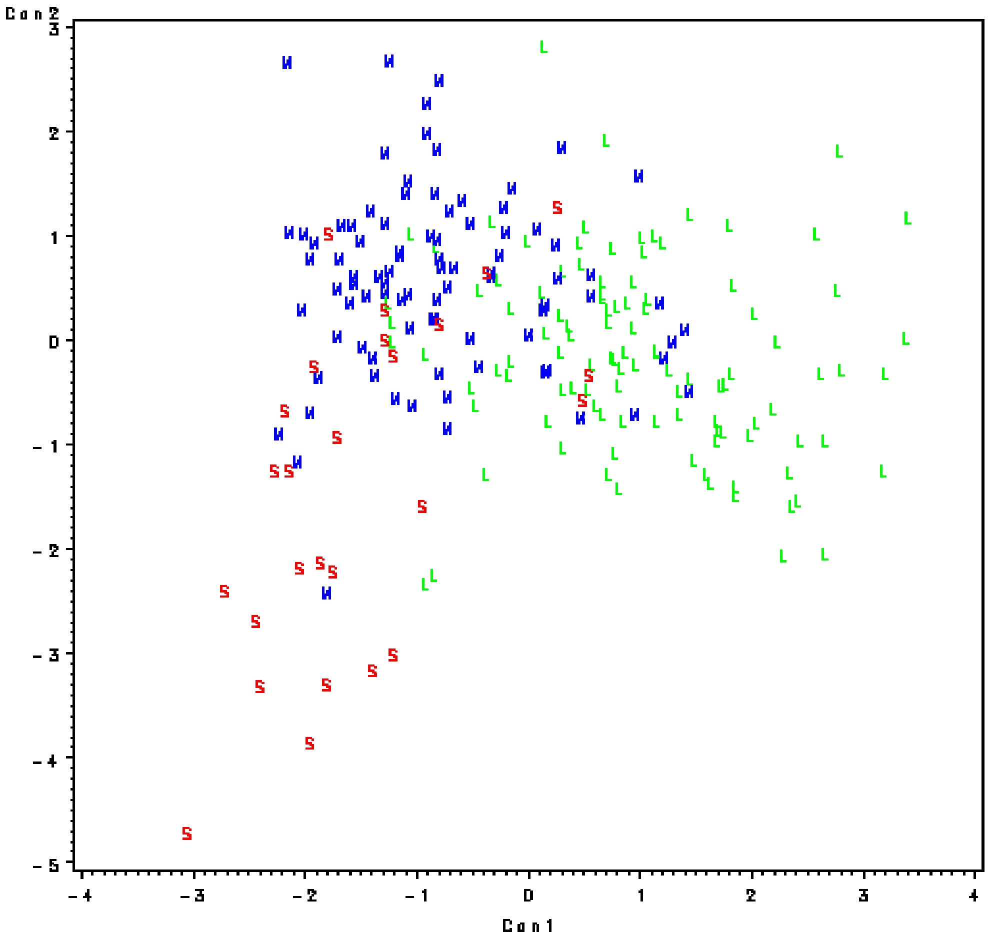


Figure 4. Plot of canonical variables 1 vs 2 for Phase 1 soil biogeochemical parameters. Data are grouped by level of site disturbance, based on visual assessment in the field: low (L), moderate (M) and severe (S).

3.1.3 Soil microbial diversity

The compositions and structures of methanotrophic bacteria were evaluated as indicators of impact along transects taken from uplands and wetlands. The primary tool used to compare the compositions of these assemblages is terminal restriction fragment polymorphism analysis (T-RFLP), a method to fingerprint the 16S rRNA gene belonging to methanotrophs. This method allows visualization of different genotypes of methanotrophs as peaks in an electropherogram, similar to different analytes being visualized as different peaks in a gas chromatogram. Most T-RFLP data are simply analyzed by comparing the presence or absence of a peak (or genotype) between samples. We attempted to extend the meaning of t-RFLP data by including the relative peak sizes as representative of the relative concentrations of the different genotypes in different samples. The validity of this assumption was checked in studies conducted early in 2001.

Most of the activity during the last quarter was to analyze data by various analytical and statistical approaches to determine the most appropriate indicators. Comparison of Shannon diversity indices for high and low impact soils indicated significantly higher methanotroph T-RFLP diversity for low impact upland

Table 2. Shannon diversity indices of four different transects

	Wetland	Upland
High impact	0.40	0.23
Low impact	0.48	0.54*

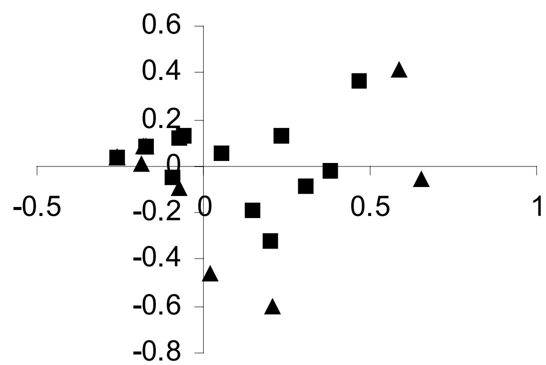
* Significantly different ($P < 0.05$)

than high impact uplands Table 2. Impact of various types is generally thought to decrease biological diversity. No significant difference was observed in diversity between high and low impact wetland samples, however.

Principal Components Analysis (PCA) (Fig. 5) did not discriminate between high and low impact samples (Fig. 5A); however, low impact wetland samples clustered together, as did high impact wetland samples (Fig. 5B).

In summary, a combination of statistical methods were necessary to identify differences between low and high impact regions of wetland and upland sites. A simple comparison of diversity indices discriminated between high and low impact uplands, whereas PCA was required to differentiate wetland samples on the basis of impact.

A



B

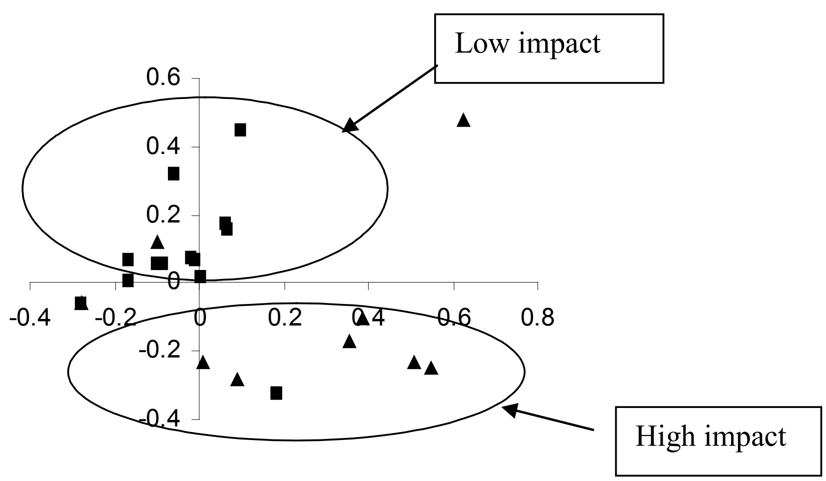


Figure 5. PCA discrimination of four soils based on methanotroph assemblage composition. a) upland samples; b) wetland samples. Close square (■), low impact sample; close triangle (▲), high impact samples. X-axis PCI, Y-axis, PCII.

3.2 VEGETATION

Structural and compositional parameters of the vegetation were measured in the summer and fall of 2000 at the same sampling sites as selected for soil biogeochemical characterization across second and third order watersheds within six watersheds: Halloca, Randall, Sally Branch, Bonham, Shell and Wolf Creek. Understory woody plants canopy cover (< 2-m tall) along three 5-m transects and overstory canopy cover (densiometer) were measured at all locations (n= 273). Understory composition and cover and biomass, including litter were measured within three 1-m^2 at the triplicate soil testing sites within the watersheds (n= 56).

Various environmental parameters were measured at all sites by the soil characterization team including: site position (upland, slope, or bottom), soil texture (sand, loam, sand/loam, clay, sand/clay, or organic), and disturbance (low, moderate, or severe). However, very few bottom sampling points had severe disturbance; most moderately and severely disturbed sites were at slope and upland positions. Disturbances resulted from both military training and logging activities.

A total of 113 woody species were encountered in the field; a small portion of these could not be identified to species, so they were given a number until definite identification can be obtained (Table 3). Inspection of the biplot generated by CCA of relative woody plant cover with environmental variables indicates a separation of low (Lo) disturbance sites from moderate (Mod) and severe (Sev) sites, but no marked separation between moderate and severe disturbance sites (Fig. 6). Severe disturbance was most closely associated with upland (Up), sandy clay (Sc) soils. Increased overstory canopy cover as estimated by densiometer measurements (densiom.) were associated with low disturbance sites. These associations have some statistical strength given the signifacance of the first eigenvalue (Table 4), however, the lack of a major decrease of the sequential eigenvalues from Axis 1 through Axis 4 indicates a lack of close association among the variables.

Severe disturbance sites were areas of active heavy military equipment training (tanks and Bradley personnel carriers). Within this classification there was a gradient of disturbance from a condition of virtual absence of woody plants to a condition of scattered larger trees (PILL, QUAR, PILO) and remnant shrubs and vines that could withstand, or be spread by, repeated vehicular trampling (OPUN, IPOM, VAC2, VIBRU, CRET) (see Fig. 6). Relative cover of RUBU and RHCO may be an important indicator of a shift from Mod to Sev conditions. These two species are prolific seed producers, enhancing their ability to colonize disturbed sites, and they appear to withstand physical disturbance once established.

We did not sample many bottom (Bot) sites that had had severe disturbance. The few sites of such classification, however, were downstream and close to road crossing. Erosional fans were evident along with some mortality of overstory trees. Consequently, most bottom sites were classified as low disturbance. Organic soils were rare and were at sites of impounded water. i.e., beaver ponds. It is possible that beaver ponds should be classified as Sev disturbance sites from an ecological viewpoint.

A total of 110 herbaceous species were encountered while sampling (Table 5). Some of these species were not identifiable to species due to immaturity, thus they were given a number. Hopefully, we will be able to identify them to species once we find them in flower and fruit. Given that a very limited number of herbaceous species were encountered within the bottom sites, CCA analysis between species cover and environmental variables was conducted for just the slope and upland sites where the vast majority of species occurred. Inspection of the biplot indicates the obvious separation of sever disturbance from moderate and low levels of disturbance along a gradient from high litter cover (Lo and Mod) to an absence of litter cover (Sev). The separation between Lo and Mod disturbance categories, however, was not distinctive, hence a possible explanation for a lack of statistical significance for the first eigenvalue of the analysis (Table 4). Inspection of the minimal degree of difference among the third and fouth eigenvalues also indicates a general a lack of structure among the relationships. Therefore, this analysis should be viewed as an indication of a possible trend among the variables. This result possibly is related to the relatively low sample size of the analysis (n= 36).

Litter cover varies with short-term forest management regimens, e.g., burning schedules. Litter cover will be related to basal area of overstory trees and basal area and density of understory plants, both woody and herbaceous

Given the limitations of the weak statistical strength of the analysis, there appears to be a relationship between the cover of a subset of the herbaceous species and sites of severe disturbance (Fig. 7). Those herbaceous species most closely associated with severely disturbed sites were: DICI, DITE, STBI, GR4, ARPU, OPHU,HADI, and PANO. Solid stands of PANO occurred on sites that had been severely disturbed in the past; this species probably was planted to reduce erosion from the sites.

Table 3. Codes for woody species encountered in Phase I.

Codes	Scientific Name	Codes	Scientific Name
AMBE, FAGR	Fagus grandifolia	QUBJ	Quercus marilandica
AMBEA	Callicarpa americana	QUBL	Quercus velutina
ANIS	Illicium floridanum (or parviflorum)	QUHE	Quercus hemisphaerica
ARAR	Aralia spirosa	QULA	Quercus laurifolia
ARARB	Aronia arbutifolia	QUMA	Quercus margaretta
ASHE	Fraxinus pennsylvanica	QUPO	Quercus stellata
AZAL	Rhododendron sp.	QUSE	Quercus sp
BLBE	Carpinus caroliniana	QUSR	Quercus falcata
BLCH	Prunus serotina	QUTU	Quercus laevis
BLGU, NYSY	Nyssa sylvatica	QUWA	Quercus nigra
CAPH	Cephalanthus	QUWH	Quercus alba
CATA	Catalpa bignonioides	REBU	Cercis canadensis
CHIN	Quercus muehlenbergeii	REMA	Acer rubrum
CLAL, CLEAL	Clethra alnifolia	RETI	Cyrilla racemiflora
COBE	Coralbeads	RHCO	Rhus copallina
CRET	Crataegus sp.	RHOD	Symplocos tinctoria
CUGL	Cudwigia glandulosa	RIBI	Betula nigra
CYRA, TYTY	Cyrilla racemiflora	ROCA	Rosa carolina
DEBA	Decumaria barbara	RUBU	Rubus sp.
DESM	Desmodium sp.	SABA	Sabal sp.
DOGW	Cornus florida	SASS	Sassafras albidum
GADU	Gaylussacia dumosa	SBMA	Magnolia virginiana
GAFR	Gaylussacia frondosa	SEFR	Sebastiania fruticosa
HICK	Carya sp.	SH10	Shrub 10
HOBE	Ostrya virginiana	SH11	Shrub 11
HOSU	Lonicera sempervirens or japonica	SH15	Shrub 15
HYHY	Hypericum hypericoides	SH2	Shrub 2
HYQU	Hydrangea quercifolia	SHSS	Shrub seedling
ILCO	Ilex coriacea	SMIL	Smilax sp.
ILDE	Ilex decidua	STAM, STAME	Styrax americanum
ILGL	Ilex glabra	STGR	Styrax grandiflorium
ILOP	Ilex opaca	SUBE	Celtis
IPOM, MOGL	Ipomea sp.	SWGU	Liquidambar styraciflua
ITEA	Itea virginica	TR3	Tree 3
KUDZ	Pueraria lobata	TR6	Tree 6
LISI	Ligustrum sinense	TRCR	Campsis radicans
LOJA	Lonicera japonica	TRSE	Tree seedling
LYON	Lyonia sp.	TUPO	Liriodendron tulipifera
MAGR	Magnolia grandiflora	UN2	Unknown 2
MYCE	Myrica cerifera	UN8	Unknown 8
MYHE	Myrica heterophylla	UNIL	Ilex sp.
MYRI	Myrica sp.	UNSE	Unknown seedling
OABJ	Quercus incana	UNTR	Unknown tree
OPUN	Opuntia sp.	UT1	Unknown tree 1
OXAR	Oxydendrum arboreum	VAAR	Vaccinium arborum
PAPA	Asimina parviflora	VAC2	Vaccinium sp.
PEBO	Persea borbonia	VAEL	Vaccinium elliotii
PERS	Diospyros virginiana	VAMY	Vaccinium myrsinites
PEVI	Ampelopsis arborea	VAST, VASTA	Vaccinium stamineum
PILL	Pinus palustris	VIBRU, VIBU, VIRU	Viburnum rufidulum
PILO, PITA	Pinus taeda	VICR	Parthenocissus quinquefolia
PISH	Pinus echinata	VIN3	Vine 3
POIV	Toxicodendron radicans	VIROT	Vitus rotundifolia
POOA	Toxicodendron pubescens	WIEL	Ulmus alata
PRAN	Prunus angustifolia	WIHA	Hamamelis virginiana
PRUM	Prunus umbellata	YEJE	Gelsemium sempervirens
QUAR	Quercus arkansana	YUCC	Yucca filamentosa

Table 4. Phase I Canonical Correlation Analysis eigenvalues for woody plant species relative cover correlated with environmental variables at all sites and herbaceous species absolute cover correlated with environmental variables at upland and slope sites.

	Axis 1[a]	Axis 2	Axis 3	Axis 4
Woody spp	0.52 (*)	0.21	0.18	0.16
Herbaceous spp.	0.56 (ns)	0.48	0.34	0.28

[a] Test of significance of first eigenvalue: *= <0.05, ns= not significant.

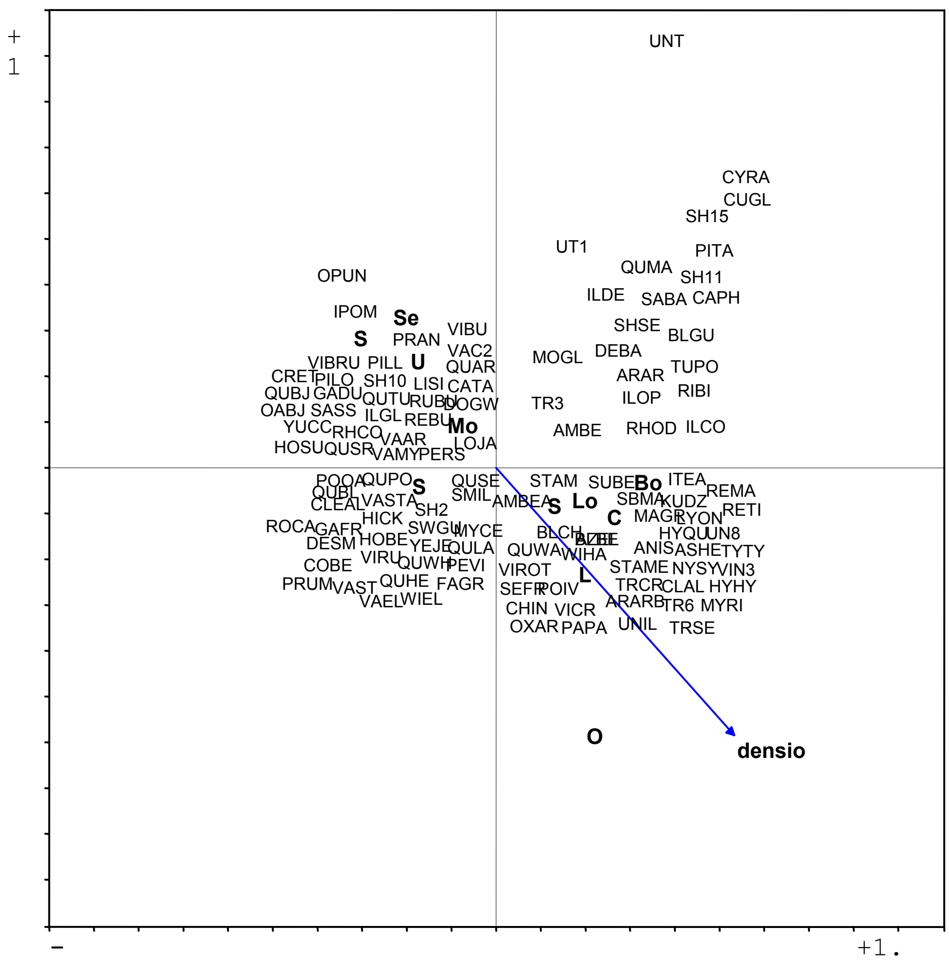


Figure 6. Phase I CCA biplot for woody species relative cover and environmental variables.

Table 5. Codes for herbaceous species encountered in Phase I.

Code	Scientific Name	Code	Scientific Name
AGTE	Agalinas tencifolia	HADI	Haplopappus dirasicatus
ANsC	Andropogon sp. (cover)	HEAR	Hexastylis arifolia (Asarum arifolium)
ANsD	Andropogon sp. (density)	HYGE	Hypericum gentioides
ANTE	Andropogon ternarius	LEVI	Leersia virginica
ANVIc	Andropogon virginicus (cover)	LECU	Lespedeza cuneata
ANVId	Andropogon virginicus (density)	LEHI	Lespedeza hirta
ANRU	Anthaenantia rufa	LIEL	Liatris elegans
ARPU	Aristida purpurescens	LITE	Liatris tencifolia
ARTU	Aristida tuberculosa	LIS	Liatrus sp.
ARGA	Arundinaria galgantium	LISQ	Liatrus squarrulosa
AS1	Aster 1	ONSE	Onoclea sensibilis
AS2	Aster 2	OPHU	Opuntia humifusa
AS3	Aster 3	OSCI	Osmunda cinnomomea
AS4	Aster 4	OSRE	Osmunda regalis
AS5	Aster 5	PACHc	Panicum chamaelanche cover
AS6	Aster 6	PACHd	Panicum chamaelanche density
ASDU	Aster dumosus	PACLc	Panicum clandestinum cover
ASLA	Aster laterifloris	PACLd	Panicum clandestinum density
ASTO	Aster tortifolias	PANO	Paspalum notatum
BRER	Brachyelytrum erectum	PASE	Paspalum setaceum
BUCI	Bulbostylis ciliatifolia	PITY	Pityopsis
CAS	Cassia sp.	POPR	Polypremum procumbens
CES	Cenchrus sp.	POS	Potentilla sp.
CHLA	Chasmanthium laxum	PTAQ	Pterydium aquilinum var. pseudocaudatum
CIAR	Cinna arundinacea	RAGW	Ragweed
CRST	Cnidoscolus stimulosus	RHMI	Rhynchosia minima
COER	Commelina erecta	RHMC	Rhynchospora microcephala
COMA	Coreopsis major	SCSCc	Schizacherium scoperium cover
COMS	Coreopsis major var. stellata	SCSCd	Schizacherium scoperium density
COS	Coriopsis sp.	SCMI	Schrankia microphylla
CRGL	Croton glandulosus	SCL	Scleria bottom
DEPA	Desmodium paniculatum	SE1	Sedge 1
DES	Desmodium sp.	SE2	Sedge 2
DICI	Digitaria ciliaris	SE3	Sedge 3
DITE	Diodia teres	SEPE	Segmaria pectinata
ELCA	Elephantopus carolineanus	SOOD	Solidago odora
ELTO	Elephantopus tomentopus	SOS	Solidago sp.
ERS	Erianthus sp.	SONU	Sorgastrum nutans
EGS	Erigonium sp.	SPMO	Sphagnum moss
ERHI	Erigrostis hirsuta	SPJUc	Sporobolus junceus cover
EUAL	Eupatorium altissimum	SPJUd	Sporobolus junceus density
EUCA	Eupatorium capillifolium	STBI	Stylosanthes biflora
EUJU	Eupatorium jucundum (Ageratina jucunda)	TEFL	Tephrosia florida
EUPU	Euphorbia pubentissima	TEVI	Tephrosia virginiana
FE1	Fern 1	TRS	Tradescantia sp.
FO1	Forb 1	TRFL	Tridens flavus
FO10	Forb 10	TRAM	Triplasis americana
FO2	Forb 2	UN	Unknown
FO3	Forb 3	VEAN	Vernonia angustifolia
FO4	Forb 4	WOOB	Woodsia obtusa
FO5	Forb 5	WOAR	Woodwardia areolata
FO6	Forb 6	XYDI	Xyrus difformis
FO7	Forb 7		
FO8	Forb 8		
FO9	Forb 9		
GAVO	Galactia volubilis		
GACI	Galium circaezans		
GAUR, GAFI	Gaura filiper		
GR1	Grass 1		
GR2	Grass 2		
GR3	Grass 3		
GR4	Grass 4		

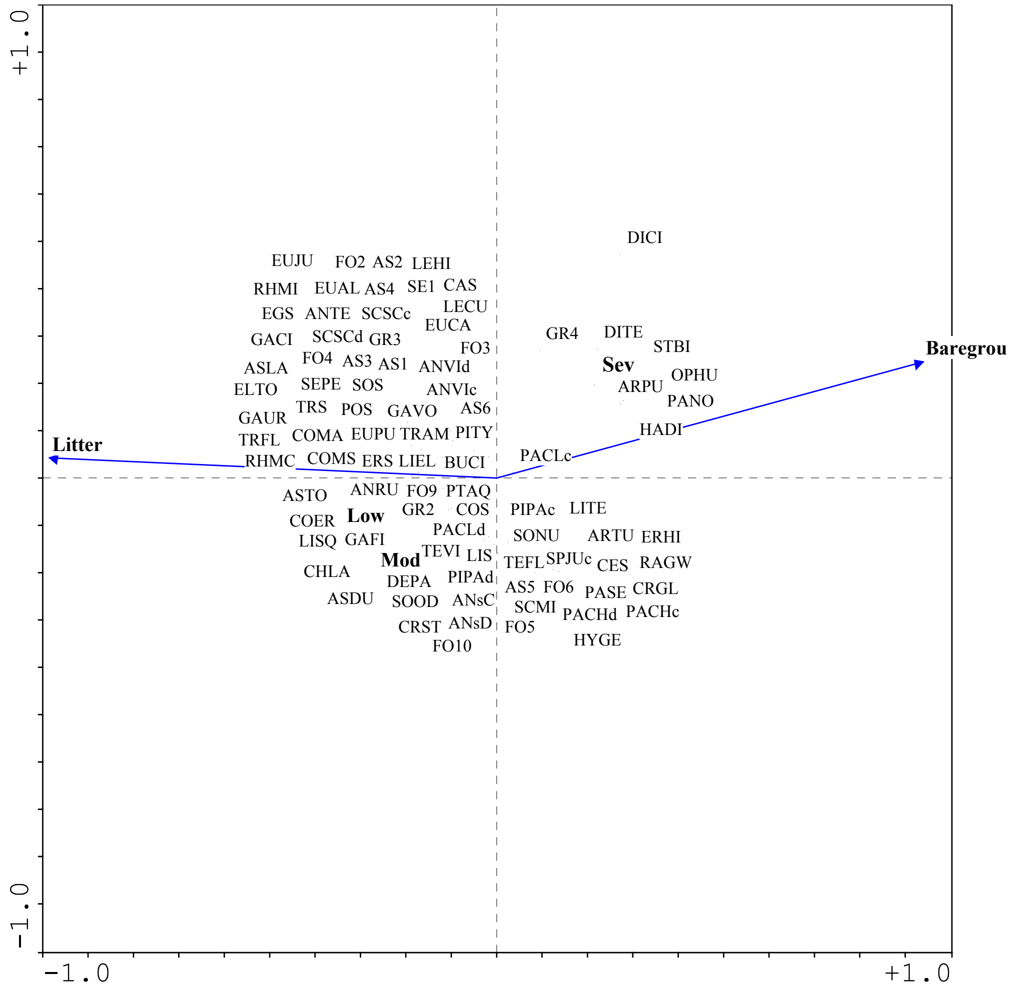


Figure 7. Phase I CCA biplot for herbaceous species absolute cover and environmental variables.

3.3 WATERSHED HYDROLOGY

3.3.1 Water Content Sampling

Monitoring how distributed storage changes both spatially and temporally was begun in FY2001. Soil moisture was measured and logged at several distributed locations and along specific transects in the "Bonham-1" subwatershed, a relatively low-impact catchment in D13 (Fig. 8). Preliminary measurements were used to estimate the total water storage and spatial moments of water content within the catchment (Fig. 9).

Distributed soil moisture content was sampled both in June 2001 and August 2001. Analysis shows relatively dry upland soils with increasing water content on the hill slopes. The majority of the water storage is confined to the areas immediately adjacent to the stream channel. More data is needed to observe water redistribution activity under different climate and seasonal situations as well as a more detailed characterization of moisture dynamics in riparian areas. Soil moisture measurements will also be extended to other watersheds as well as impacted areas for comparison purposes.

3.3.2. Watershed Hydrologic Budget

Stream flow, stage, rainfall and throughfall data collection was continued and expanded during FY2001. Period 1 of 4 for the throughfall study was completed and initial results show a distinct signature among the 5 vegetation categories into five different groups: wetland, pine plantation, hard wood, mixed, and pine. The spatially distributed hydrological input model was developed, including a Gash throughfall model coupled to a GIS system which uses landuse coverages. Preliminary hydrologic modeling efforts in Bonham-2 were conducted using TOPMODEL. The model was run and produced reasonable results.

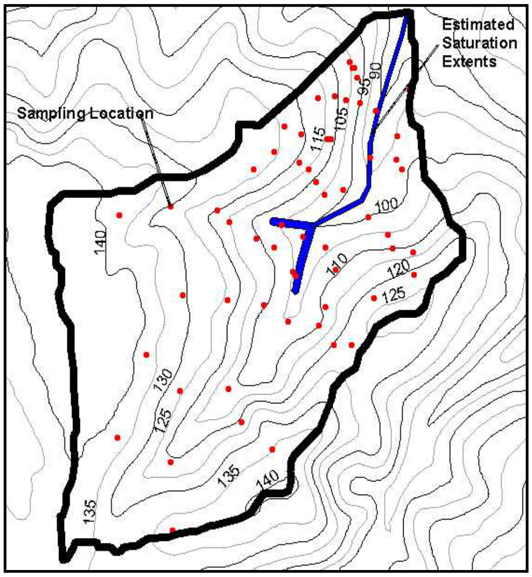
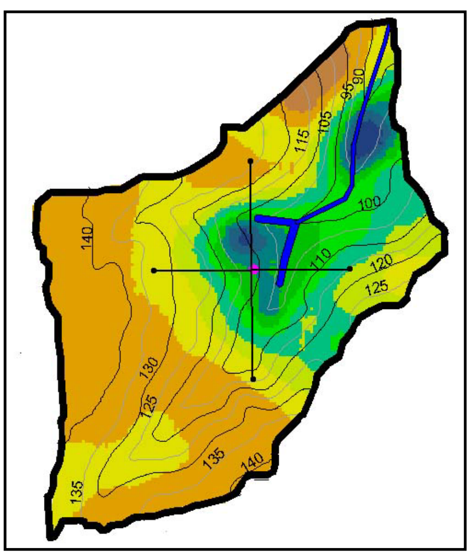


Figure 8. 70 Sampling locations in D13 catchment of Bonham-1 watershed – August 8, 2001.



Spatial Moment Summary

	w/o Stream Zone	w/ Stream Zone
Total Water (m3)	38,896	42,880
Centroid - x (m)	710,313	710,330
Centroid - y (m)	3,588,465	3,588,488
Centroid - z (in)	13	13
stddev - x (m)	251	247
stddev - y (m)	274	276
stddev - z (in)	9	9
Total Volume (m3)	580,710	
Average Water Content	0.067	0.074

Figure 9. Integrated water content in upper 30-inches, D13 Bonham-1 watershed - August 8, 2001. Shown on the plot are also the spatial mean water content (red point) and standard deviation about the mean (black lines).

4.0 PROJECT MILESTONES (FY2001)

The following are milestones for FY2002, as listed in the FY2002 Execution Plan, for the University of Florida-Purdue University research team:

Task	Due Date	Status
Sub-watershed sampling and analysis of soil and vegetation changes along ecological and land use/disturbance gradients	09/2002	Completed
Analysis of surface water hydrology processes as indicators of military disturbance	09/2002	Completed
Sub-watershed scale dynamics of spatial changes in soil-water storage	09/2002	Completed
Characterization of sediment deposition history and linkage to training activities	09/2002	Completed

5.0 FY2002 RESULTS AND SUMMARY

A summary of accomplishments for FY 2002 are presented below, for soil biogeochemistry, vegetation, and hydrologic components.

5.1. Soil Biogeochemistry

In FY2002 soil samples were obtained at 115 sites corresponding to the chronosequence study focusing on recovery of ground cover vegetation after tree harvest and reforestation (see Vegetation section below). In addition, sampling was repeated at wetland and upland regions previously sampled in December 2000 and August 2001 (i.e. highly-disturbed [D-15 compartment] and minimally-disturbed [D-4] areas). These areas were sampled in order to continue study of the temporal variability in soil indicators. Soil analyses were completed in FY2002 and data analysis is ongoing.

During 2001-2002 hyperspectral analysis was conducted on soil samples taken from the Ft. Benning Installation in Phase I (FY2000). The objectives of the spectral analyses were to 1) determine whether soil sample spectral signatures can be used to discriminate ecological impact at the Ft. Benning installation, and 2) determine the relationship between biogeochemistry and spectral reflectance for soil samples taken from the Ft. Benning installation. Hyperspectral scanning of 600+ soil samples was conducted in the lab using an ASD Spectrometer. Reflectance signatures of each soil sample were taken at a 1 nm sampling interval covering the range between 350 to 2500 nm. The reflectance signatures of the soil samples were analyzed using multivariate statistical methods. Principal Components Analysis was performed to achieve reduction of the dimensionality of data (2000+ variables of wavelengths) into a few important variables. Canonical Discrimination and Discriminant Function Analysis were conducted to determine whether spectral signatures can be used to discriminate soils taken from bottomlands and uplands and also from low, medium and highly disturbed sites. Canonical Correlation and Partial Least Squares were carried out to relate spectral signatures to soil biogeochemistry.

Results and Discussion:

Using Principal Component Analysis the 2000+ variables (wavelengths) were reduced to 7 principal components that explained 99.7% of the variation in the dataset (see Table 6). Loading factors for each of the 7 principal components illustrate which wavelengths contribute most to the variation among the samples (see Figure 10).

Table 6. Principal Components Analysis Results

	Eigen Value	Proportion	Cumulative
1	1608.52	0.7478	0.7478
2	287.03	0.1334	0.8812
3	174.24	0.0810	0.9623
4	44.52	0.0207	0.9830
5	17.37	0.0081	0.9910
6	9.76	0.0045	0.9956
7	3.47	0.0016	0.9972

The 7 principal components were then used to perform a canonical discrimination analysis based on the disturbance type (low, medium and high) and landscape position (uplands and bottomlands). Discrimination on the basis of landscape position was successful using one canonical variable. Results were comparable to Cannonical Discrimination Analysis results found using biogeochemistry data directly (see Figure 11-13).

Cannonical Discrimination on the basis on disturbance was found to be adequate using two canonical variables. This discrimination was not as successful as that obtained using 20 biogeochemical variables, but comparable to that obtained using 4 variables (see Figures 14-16).

Results of the Discriminant Function Analysis for landscape position based on the reflectance data are summarized in Table 7. These results are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables. Results of the Discriminant Function Analysis for disturbance based on reflectance data are summarized in Table 8. This table again shows that the results based on reflectance are slightly less accurate than those obtained using 18 biogeochemical variables, but provide approximately the same accuracy as those obtained using 4 biogeochemical variables.

Table 7: Discriminant Function Analysis for Landscape Position based on Reflectance

From Landscape Position	***Bottomlands***	***Uplands***	***Total***
Bottomlands	96 (74.4%)	33 (25.28%)	129 (100.0%)
Uplands	22 (8.21%)	246 (91.79%)	268 (100.0%)
Total	118	279	397

- Analogous results using 18 soil biogeochemical variables were 94% and 98%, respectively
- Analogous results using 4 soil biogeochemical variables were 82% and 91%, respectively

Table 8: Discriminant Function Analysis for Disturbance based on Reflectance

From Dist	***Low***	***Medium***	***Severe***	***Total***
Low	101 (55.4%)	58 (31.8%)	23 (12.6%)	182 (100.0%)
Medium	23 (13.2%)	119 (68.7%)	31 (17.9%)	173 (100.0%)
Severe	2 (4.7%)	21 (50.0%)	19 (45.24%)	42 (100.0%)
Total	126	198	73	397

- Analogous results for 18 biogeochemical variables were 72%, 90%, 10%.
- Analogous results for 4 biogeochemical variables were 43%, 90%, and 31%, respectively
- Misclassification rate related to continuity and overlap between disturbance classes

Partial Least Squares Analyses was used to develop predictive relationships between spectral reflectance and soil biogeochemistry. Phase 1 data were used to develop the relationships, and Phase 2 data were used for validation. Tables 9 and 10 summarize the accuracy of the relationships obtained. Good Phase 1 relationships were identified for TC, TN, TP, Meh Mg, Meh K, and Meh Ca. Good Phase 2 relationships were validated for TC, TN, TP, and Meh K. Figures 17-22 illustrate the quality of the relationships developed.

Table 9. Statistics for PLS predicted values for first phase sites.

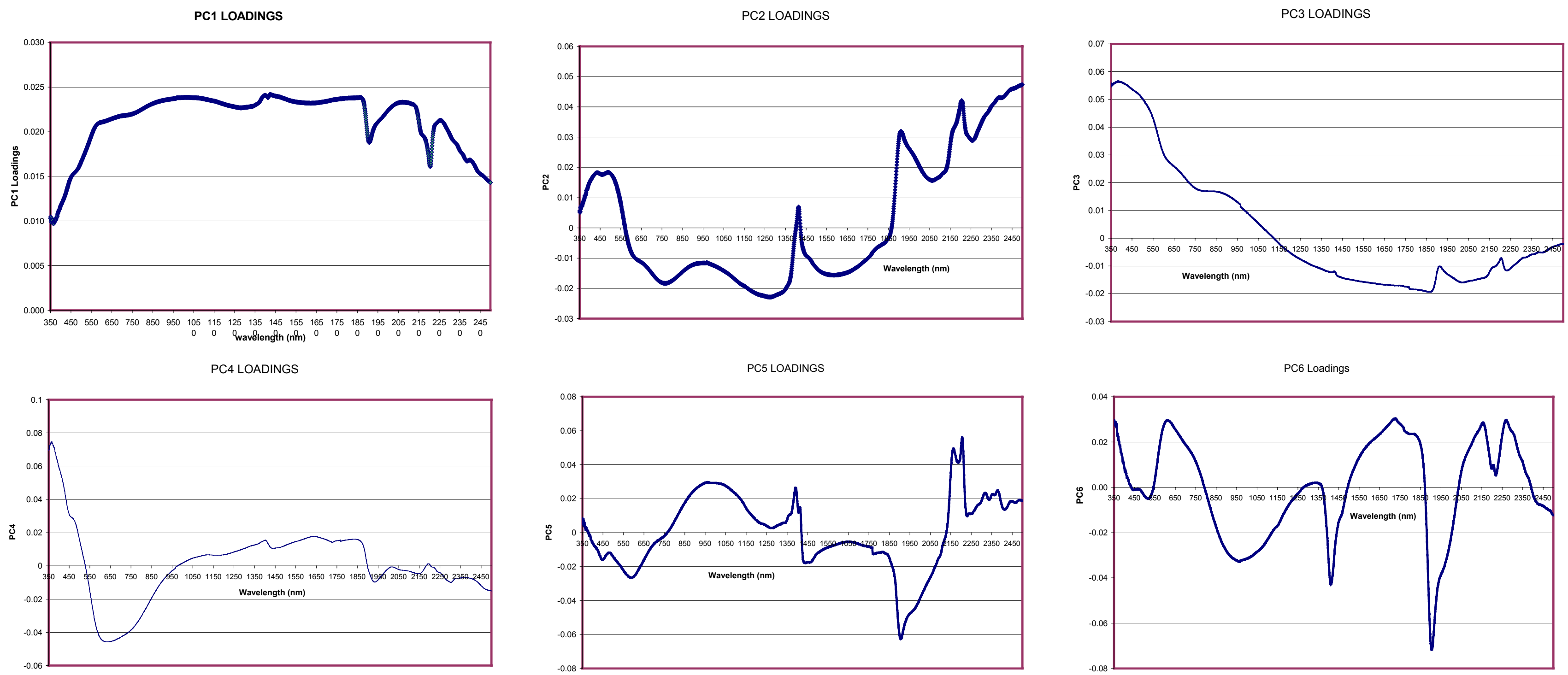
	Mean Error	RMS	F.E. *
pH	0.045	0.497	0.157
Ash	0.007	0.047	0.242
Total Carbon	0.003	0.152	0.810
Total Phosphorus	0.004	0.159	0.691
Total Nitrogen	-0.01	0.180	0.795
Oxalate Al	-0.01	0.134	0.603
Oxalate Iron	0.048	0.315	0.616
Oxalate Phosphorus	-0.19	0.283	0.478
Mehlich Al	0.0	0.165	0.699
Mehlich Iron	0.004	0.290	0.575
Mehlich Phosphorus	-0.04	0.319	-0.044
Mehlich Mg	-0.00	0.306	0.782
Mehlich Potassium	-0.01	0.206	0.731
Mehlich Calcium	0.01	0.360	0.669
Microbial Carbon	-0.06	0.326	0.269
Microbial Nitrogen	-0.02	0.25	0.464
Microbial Phosphorus	-0.06	0.434	0.188
Water Ext. Carbon	-0.05	0.383	-0.07
Water Ext. Phosphorus	-0.01	0.47	-0.08
KCl Ext. NH_4	0.03	0.01	0.131

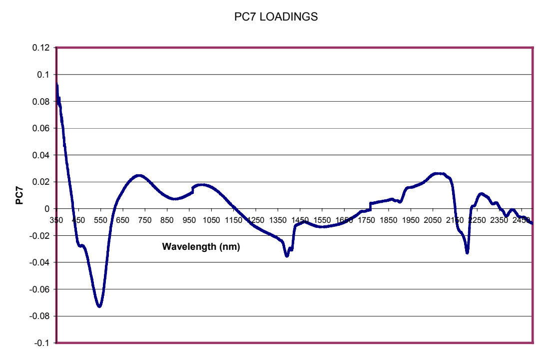
* Forecasting Efficiency

Table 10: Statistics for PLS predicted values for second phase sites

	Mean Error	RMS	F.E.*
pH	0.1974	0.5375	-0.385
Ash	0.039	0.445	-0.322
Total Carbon	0.022	0.234	0.841
Total Phosphorus	0.036	0.200	0.936
Total Nitrogen	0.022	.0234	0.976
Oxalate Al	0.058	0.197	-0.064
Oxalate Iron	0.004	0.372	0.448
Oxalate Phosphorus	0.041	0.352	0.352
Mehlich Al	-0.404	0.601	-0.070
Mehlich Iron	-0.304	0.524	0.245
Mehlich Phosphorus	-0.387	0.593	-0.352
Mehlich Mg	-0.473	0.781	-0.141
Mehlich Potassium	0.056	0.366	0.897
Mehlich Ca	0.108	0.432	-0.510
Microbial Carbon	-0.091	0.303	0.499
Water Ext. Carbon	-0.319	0.556	-0.153
Water Ext. Phosphorus	-0.305	0.759	-0.201
KCl Ext. NH_4	0.074	0.391	-0.919

* Forecasting Efficiency





PC1 accounts for brightness variation (related to albedo)
PC2 weights high wavelengths heavily, particularly around 1400, 1900, 2200 –OH absorption bands
PC3 and PC4 weight wavelengths through 850 nm heavily which are important in organic matter determination
PC5 weights wavelengths around 1000nm which are related to Fe content. Also –OH absorption bands
PC5,6,7 don't contribute much to reflectance variability but important for discriminating landscape position and disturbance

Figure 10: Principal Component Loadings for reflectance

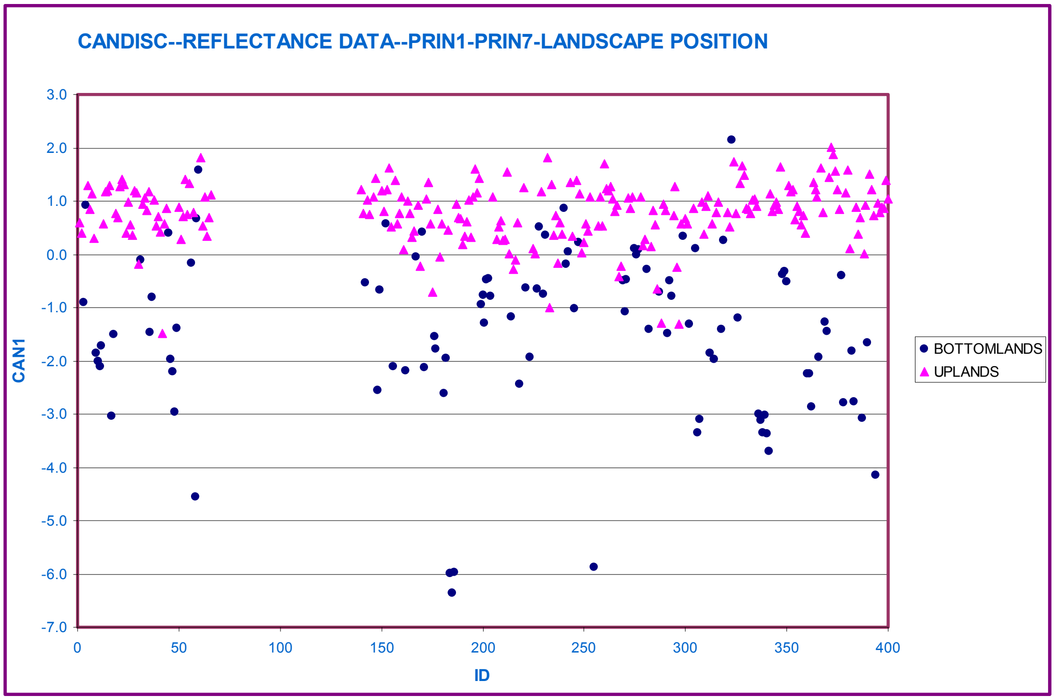


Figure 11: Discrimination on the basis of landscape position using reflectance data

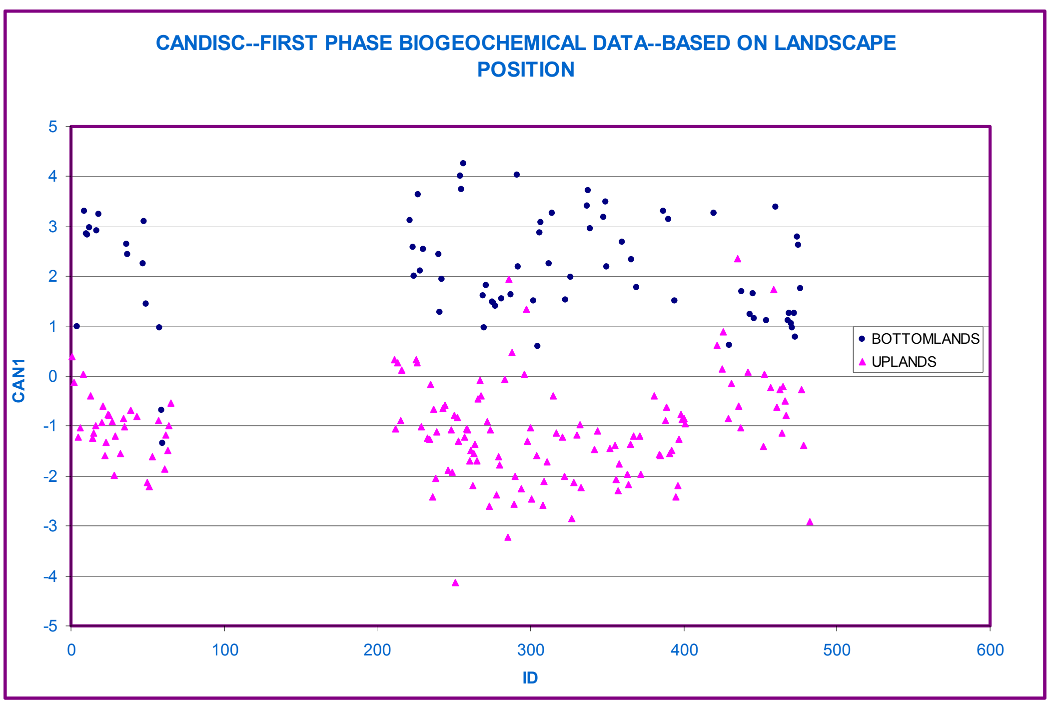


Figure 12: Discrimination on the basis of landscape position using 18 biogeochemical

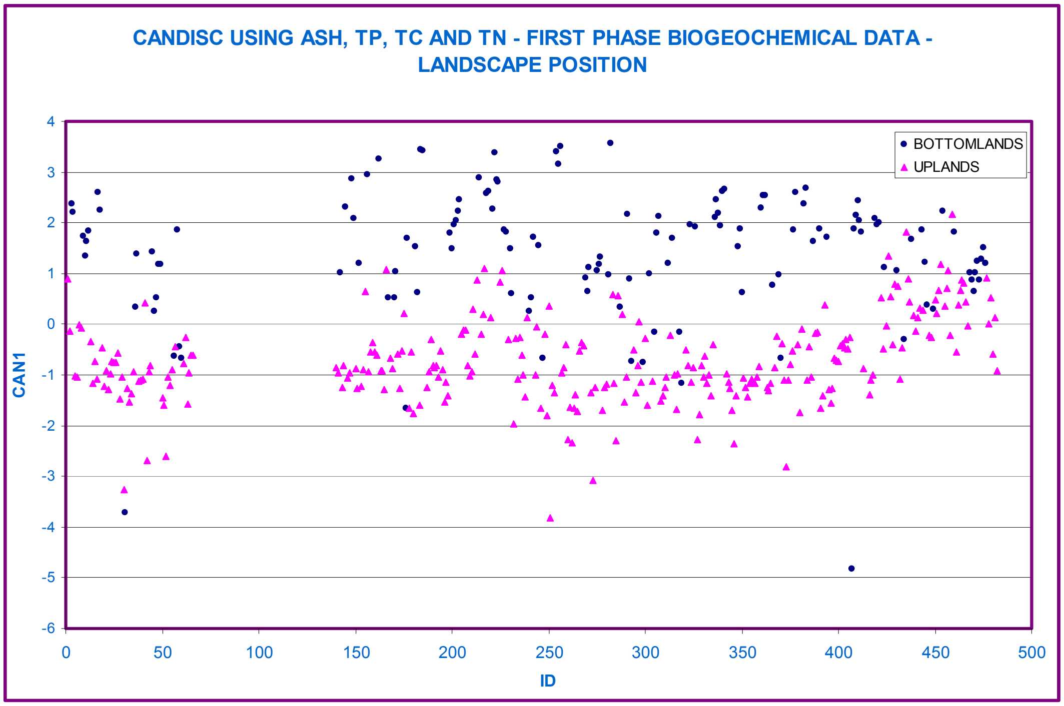


Figure 13: Discrimination on the basis of landscape position using 4 biogeochemical constituents

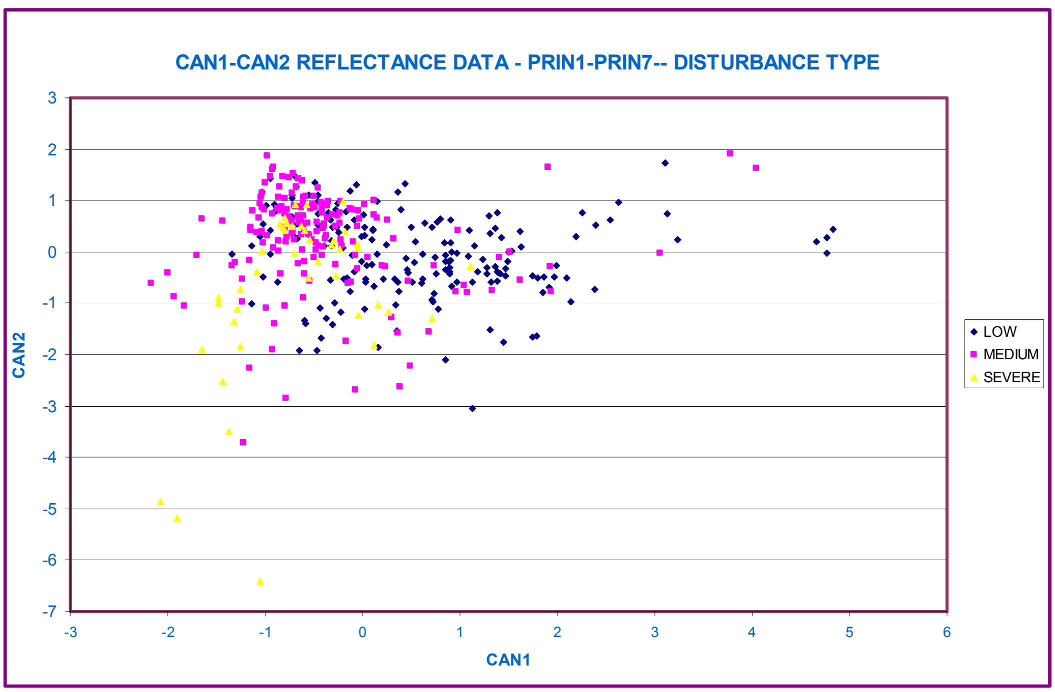


Figure 14: Discrimination on the basis of disturbance using reflectance

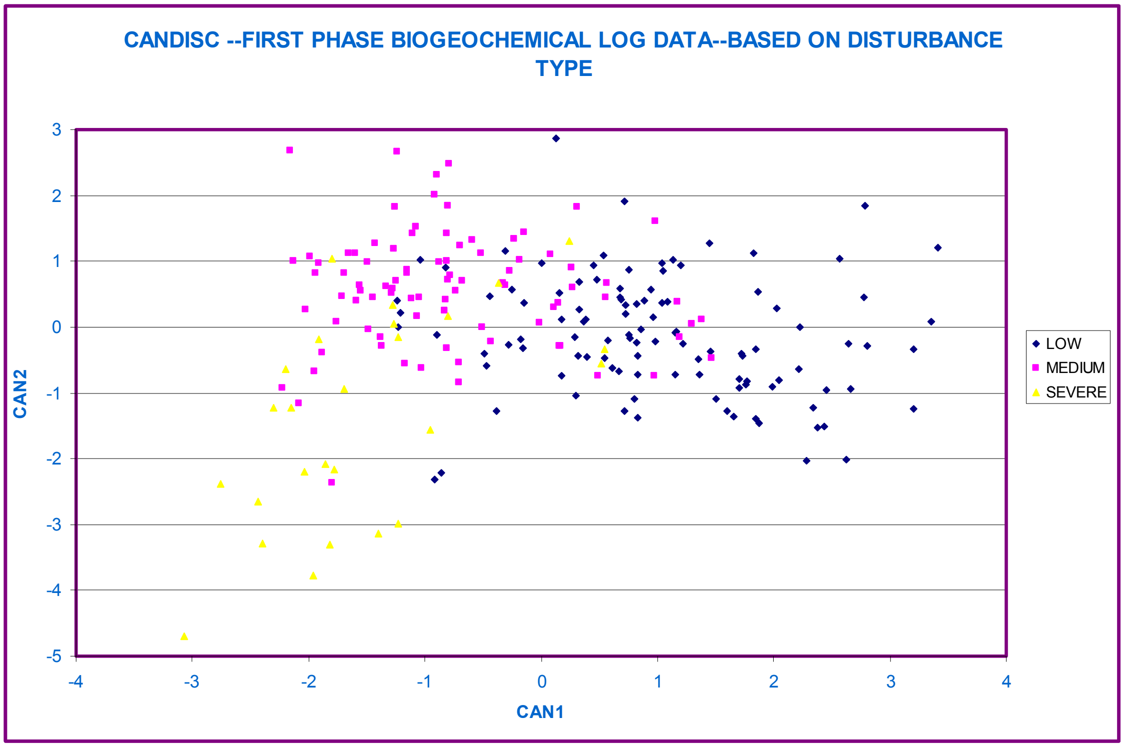


Figure 15: Discrimination on the basis of disturbance using 18 biogeochemical

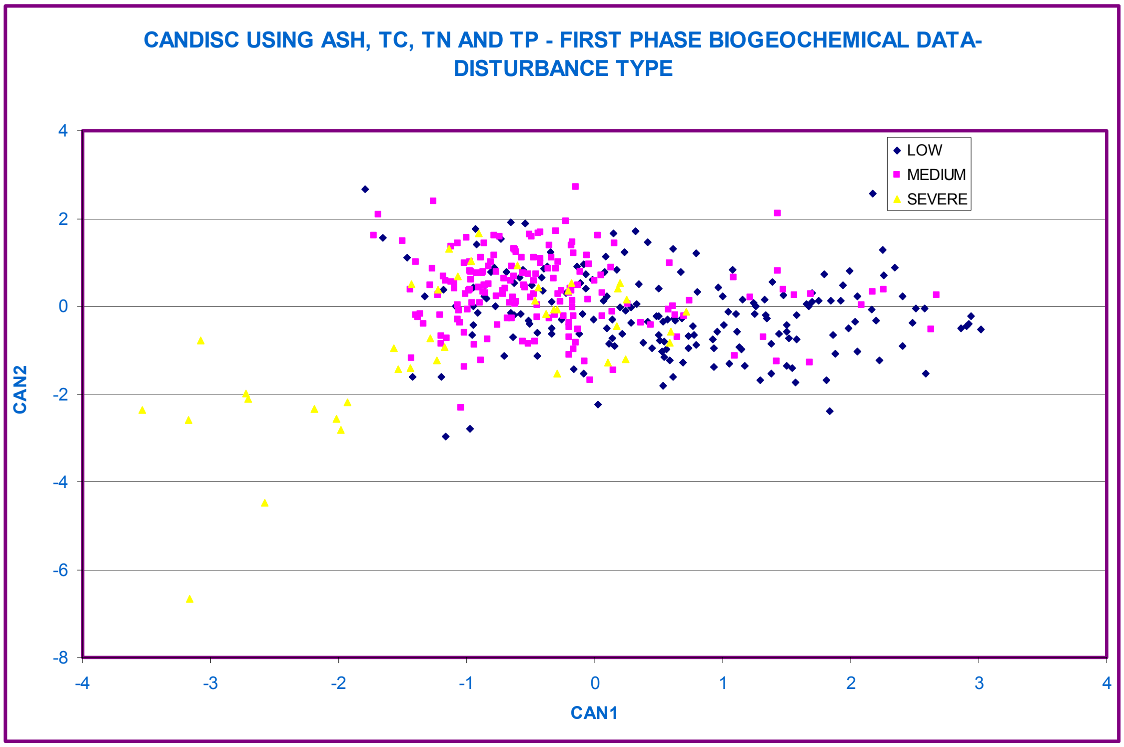


Figure 16: Discrimination on the basis of disturbance using 4 biogeochemical

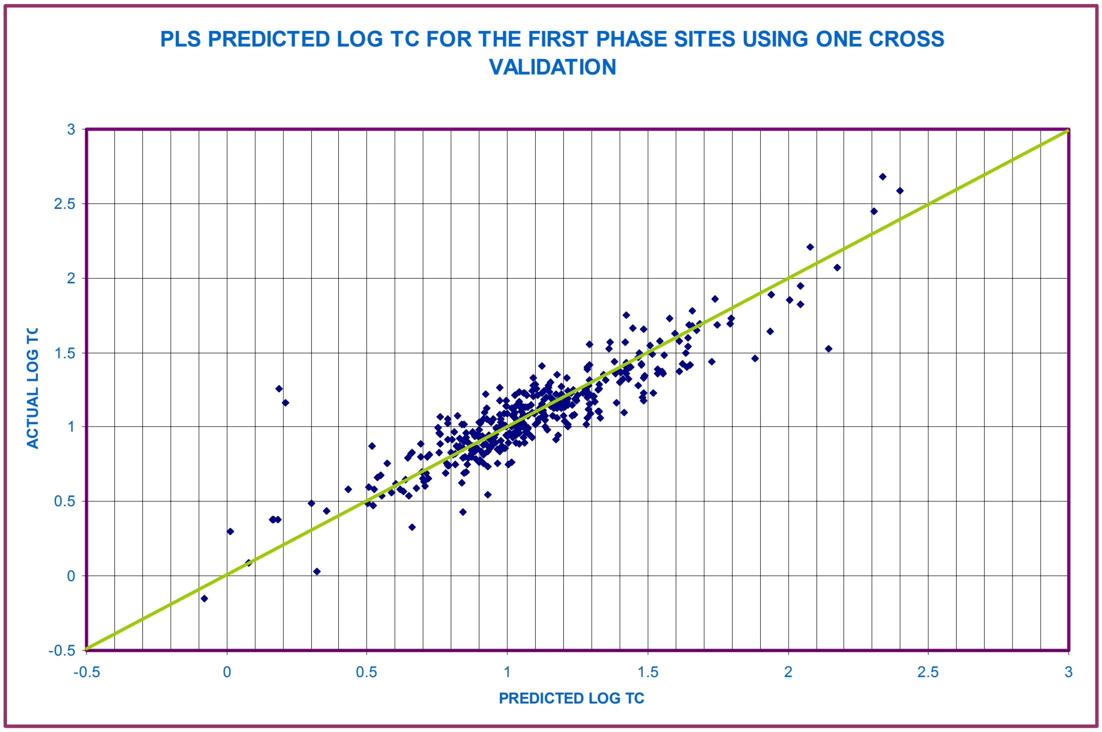


Figure 17: Phase 1 TC Prediction Accuracy

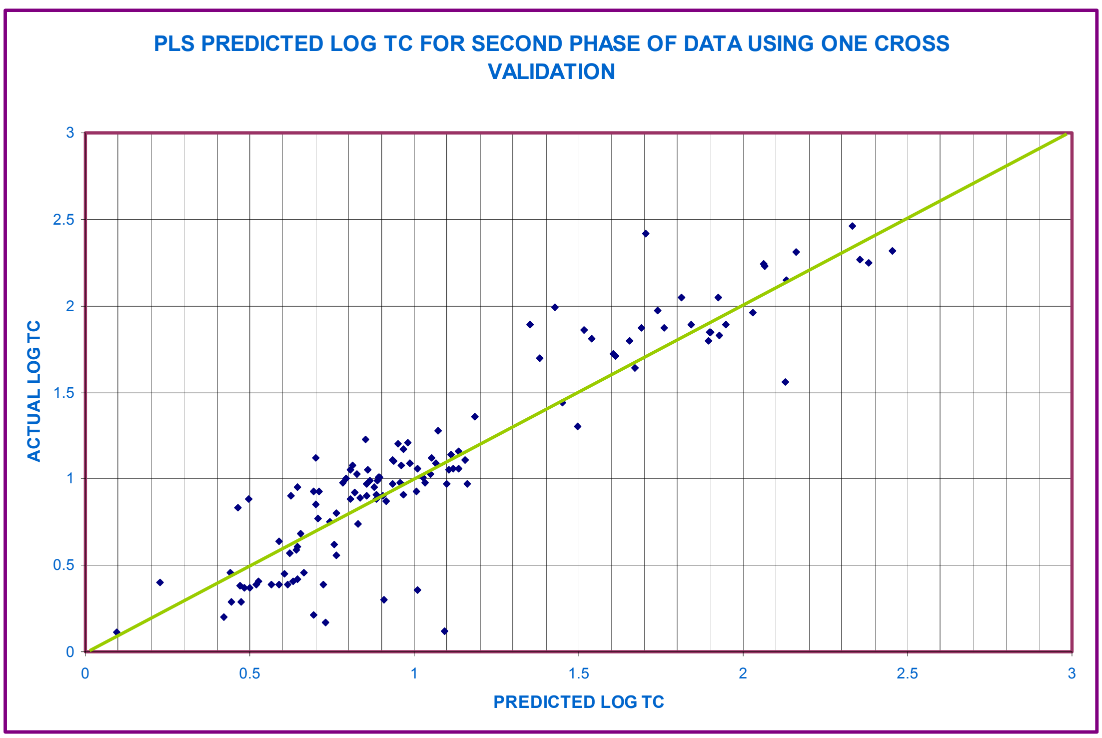


Figure 18: Phase 2 TC Prediction Accuracy

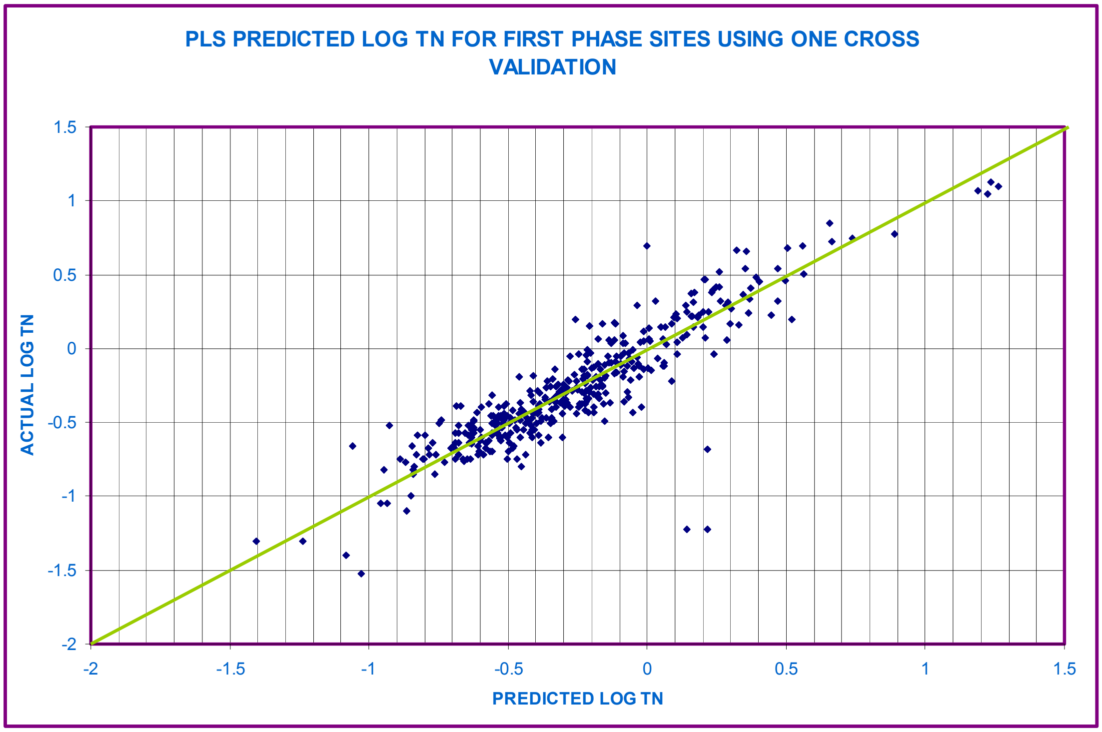


Figure 19 : Phase 1 TN Prediction Accuracy

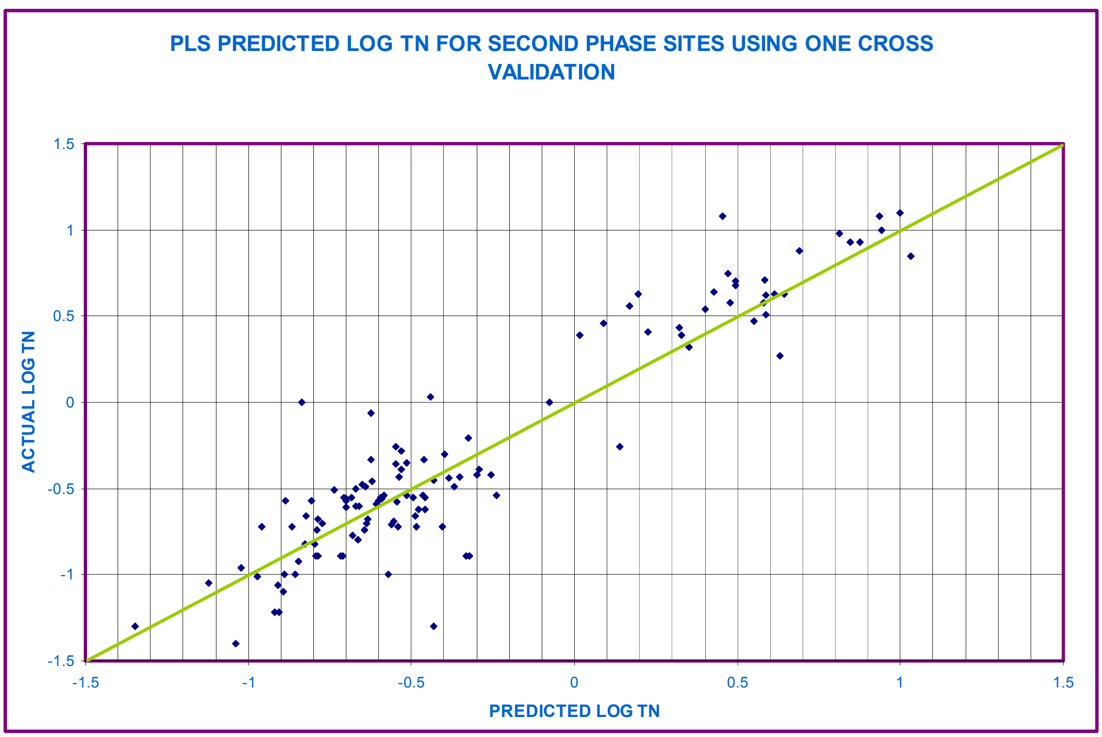


Figure 20 : Phase 2 TN Prediction Accuracy

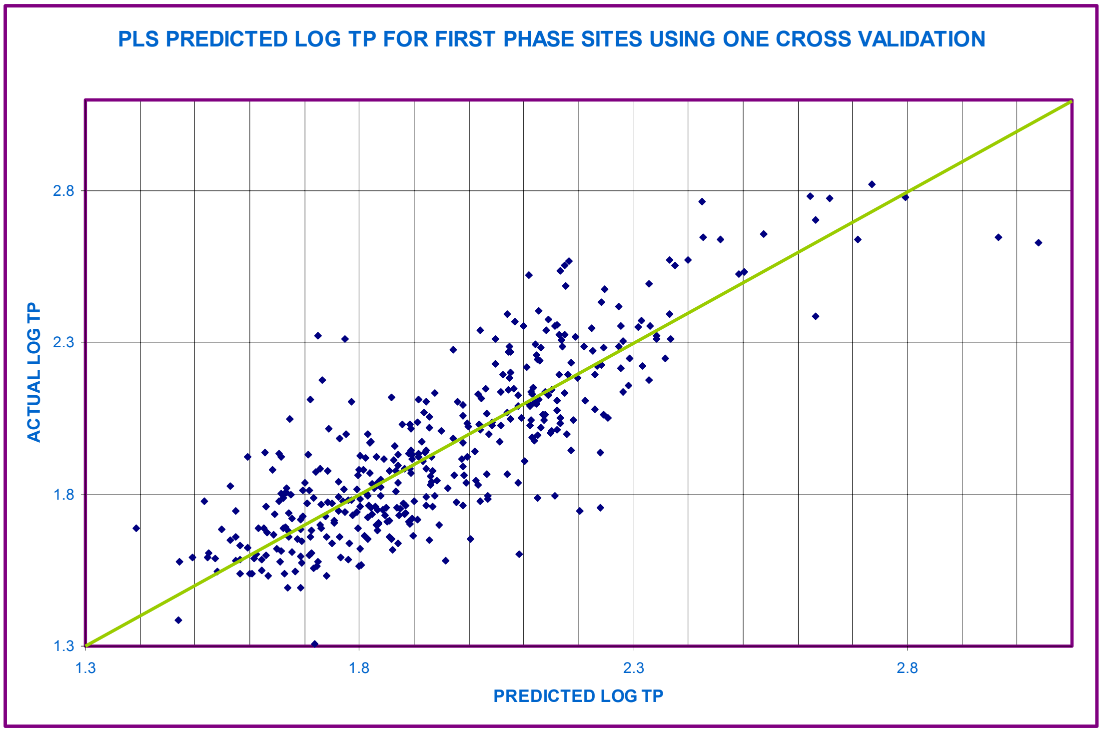


Figure 21: Phase 1 TP Prediction Accuracy

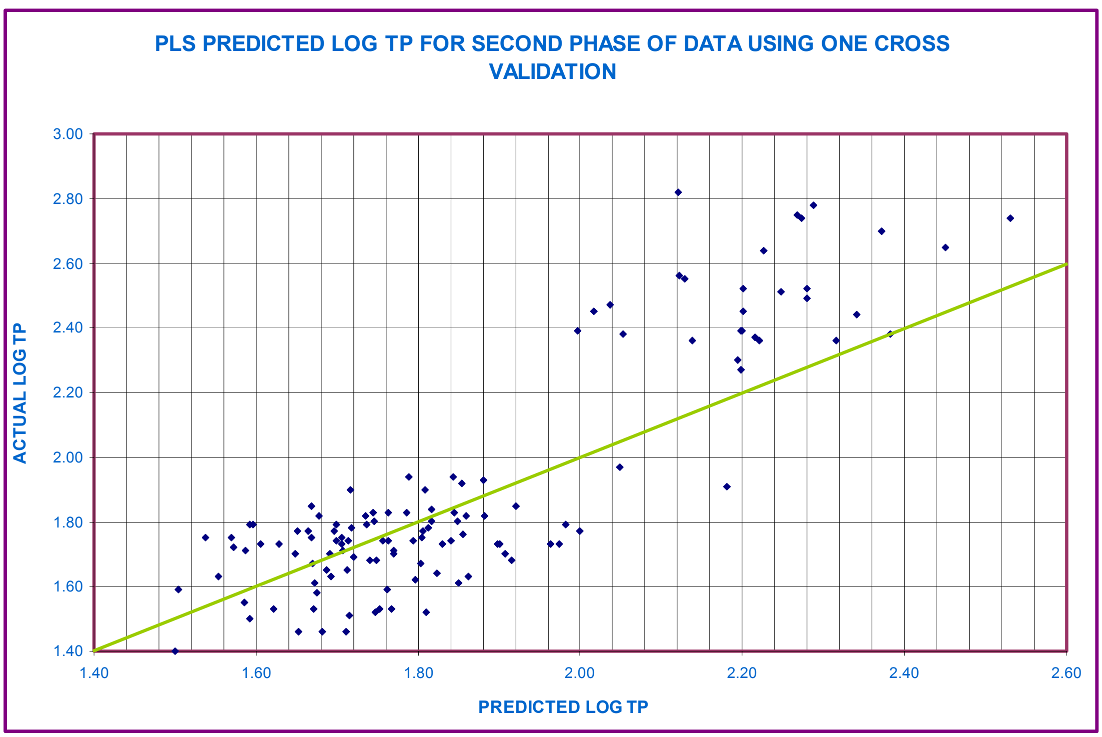


Figure 22: Phase 2 TP Prediction Accuracy

5.2. Vegetation Parameters Associated with Disturbance

A chronosequence study focusing on recovery of ground cover vegetation after clear cutting was conducted in 2001/2002. Ground cover vegetation was assessed within two major soil groups (loamy vs sandy soils) and four time intervals after logging for a total of 32 sites. Military activity for these sites was low to moderate. Identification of pattern and rate of ground cover recovery following clear cutting will aid in identification of sensitivity and rate of return of herbaceous species following low to moderate levels of disturbance and further separate natural variation from variation attributed to anthropogenic disturbance.

Within each soil type, 4 sites were selected from each of the following categories representing time since last clear-cut: 0-3, 8-10, 18-20, and >30 years. Potential sites were subjected to the same logging techniques, which included roller chopping and burning but no herbicides and had similar fire histories and slope (0-6%). While all sites were clear-cut, only sites > 30 yr. stands were thinned. All pine stands within the reservation that fit these criteria were compiled into a list from which study sites were randomly chosen. The 0-3 yr. sites were longleaf plantations, with no overstory and generally high ground cover. The 8-10 year sites were either longleaf or loblolly plantations (all plantations were loblolly before 1996) with no overstory above 10 feet. While overstory cover increased and ground cover decreased for 15-20 year sites, the highest canopy cover was found on the oldest sites (>30 years).

Five random subplots were selected at each of the 32 sampling sites. Each subplot was categorized as: skid trail/road, low disturbance or unknown based on a visual assessment of the disturbance. Overstory canopy cover was measured with a concave spherical densiometer by averaging the readings of the four cardinal directions from the center point of the subplot. Radiating from the center point, three-meter transects were established at 0^o, 120^o, and 240^o. Along each transect, woody (<2m in height) cover by species was measured. Aerial herbaceous vegetation cover by species was estimated using foliar ocular observation in 1 m^2 quadrats at the center point and at the terminus of the 240^o transect.

An undisturbed soil core was taken adjacent to each herbaceous quadrat for laboratory bulk density determination. Additional soil samples were collected at the terminus and centerpoint of each transect and at each center point for a total of 4 samples; 20 overall for the site. These samples were combined in a single container for each subplot. Texture, pH, organic matter, total nitrogen and total carbon were measured for these composite samples.

Data Analysis:

Canonical correspondence analysis (CCA) was used as an ordination technique to determine the relationship between species cover and measured environmental variables. Initial CCA analysis and regression found no significant relationship between pH, organic matter, total nitrogen and total carbon and variation in vegetation. Additional CCA analysis included only environmental variables contributing to the variation in vegetation including time since clear-cut, % clay and sand, canopy cover (DENS) and soil bulk density (BD).

Sites were originally classified as sandy or loamy based on soil maps. After textural analysis of samples collected at each site revealed disagreement with the soil map, sites were reclassified to reflect quantified textural differences.

Results and Discussion:

For the chronosequence study a total of 50 woody species were recorded in the field (Table 11). Initial CCA analysis of woody vegetation cover with environmental data indicated percent clay and sand were the environmental variables most strongly related to the second CCA axis while the first axis was related to separation of species associated with 8-10 yr sites from 15-20 yr sites. Further segregation of species associated with age since clear-cut was not clear. To better differentiate variation in vegetation associated with time since clear-cut, further CCA analysis was performed on clay and sand sites separately.

Inspection of biplots generated by CCA analysis of woody species associated with clay sites indicated weak separation of all four-time intervals along two axis (Figure 23). The first axis was most closely associated with the separation of species associated with 8-10 and 15-20 yr sites while the second axis clearly separated species associated with 0-3 and >30 year sites. However, species associated with the 15-20 yr interval were not differentiated from representing >30 yr since clear-cut. Biplots generated by analysis of woody vegetation in plots with higher % sand did not reveal separation among species for 15-20yr and 8-10 yr. (Figure 24). The validity of the associations generated in both analyses was supported by the statistical significance of the first ordination axis as determined by a Monte Carlo permutation test (Table 12).

Across all CCA analysis, increased overstory canopy cover (densiometer readings DENS) was closely associated with older age intervals (15-20 and >30 yr). Increased bulk density (BD) was associated with 0-3 yr sandy sites.

Of the 152 herbaceous species encountered, only 14 remain unidentified (Table 12). Forty-eight of the species were encountered in only 1 plot of the 80 sampled for each soil type. These rare species were eliminated from the CCA analysis. Inspection of the species biplot generated by CCA of herbaceous cover data with environmental data depicts a weak separation of species associated with the 4 time intervals post clear-cut (0-3, 8-10, 10-15, >30 years). Percent clay and sand also contributed significantly to variation in vegetation. Similar to the analysis for woody species, CCA analysis was performed on clay and sand sites separately to further differentiate relationships of suites of species with age intervals.

Biplots generated from analysis of herbaceous species found in clay sites with environmental variable indicated less separation of species association with 0-3 yr from 15-20 yr species with more separation among all other time intervals along two axis (Figure 25). For sand sites 15-20 yr and >30 yr species were not as clearly differentiated (Figure 26). In both cases the first axis was significant (Table 12).

CCA analysis suggests a relationship between a subset herbaceous and woody species with age since clear-cut (Figures 23-26). The woody and herbaceous species most closely associated with each of the time intervals following clear cutting include: 0-3 yr clay sites WOAK, HIC, DOG, BLUOAK, OAKSE; 0-3 yr sand sites WELM, OAK2, BB, BCH, MOVE, TEFL, BUBA;. 8-10 yr clay sites YUK,ROAK, POAK, W4, H2OAK, POISI, ANGE, TRDI, VIPR, LEMA, DIFI, .LS.; 8-10 yr sand sites OXCO, SPJU, AGSE, SPH, .C LEHI, ANVI; 8-10yr clay VIROT, REDMAP, SMI, SWE, RUFU, SOOD; > 30 clay sites AS.l, PAVI, TRUR, DERO, HECO; > sand sites 30 VACST and SAS (Table 11).

Table 11. Codes for herbaceous and woody species encountered in Chronosequence Study.

Herbaceous Species		Woody Species	
Scientific Name	Code	**Scientific Name**	Code
Crotalaria rotundifolia	?c	Callicarpa amiericana	bb
Galactia microphylla	?g	Prunus serotina	bch
Haplopappus divaricatus	?ha	Quercus marilandica	bloak
Hieracium sp	?hi	Quercus incana	bluoak
Ipomoea sp	?i	Cherry Laurel	cherr
Kummerowia striata	?k	Cretagus sp.	cret
Lespedeza hirta	?l	Cornus florida	dog
Piriqueta caroliniana	?p	Gaylussacia mosieri	gay
Rhus copallinum	?r	Hazelnut	haz
Solidago fistulosa	?sf	Carya sp.	hic
Solidago sp	?so	Lonicera japonica	hon
Tragia urens	?t	Hypericum	hyp
Lechea sp	?ls	Hypericum2	hyp2
Phlox nivalis	?ph	Ilex glabra	ilexg
Tephrosia virginiana	?tv	Quercus hemispaerica	loak
Acalypha gracilens	acgr	Pinus taeda	lob
Acanthaceae fam	acfa	Pinus palustris	llp
Agalinis setacea	agse	Quercus sp.	oak2
Agrimonia microcarpa	agmi	Quercus seedling	oakse
Andropogon gerardii	ange	Diospyros virginiana	pers
Andropogon gyrans	angy	Toxicondendron radicans	poisi
AndropogonC	anvi	Toxicondendron pubescens	poiso
Apiaceae fam	apfa	Quercus stellata	poak
Aristida purpurascens	arpu	Acer rubrum	redmap
Aristida sp	ars	Quercus falcata	roak
Arundinaria gigantea	argi	Rubus sp.	rub
Aster ? Linariifolius	as?l	Sassafras albidum	sas
Aster ? Patens	as?p	Smilax sp.	smi
Aster ?tortifolia	as?t	Vaccimium arboreum	spa
Aster concolor	asco	Pinus glabra	spr
Aster dumosus	asdu	Rhus copallina	sum
Aster patens	aspa	Liquidambar styraciflua	swe
Aster paternus	asps	Campsis radicans	tru
Aster solidagineus	asso	Quercus laevis	toak
Aster sp	ass	Vaccinium elliotti	vacel
Aster tortifolius	asto	Vaccinium myrsinites	vacmy
Aster2	as2	Vaccinium stamineum	vacst
BrackenFern	brfe	Virginia Creeper	virg
Bulbostylis barbata	buba	Vitis Rotundifolia	virot
Centrosema virginianum	cevi	Quercus nigra	h2oak
Cercis canadensis	ceca	Myrica cerifera	wax
Chasmanthium laxum var. sessiliflorum	chla	Quercus alba	woak
Chrysopsis mariana	chma	Ulmus alata	welm

Table 11 cont.

Herbaceous Species Scientific Name	Code	Woody Species Scientific Name	Code
Cirsium sp	cis	Woody1	w1
Clover3	cl3	Woody3	w3
Conyza canadensis	coca	Woody4	w4
Coreopsis sp	cos	Woody5	w5
Crotonopsis linearis	crli	Woody6	w6
Cyperus sp	cy?c	Gelsemium sempervirens	yjes
Dalea sp	das	Yucca sp	yuc
Desmodium (standup vine)	des1		
Desmodium rotundifolium	dero		
Desmodium sp(hitchhiker)	des2		
DichC	dis		
Digitaria cognata	dico		
Digitaria filiformis var. filiformis	difi		
Diodia teres	dite		
Eupatorium capillifolium	euca		
Elephantopus elatus	elel		
Eragrostis hirsuta	erhi		
Eupatorium rotundifolium	euro		
Eupatorium aromaticum	euar		
Eupatorium capillifolium	euca		
Eupatorium mohrii	eumo		
Euthamia caroliniana	euth		
Fabaceae fam	fab		
Florichia floridana	flfl		
Galactia sp	gas		
Galium pilosum	gapi		
Gnaphalium obtusifolium	gnob		
Gnaphalium sp	gns		
Gymnopogon ambiguus	gyam		
Hedyotis procumbens	hepr		
Helianthemum corymbosum	heco		
Helianthus floridanus	hefl		
Heterotheca subaxillaris	hesu		
Hypericum gentianoides	hyge		
Juncus dichotomus	judi		
Kummerowia striata	kust		
Lechea minor	lemi		
Lechea mucronata	lemu		
Lechea sp	les		
Lespedeza hirta	lehi		
Lespedeza stuevei	lest		
Liatris elegans	liel		
Liatris elegans	lieg		
Liatris tenuifolia	lete		

Table 11 cont.

Herbaceous Species		Woody Species	
Scientific Name	**Code**	**Scientific Name**	**Code**
Liatrus sp	liat		
Lobelia puberula	lopu		
Mollugo verticillata	move		
Urtica sp	urts		
Opuntia humifusa	ophu		
Oxalis corniculata	oxco		
Panicum anceps	paan		
Panicum rigidulum	pari		
Panicum verrucosum	pave		
Panicum virgatum	pavi		
Chamaecrista fasciculata	chfa		
Paspalum setaceum	pase		
PaspalumNot	pano		
Pityopsis	pis		
Poaceae	pos		
Poaceae fam	pof		
Polygala grandiflora	pogr		
Polypremum procumbens	popr		
Ludwigia sp	lus		
Rhexia mariana	rhma		
Rhynchosia reniformis	rhre		
Rhynchosia tomentosa	rhto		
Rudbeckia fulgida	rufu		
Ruellia caroliniensis	ruca		
Saccharum alopecuroides	saal		
SchizgenusC	scg		
SchizScopC	scsc		
Scleria sp	scs		
Seymeria pectinata	sepe		
Silphium compositum	sico		
Solidago fistulosa	sofi		
Solidago latissimifolia	sola		
Solidago nemoralis	sone		
Solidago odora	sood		
Sorghastrum secundum	sose		
Sphagnum Moss	sph		
Schizacharium ternaria	scte		
Sporobolus junceus	spju		
Stylisma patens	stpa		
Stylodon carneum	stca		
Tephrosia florida	tefl		
Tephrosia sp	tes		
Tragia urens	trur		
Trichostema dichotomum	trdi		

Table 11 cont.
Herbaceous Species

Scientific Name	**Code**
Trichostema setaceum	trse
Tridens carolinianus	trca
Tridens flavus	trfl
U032	U032
U064	U064
U070	U070
U073	U073
U074	U074
U075	U075
U087	U087
U091	U091
U102	U102
U107	U107
U110	U110
U111	U111
U112	U112
U113	U113
Vicia sp	vic
Viola palmata var. triloba	vipa
Viola primulifolia	vipr
Wahlenbergia marginata or Juncus dichotomus	Wa

Table 12. Canonical Correlation Analysis eigenvalues for woody and herbaceous plant species cover correlated with environmental variables at clay and sand sites (Chronosequence Study).

	Axis 1[a]	Axis 2	Axis 3	Axis 4
Woody spp				
Clay	0.44(*)	0.12	0.18	0.15
Sand	0.46(*)	0.25	0.26	0.14
Herbaceous spp				
Clay	0.26(*)	0.22	0.17	0.12
Sand	0.33(*)	0.24	0.20	0.12

[a]Test of significance of first eigenvalue: * $\leq$ 0.05

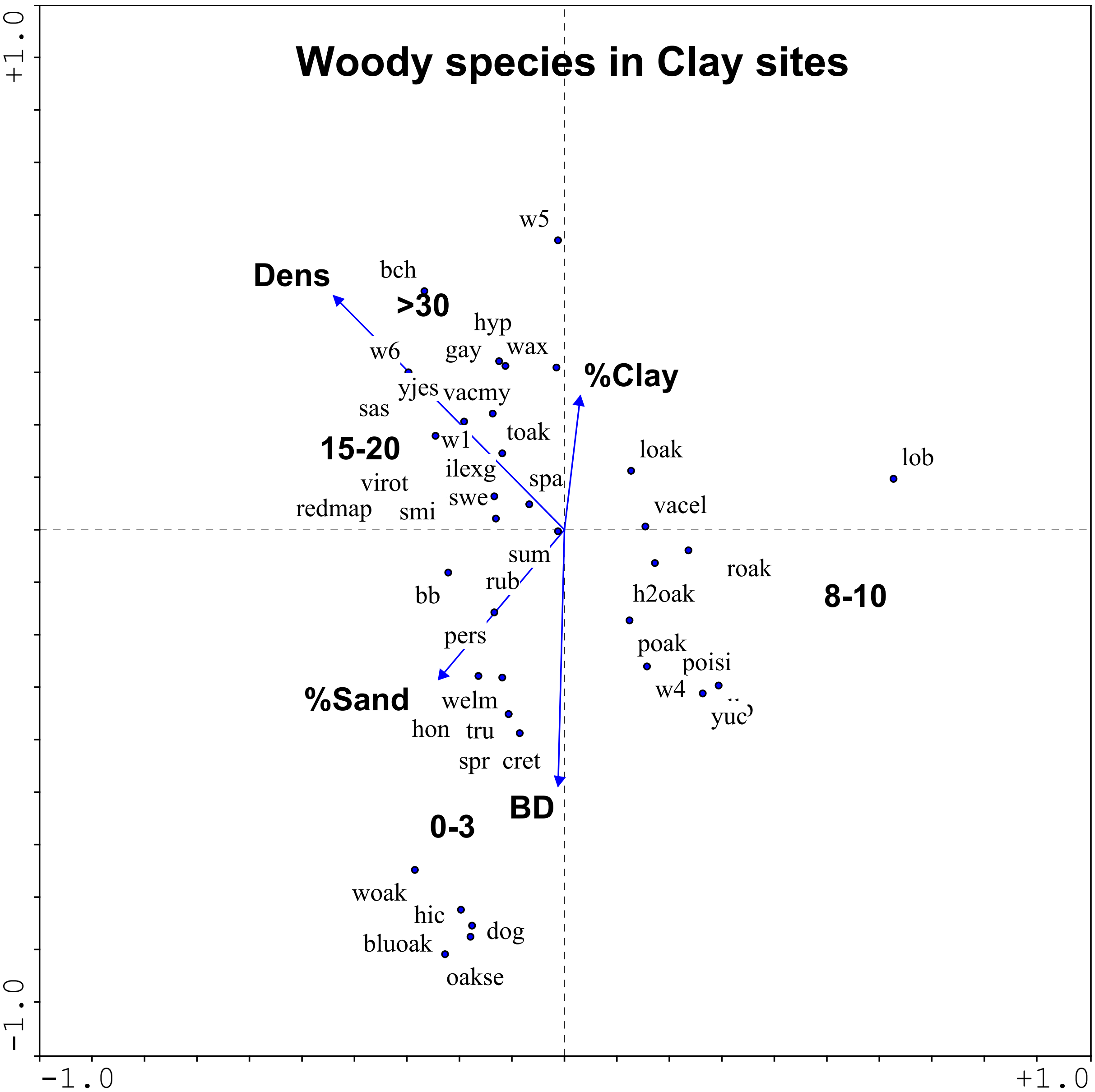


Figure 23. CCA biplot for woody species cover and environmental variables on clay sites (Chronosequence Study).

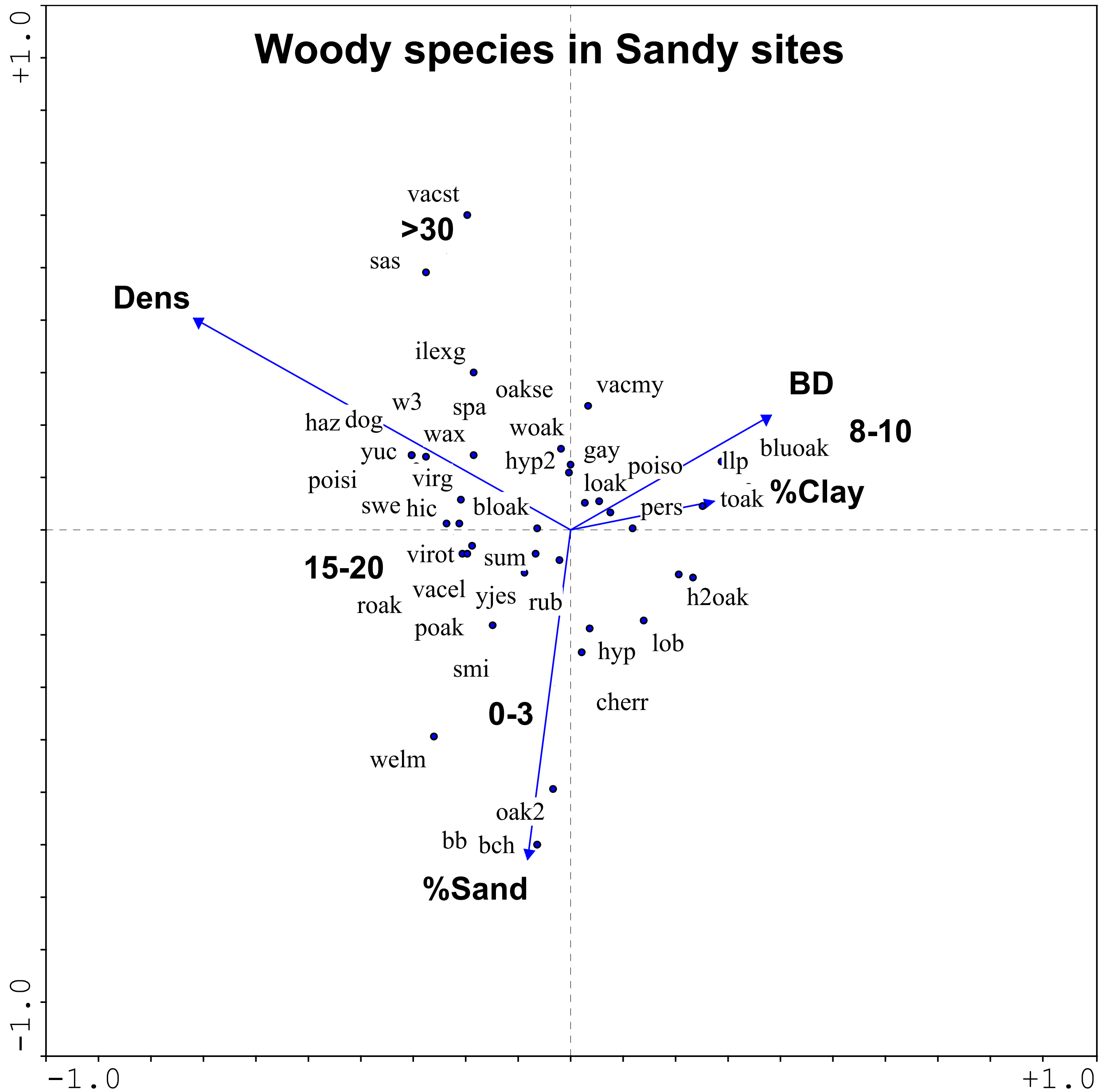


Figure 24. CCA biplot for woody species cover and environmental variable on sandy sites (Chronosequence Study).

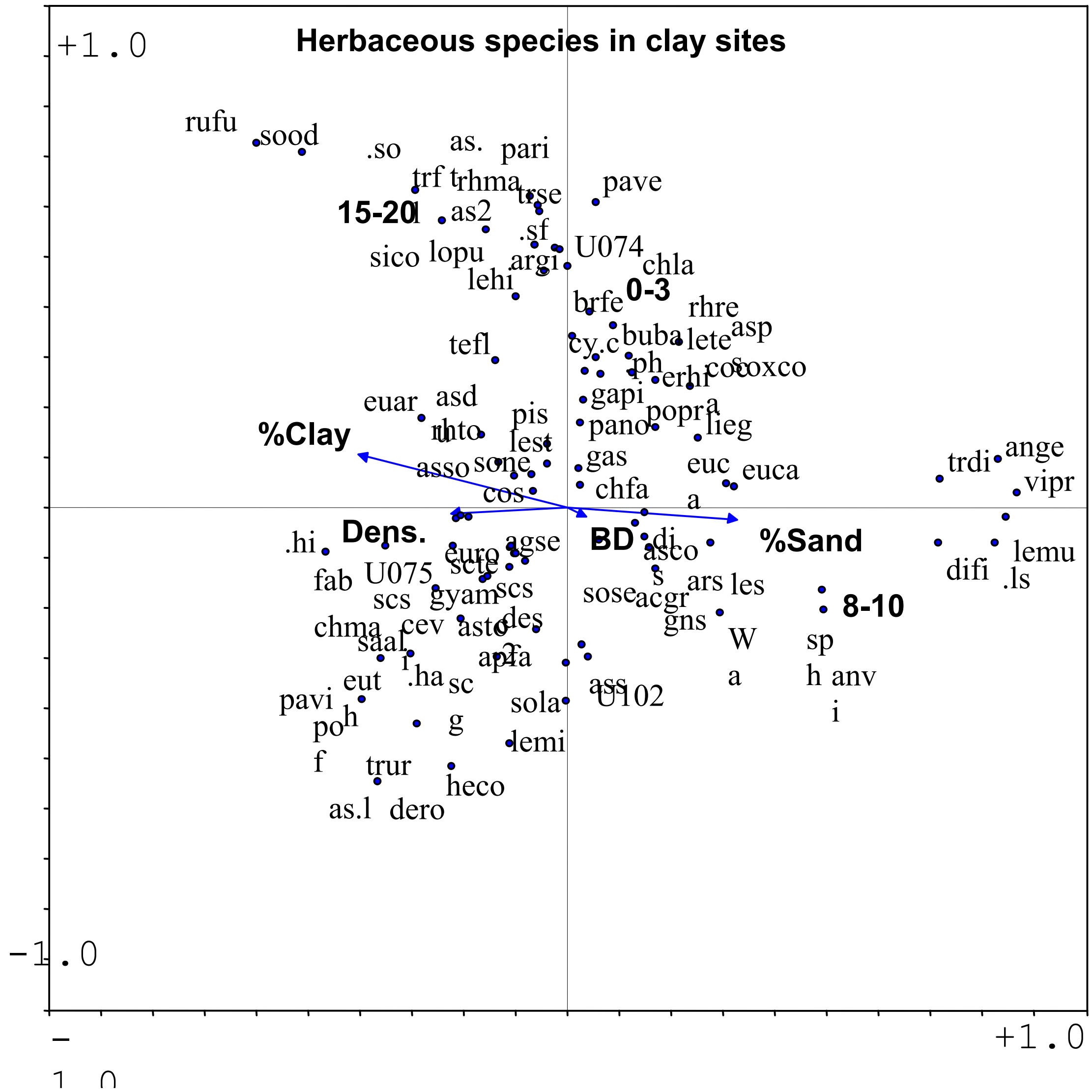


Figure 25. CCA biplot for herbaceous species cover and environmental variables on clay sites (Chronosequence Study).

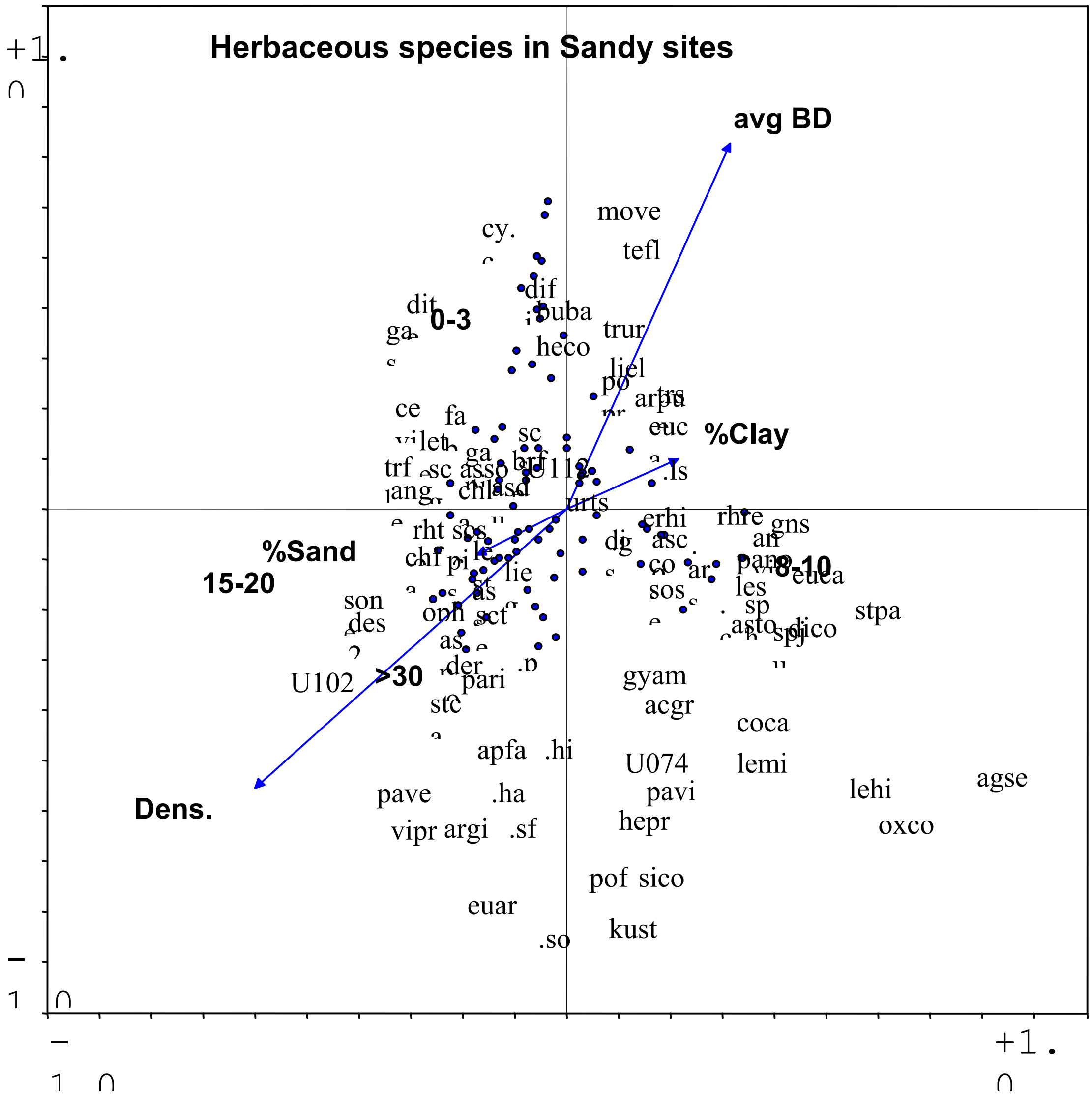


Figure 26. CCA biplot for herbaceous species cover and environmental variables on sandy sites (Chronosequence Study).

5.3. Watershed Hydrology

Soil-water content and storage dynamics play a dominant role in determining hydrologic processes (e.g., infiltration and runoff) and biological processes (e.g., biogeochemical rates; plant-water stress) in watersheds. Efforts of the Purdue group under Dr. Suresh Rao were focused on long-term monitoring of water storage dynamics in the Bonham-1 watershed and linking this information to stream flow monitoring data being collected by Dr. Jennifer Jacobs (University of Florida). Spatial distribution of soil hydraulic properties is also needed as inputs in spatially-distributed hydrologic models for forecasting infiltration, recharge and stream flow.

5.3.1 Soil-water Storage Estimation

Every two months since June of 2001, point water content measurements were obtained in the Bonham-1 watershed using the Delta-T® TH2O Soil Moisture Meter. Sample locations were predetermined at relatively regular intervals over the 95.1 Ha (~0.3 sq. miles) watershed using 50-meter contour lines as references. Measurements were used to estimate the total water storage and spatial moments of water content within the catchment. Near-stream spatial soil saturation limits were recorded to compare previous near-stream saturation delineation. At each sample location, water content measurements were taken at the soil surface as well as depths of 15, 30, 45, 60, and 75 centimeters by first digging with a soil auger to the desired depth, inserting the probe into the soil, and then obtaining a water content reading. This process was repeated at all sampling locations on a given sampling campaign (about 50).

Each depth was treated as a horizontal cross-section of the watershed and was analyzed separately for estimating soil-water storage. In order to interpolate water content between measured points, a statistical distribution of water content was computed for each depth to eliminate potential outliers. Then variograms were computed and used to develop spatial water content models by ordinary kriging. GEO-EAS® software (EPA software) was used to calculate and assign unbiased water content values over the Bonham-1 watershed for each depth. Maps of soil-water storage distribution were generated from the GEO-EAS grid output using ARCVIEW® (Figure 27).

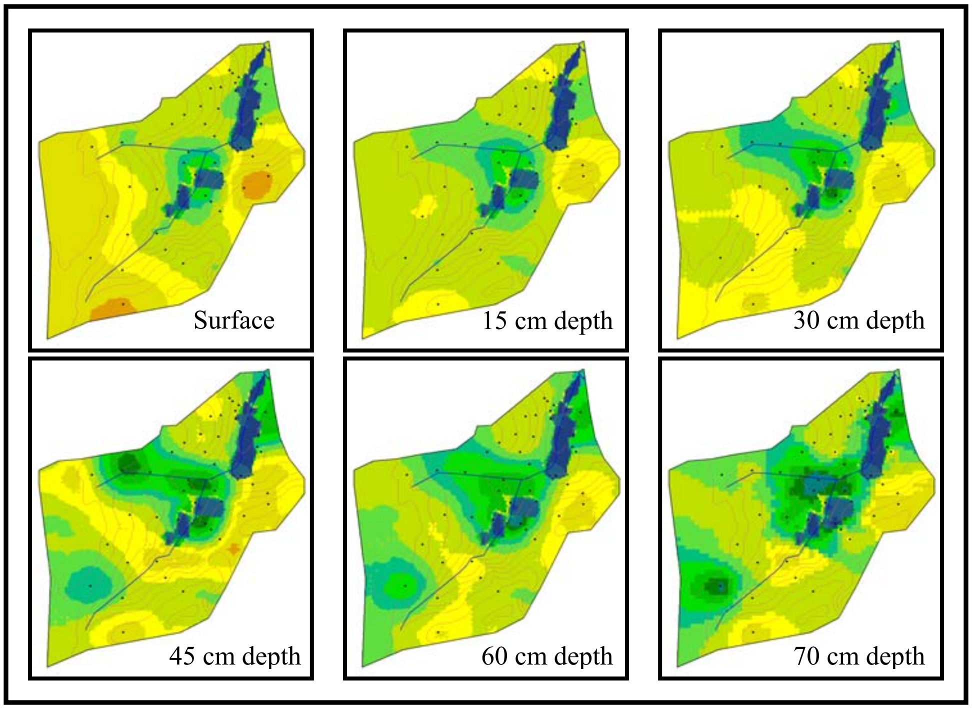


Figure 27. Depth-specific water content estimation maps of Bonham-1 watershed for March, 2002. Blue areas contain more water than yellow and brown areas.

Results and Discussion:

Total water storage of each depth was calculated and added to soil-water storage in the riparian area to yield the total soil-water storage. Based on a preliminary analysis of a water balance, the current method of ordinary kriging of water content does not call for more spatial water content information than has been gathered to take advantage of its full potential as an unbiased estimator.

After a one-year cycle of soil-water storage monitoring, we have observed that a temporal pattern of total soil-water storage emerges (Figure 28). Total volume of soil-water storage measured during drier months (June-August) was consistently lower than the higher storage that was observed during wetter months (September – May). This observation will be explored by statistical moment analysis that will define total mass of water, the centroid (center of mass of water), and standard deviation. We are investigating the temporal stability of the spatial patterns in soil-water storage as it relates to vegetation, soil type, and rainfall patterns.

When compared to volumes estimated from precipitation and hydrograph data, our estimated soil-water storage appeared to attribute an appropriate volume when compared to the expected volume of precipitation minus hydrograph volume (Table 13).

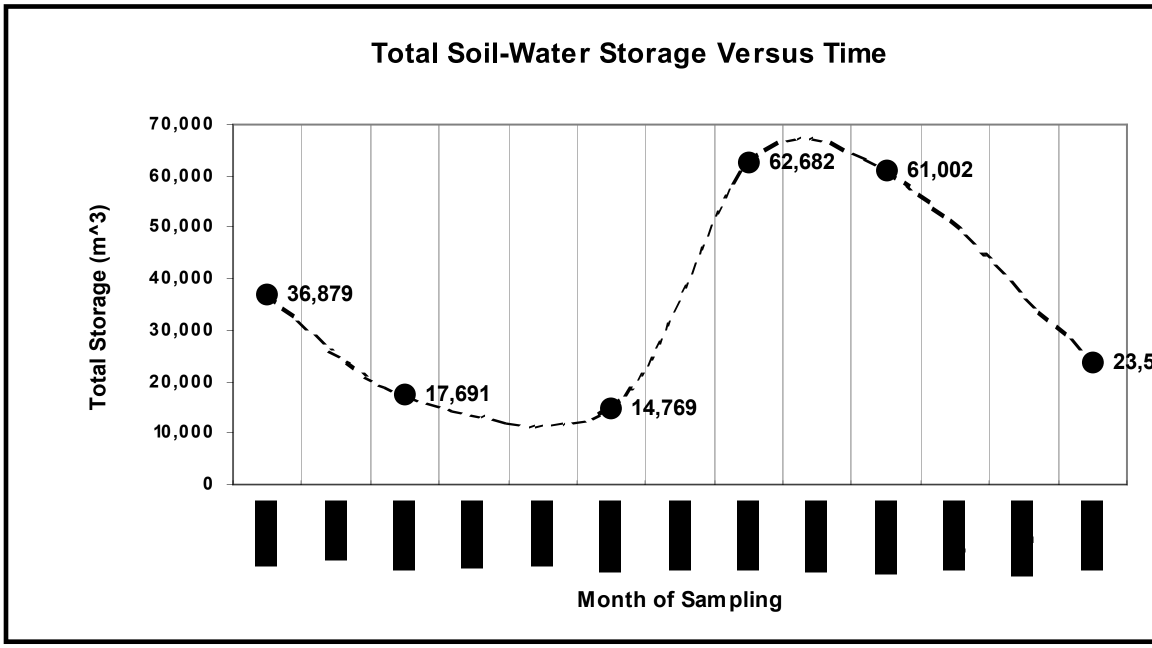


Figure 28. Observed temporal trend in total soil-water storage.

Table 13. Water balance for January 18th – 22nd. Throughfall is estimated as 95% of the precipitation. Storage (δθ) is the soil-water storage estimated from point-interpolated measurements. Storage (hydrograph) is throughfall minus hydrograph volume. ***Precipitation and hydrograph data courtesy of Jennifer Jacobs and Shirish Bhat, University of Florida.***

SOURCE	VOL. WATER (m^3)
Precipitation	23,850
Throughfall	22,660
Hydrograph	431
Storage (δθ)	21,915
Storage (hydrograph)	22,229
Evapotranspiration	314

Now that spatial soil-water storage has been developed, multi-variate analysis will be performed to find correlation between water content and landscape features (Slope, elevation, vegetation patterns, etc). Initially, digital delineation of vegetation and 10-meter contour lines overlayed on the soil-water storage maps to explore the idea that water content could be spatially dependent on landscape features (Figure 29). Then, a preliminary statistical analysis of Bonham-1 watershed using a principal component approach showed that when water content was compared to slope and elevation it could only account for 22% of the variation and was not a principal component. Although this preliminary analysis did not confirm our hypothesis that water content is spatially dependent on landscape features, different landscape features (e.g., understory vegetation; trees) need to be considered in another multi-variate analysis.

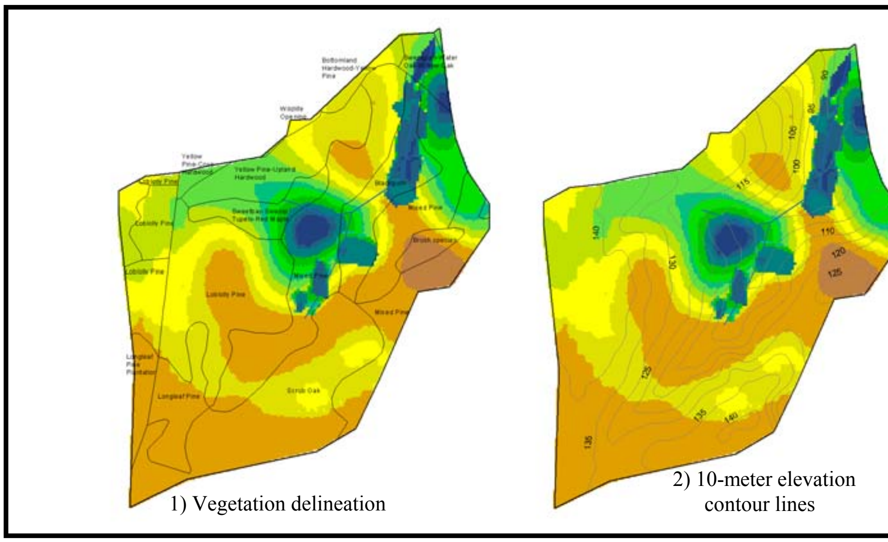


Figure 29. 1) Vegetation delineation and 2) contour lines overlayed on a total soil-water storage map that was derived from the sampling campaign in January, 2002.

5.3.2. Channel Sediment Sampling:

In June of 2001, an exploratory sampling effort was made to obtain sediment samples from several channels on Rowan Hill and Cannons. These sediment channels would potentially be a source of sediment in Bonham Creek. The thought behind this effort was that a historical approach to erosion and sedimentation could be found by analyzing the sediment deposition in the channels. Sampling was done at depth and the original A-horizon (A_b horizon) was recorded. Particle size distribution was characterized in the lab, but no significant variation in sediment size distribution was found at depth or along the length of any channel. Results suggest that an ongoing monitoring of sedimentation would yield better results and would have more potential to describe historical sedimentation events.

5.3.3 Watershed Hydrologic Budget

Activities:

The project objectives are to identify physical variables associated with hydrologic processes as potential indicators. Toward that end, routine measurements of watershed scale hydrologic parameters were conducted in FY2002. Specific monitoring activities during the past year include precipitation monitoring, stream flow gaging, throughfall measurements, water content sampling, and soil water, groundwater and stream water sampling. Hydrological sampling occurred approximately 2 times per month during FY2002.

The throughfall study initiated in FY2001 was completed in June 2002. Throughfall and stem flow were measured for a one-year period in five different land types, wetland, pine plantation, hard wood, mixed, and mature pine, using four replications (Figure 30). In addition, measurements were made in four additional mature pines and wetland plots to characterize the impact of canopy cover on water input. All trees in study plots were identified and characterized by species count, height, canopy radius, and diameter at breast height (DBH). Bi-weekly measurements of throughfall, stem flow, and canopy cover were made throughout the study.

Stream flow and water quality monitoring studies continued throughout FY2001. The streamflow was continuously monitored in Bonham-1, Bonham-2 and Oscar-1. Water quality was sampled in 9 stream locations (Figure 31). Analysis of stemflow, throughfall, and precipitation chemistry were made in significant land and forest communities. Measurement parameters include NH_4-N, TKN, TP, TOC, Chloride, DOC, SRP, NO_3-N, pH, temperature, and conductivity. A focused, single watershed experiment was established in Bonham-2 during the Summer 2002. The existing instrumentation to monitor throughfall, precipitation, and streamflow was expanded to include groundwater levels and chemistry, soil water chemistry, and surface water chemistry. Lysimeters and groundwater wells are constructed and installed. The sampling design consists of four riparian transects that are perpendicular to the stream. There are three wells in each transect located at near stream, midpoint of the riparian area, and at the toe of the upland area. Two lysimeters are collocated with each well. The lysimeters are located above and below the main rooting zone. There are a total of 24 lysimeters installed for soil water sampling. Water levels are measured continuously. Water chemistry samplings are conducted bi-weekly.

A joint effort between the UF (Jacobs) and ORNL (Garten and Ashwood) was established to generate a distributed, regional model of excess nitrogen at Fort Benning and to develop a hydrologic modeling framework that links the nitrogen model to the stream water chemistry. This effort will be continued during FY2003.

Results and Discussion:

The impact of vegetation community and dynamics on water input were characterized by the throughfall study. A strong seasonal variation in canopy cover was observed (Figure 32). This variation was determined to have a significant influence on the characterization in water input for intra-annual time-scales. The Gash model parameters by forest type were developed and the model was successfully applied to simulate interception (Figure 33). Inclusion of seasonal canopy dynamics improved the model results for all land uses. Variations in tree species contribution among forest types and understory contribution to canopy cover measurements were found to have a significant impact on local interception loss calculations. These results suggest that forests that are comprised of multiple species may require species-based corrections to model parameters. In addition, the relative composition of overstory and understory to interception needs to be considered prior to applying experimentally determined parameters to other sites. New methods were developed to correct canopy cover measurements and canopy storage capacity values that provide a preliminary approach to characterize canopy specific parameters on the basis of site characteristics.

Examination of the watershed on an individual forest type scale, the lumped approach to throughfall modeling under predicts annual throughfall for all forest types. Most significantly, it underpredicts throughfall by 27.2% for hardwood forests and 22.6% for wetland forests when an annual average canopy cover is used in the Bonham watersheds. A lumped model also under-predicts throughfall by 23.5% for hardwood forests and 23.6% for wetland forests using seasonal canopy cover. This error is of particular concern for the riparian wetland forest as the watershed storm response is most critical for areas closest to the stream in watersheds dominated by the saturation excess mechanisms of runoff generation. When shorter temporal periods are examined, seasonal instead of annual, the associated errors with the lumped approach are even more pronounced. For example, the lumped approach predicts wetland throughfall within 2.6% of the spatially distributed approach using seasonal canopy cover during the winter. However, the difference is over 25% for the remaining seasons. A large variation is also seen in the pine plantation communities where the error ranges from a 3.3% over-prediction to a 33.2% under-prediction in throughfall.

5.3.4 Stream Water Quality

Water quality measurements revealed low levels of most nutrients. Significantly higher levels of some nutrients (TKN, sulfate, DOC, TOC, NH_3, Cl) were observed in throughfall and stemflow than in soil and stream waters. A seasonal increase in stream water nitrogen was observed during the winter months (Figure 34). This increase coincided with the decreased canopy cover in the wetland and hardwood communities (Figure 32). Preliminary modeling results suggest that an understanding of hydrologic pathways is necessary to link excess nitrogen to stream water chemistry.

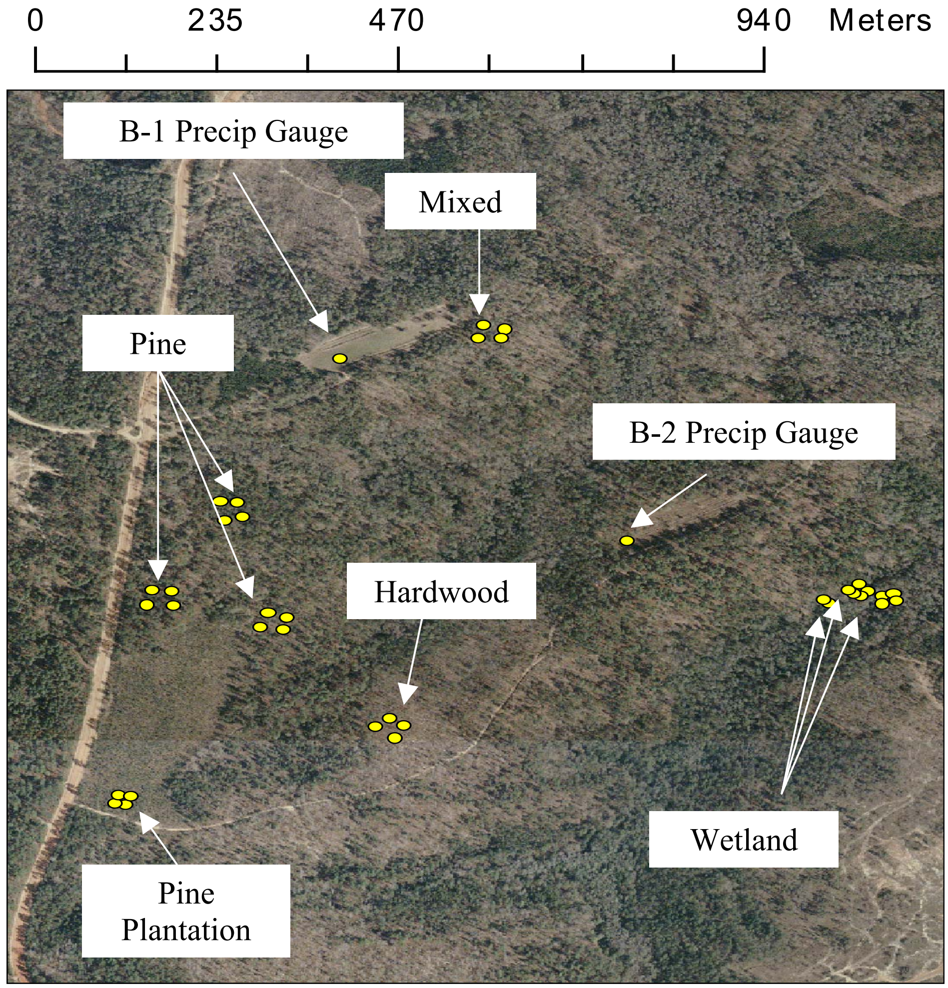


Figure 30. Throughfall and stemflow sampling locations in D12/D13 catchments.

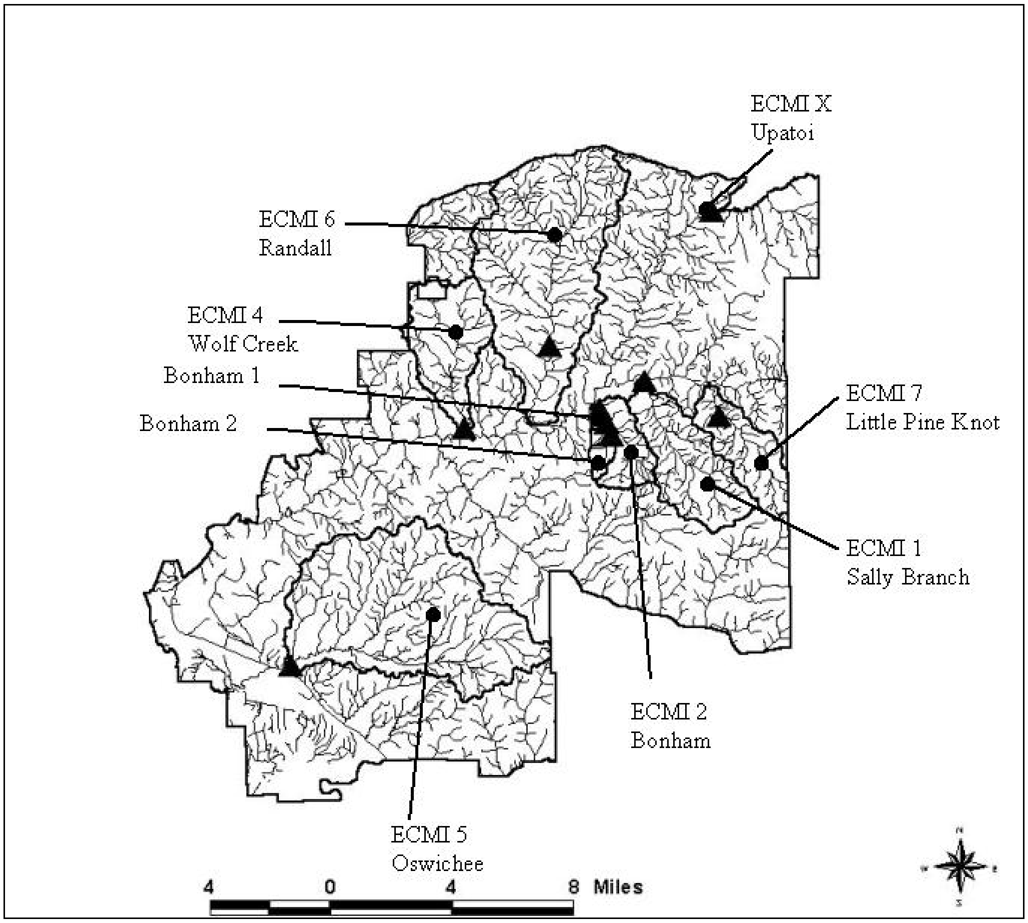


Figure 31. Streamwater chemistry sampling locations.

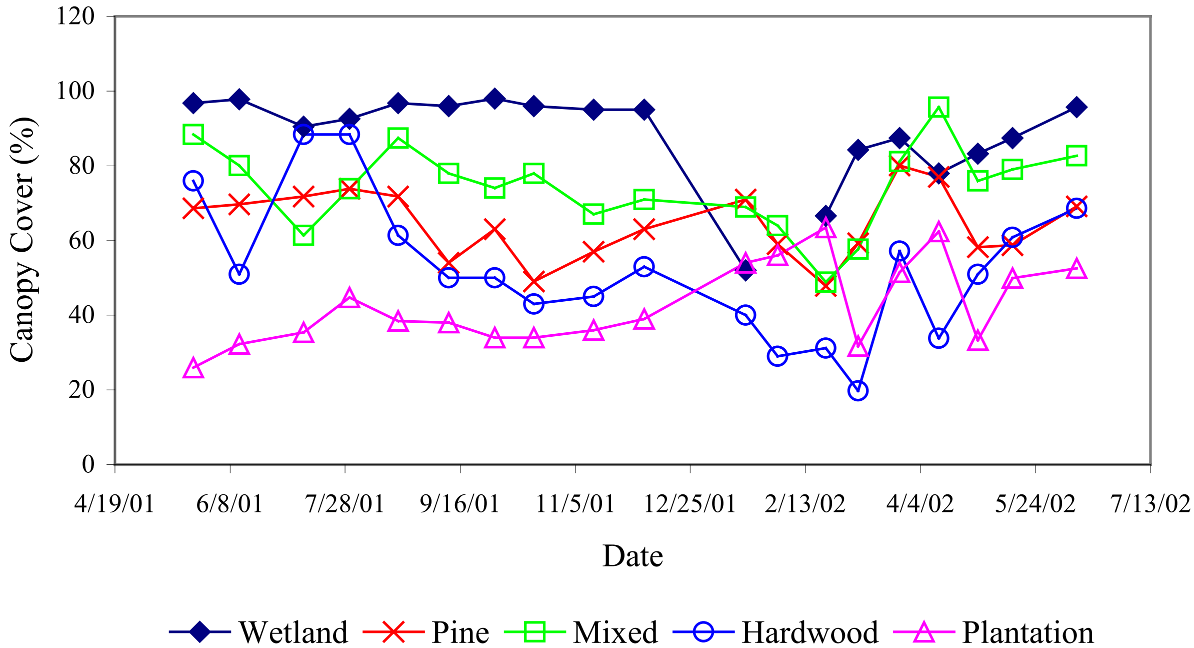


Figure 32. Canopy cover measurements for the five forest types.

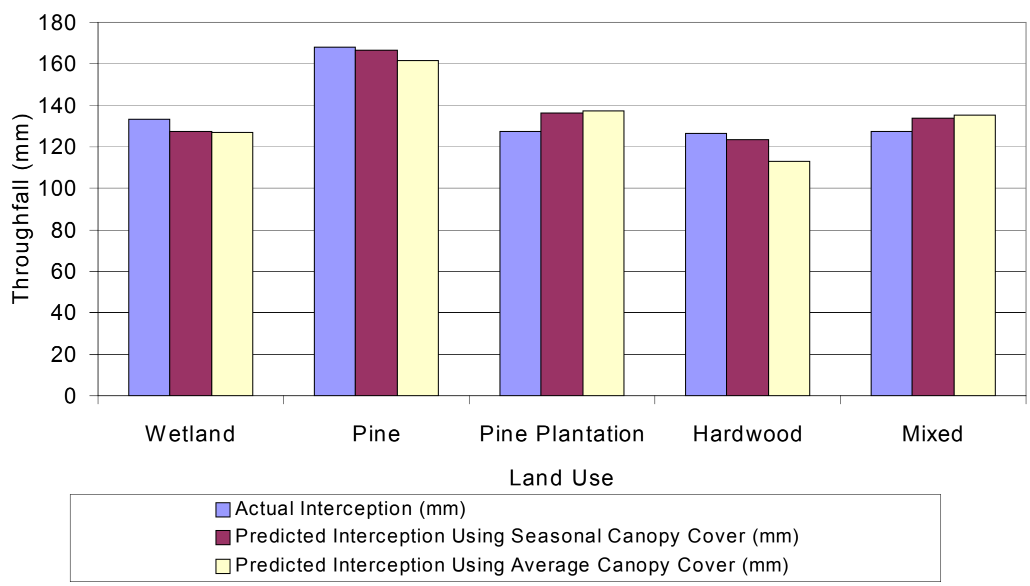


Figure 33. Measured and modeled interceptions results using the Gash model with and without seasonal canopy cover by forest types.

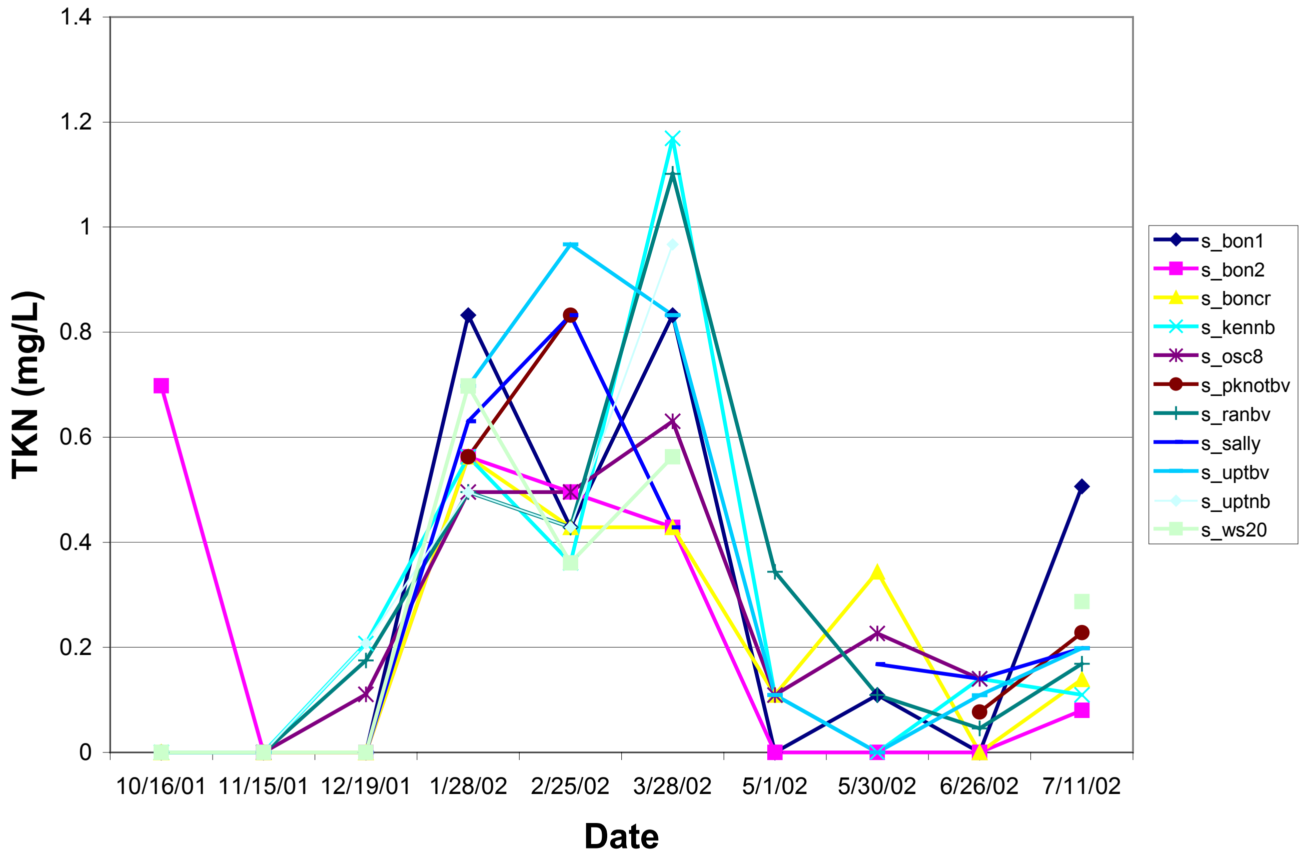


Figure 34. Measured water quality from October 2001 to July 2002 for the UF and ECMI watersheds.

6.0 PLANNED AND ONGOING ACTIVITIES FY2003

6.1 Soil Biogeochemistry

6.1.1 Validation of Selected Indicators

Resampling of a subset of Phase I sites will be undertaken. Results of biogeochemical analyses will be used to validate relationships developed in Phase I and II.

6.1.2 Litter Decomposition and Carbon Dynamics

Because of the importance of carbon dynamics in ecosystem function, and its emerging role as an indicator of disturbance, a study has been initiated to examine carbon storage and turnover. Leaf bags will be used to investigate temporal responses in plant litter decomposition as influenced by land use. This study will focus on: litter turnover rates; microbial communities; nutrient availability; Low, Moderate, High Impact areas; and bottomland vs. upland communities.

6.1.3 Correlation of Soil Biogeochemistry with Watershed Hydrology Model

The objective of this study will be to determine soil chemical and biogeochemical parameters that affect stream and ground water chemistry. Samples will be obtained from transects paralleling Bonham 1 and 2 streams. Samples will be analyzed for: TOC, DOC, NO3, NH4, TKN, TP, SRP, Cl-, and SO4.

6.1.4 Hyperspectral Analysis of Soils

During 2002-2003 field experiments will be conducted to determine whether quantification of soil nutrient content and disturbance using spectral analyses can be done *in situ*, i.e. without bringing soil samples back to the lab. If successful, the procedure will be used to map soil nutrient content and disturbance for a few representative watersheds using the field spectrometer. The soil nutrient content maps will be provided to the hydrology group for comparison with stream chemistry.

Critical Research Needs Beyond Current Scope of Work:

Research needs beyond the current scope of work include 1) Developing relationships between field measurements of soil spectra and NASA's AVIRIS reflectance data, and 2) investigating the feasibility of mapping soil/vegetation nutrient status and disturbance using AVIRIS.

6.2 Vegetation

Analysis of vegetation community structure and composition with respect to disturbance and soil characteristics will be completed.

6.3 Hydrology

6.3.1 Sediment Water Storage

Since a temporal pattern of total soil-water storage was observed, further analysis by statistical moment analyses will be performed to find seasonal or periodic variation trends.

These trends may be useful as an indicator of microbiologic and vegetative activity. In addition, spatial soil-water storage patterns will be used in a multi-variate analysis that will attempt to more precisely predict soil-water storage in other watersheds. Part of this analysis will include water content measurements made over three transects in other areas of the base that would serve as validation data sets.

6.3.2 Watershed Hydrologic Budget

The throughfall model will be extended to generate distributed water input data for the entire Fort Benning region. A GIS framework will be used to characterize the water input. Throughfall data will be submitted to the ECMI database.

Routine stream, precipitation, and water chemistry monitoring will continue bi-weekly during FY2003. The linked landsurface-streamflow seasonal nitrogen excess model will be developed a tested using four hydrologic formulations. Other analyses to determine hydrological indicators of environmental change will include relationships between hydrological indicators, watershed physical characteristics, solute concentrations, vegetation classes and land use in the University of Florida and ECMI watersheds.

7.0 PUBLICATIONS AND PRESENTATIONS

7.1 Publications

Dabral, S., W. D. Graham, J.P. Prenger, and W. F. DeBusk. (in preparation). Multivariate analysis of soil biogeochemical parameters for assessment of ecological condition. To be submitted to J. Environ. Qual. or Ecological Indicators.

Dabral, S., W. D. Graham, and J.P. Prenger. Development of a spectral reflectance technique for predicting soil quality and classifying ecological disturbance. In preparation. To be submitted to Journal of Environmental Quality or Ecological Indicators Journal

Prenger, J. P., B. L. Skulnick, and W. F. DeBusk (in preparation). Evaluation of soil organic C storage and cycling as the basis for development of ecological indicators. J. Environ. Qual. *or* Biogeochemistry.

7.2 Presentations

Archer, J.K. and D.L. Miller. Vegetation and soil response to timber thinning operations: a chronosequence study. Abst. 87th Annual Meeting, Ecological Society of America, Tucson. Arizona, August 4-9, 2002.

Dabral, S., W. D. Graham, and W. F. DeBusk. Determination of Soil, Hydrologic, and Vegetation Indicators for Military Land Management Ft. Benning Georgia. Soil and Water Science Department Graduate Research Forum, University of Florida, 2001.

DeBusk, W. F., and J. P. Prenger. 2001. Wetland soil biogeochemical indicators of ecological condition for military land management. Poster presented at Annual Meeting of Society of Wetland Scientists, May 28 – June 1, 2001, Chicago, IL

DeBusk, W. F., and J. P. Prenger. 2002. Soil Biogeochemical Indicators for Wetland and Watershed Assessment. Oral presentation at Annual Meeting of Society of Wetland Scientists, June 2-7, 2002, Lake Placid, NY.

Jacobs, J. J., S. Bhat, W. D. Graham, P. S. C. Rao, N. Haws, W. F. DeBusk, and J. W. Jawitz. 2001. Identification of eco-hydrologic indicators of ecological impact: Phase I results from Fort Benning, Georgia watersheds. Poster presented at Spring 2001 Meeting of the American Geophysical Union, May 29 – June 1, 2001, Boston, MA.

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