BRUCE ALLEN PRUITT
Hydrologic And Soil Conditions Across Hydrogeomorphic Settings
(Under the direction of WADE LOWERY NUTTER)

Though it is well accepted that hydrology, soil temperature, and soil reducing conditions are critical controlling factors in determining growing season and wetland status, inadequate data exist on regional scales. Even less is known about the temporal and spatial variability in these controlling factors in different landscape positions and hydric regimes. Hence, there is a need to develop more appropriate and reliable scientific-based data on wetland hydrology, soil temperature, and soil redox potential within specific regions. In addition, relationships between long-term measurements of these controlling factors and indicators of their presence or absence need to be established. Consequently, a study was undertaken to determine the correspondence between wetland hydrology, soil temperature, and soil redox potential, and ultimately, the expression of these factors in the form of field indicators.

The goal of the study was to identify the variation in hydrologic and soil conditions across hydrogeomorphic gradients in the southern Piedmont physiographic province, USA. Research objectives were to identify predominant subclasses of riverine systems, determine the correspondence between hydrology, soil temperature, and soil redox potential within the subclasses, establish relationships between measured parameters and indicators of federal wetland jurisdiction, and propose additional research needs.

The study was conducted at two different scales: regional and intensive. The regional study consisted primarily of identifying subclasses of Piedmont riverine wetlands, indicators of federal wetland jurisdiction, and comprehensive vegetational surveys. Relationships were developed between soil properties and hydrologic indicators as compared to vegetative response. The intensive survey was initiated based on the findings of the regional study and included automated instrumentation designed to measure water table, air and soil temperature, and soil redox potential.

Based on hydrogeomorphic settings, water source and transport, hydrodynamics, particle size distribution, and mineralogy, four subclasses of Piedmont riverine systems were identified: overbank, depression, fine seep, and coarse seep. Excellent correspondence between hydrophytic vegetation and redoximorphic features such as masses, pore linings, chroma of 2 or less, and concretions was observed. However, the correspondence between hydrophytic vegetation and hydrologic indicators such as water-stained leaves, drift, and deposition was fair.

A regional dimensionless rating curve specific to the Piedmont was found to be useful in determining flood frequency and discharge onto adjacent riverine wetlands. Flood frequency and discharge were observed to be dependent on channel capacity and geomorphology.

Mean, minimum, and maximum soil temperature at all depths could be estimated annually and during any season from mean air temperature by simple linear regression. A lower air temperature was required to reduce the soil temperature at the overbank and forested seep to non-growing season conditions as compared to the depression and emergent seep.

In general, soil redox potential was observed to be negatively related to air temperature and positively related to increases in water table elevation. Water table was lower and soil redox potential was higher at the overbank as compared to the other subclasses. Optimal soil temperature in combination with adequate water table which occurred in the spring in the depression resulted in the lowest redox potential observed in the subclasses during the study.

INDEX WORDS: Hydrogeomorphic Classification, Wetland Delineation, Hydric Soils, Soil Redox Potential, Soil Temperature, Redoximorphic Features, Regional Hydraulic Curves, Growing Season, Wetland Hydrology, Hydric Soils Technical Standard, Piedmont Riverine Wetlands

HYDROLOGIC AND SOIL CONDITIONS ACROSS HYDROGEOMORPHIC SETTINGS

by

BRUCE ALLEN PRUITT

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M.S., Georgia State Universty, 1988

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HYDROLOGIC AND SOIL CONDITIONS ACROSS HYDROGEOMORPHIC SETTINGS

by

BRUCE ALLEN PRUITT

Approved:

Major Professor: Wade L. Nutter

Committee: Larry T. West
David S. Leigh
Lawrence A. Morris
Bruce L. Haines

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2001

DEDICATION

This paper is dedicated to my son, Carson Allen Pruitt, born August 23, 1991 and my daughter, Madison Anne Pruitt, born October 9, 1998. May their young minds, full of curiosity, open mindedness, and desire to learn, never be tainted but be fulfilled at maturity and last a life-time and perhaps beyond.

This paper is also dedicated in memory, uttermost respect, and admiration to my grandmother, Mary Bowie Pruitt (1896 - 1993). May we all wish for her wisdom, perseverance, mental sharpness, and wittiness which spanned across two centuries and four generations.

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CHAPTER 1

INTRODUCTION

Background

Wetlands have been described as "the most important ecosystem on the Earth" (Mitsch and Gosselink 1986). Over the past three decades, federal regulatory agencies and wetland scientists have devoted considerable resources toward research and indicators of federal wetland jurisdiction which are supportive of the protection of wetland ecosystems (Daiber 1982, Adamus and Stockwell 1983, Mitsch and Gosselink 1986, Environmental Laboratory 1987, Sipple 1988, Adamus et al. 1991, Marble 1992, Brinson et al. 1995).

From the most general of categories such as swamps and bottomlands to the more specific such as reed marshes (Niering 1986) and pocosins (Ash et al. 1983), a number of different wetland types have been described. They can be found along coastlines, in estuaries, along rivers and lakes, in floodplains and even in isolated pockets not directly connected hydrologically to surface or ground water.

Several wetland classifications have been established to reduce natural variability, improve wetland inventories, assess wetland functions and values, and develop restoration or enhancement criteria. The most reliable method of wetland classification includes identification of hydrologic regime, botanical composition, and soil properties. For the past two decades, the most widely utilized wetland classification was a system developed by Cowardin et al. (1979). The U.S. Fish and Wildlife Service (USFWS) adopted Cowardin's *Classification Hierarchy of Wetlands and Deepwater Habitats* and has used it extensively in wetland inventory, mapping, and publishing on National Wetland Inventory (NWI, USFWS 1995) maps which overlay 7.5-minute United States

Geologic Survey (USGS) topographic maps. NWI maps are presently used in watershed and site-specific management and construction plans.

Recently, Brinson (1993) developed a wetland classification system which forms the framework for an approach to functional assessment. The core of Brinson's hydrogeomorphic classification is the identification of three components: geomorphic setting, water source, and hydrodynamics. Geomorphic position coupled with the effects of water source(s), direction, and magnitude is critical in the hydrogeomorphic classification. Brinson's wetland classification formed the critical framework for assessment of wetland functions which were based on hydrogeomorphic settings on both national and regional scales (Brinson et al. 1995, Ainslie et al. 1999). Later, Brinson et al. (1996) recommended three subclasses of riverine wetlands in the Piedmont of Georgia and the Carolinas: overbank, depression, and seepage. However, until now, these subclasses had not been used to address spatial and temporal variation in wetland hydrology and soil conditions.

Several definitions of wetlands have been proposed by regulatory agencies. The USFWS defined wetlands as follows (Shaw and Fredine 1956):

> "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purposes of this classification, wetlands must have one or more of the following attributes:
>
> - At least periodically, the land supports predominantly hydrophytes;
> - The substrate is predominantly undrained hydric soils; and
> - The substrate is nonsoil and is saturated with water or covered by shallow water at the same time during the growing season of each year."

The Natural Resource Conservation Service (NRCS, previously the Soil Conservation Service) defined wetlands under the 1985 Food Security Act (USDA 1985) as:

> "Wetlands are defined as areas that have a predominance of hydric soils and that are inundated or saturated by surface water or groundwater. Wetlands occur when water saturation is at a frequency and duration sufficient to support, and under normal circumstances does support, a prevalence of hydrophytic vegetation (wetland plants) typically adapted for life in saturated soil conditions."

Under Section 404 of the Clean Water Act (1977) and 40 CFR Part 230, wetlands are defined as:

> "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

Based on the wetland definition in the Clean Water Act (1977), Section 404, the 1987 *Corps of Engineers Wetlands Delineation Manual* (hereafter, referred to as COE Manual) was developed by the United States Army Corps of Engineers (Environmental Laboratory 1987). Even though attempts were made to modify the manual in subsequent years (Federal Interagency Committee for Wetland Delineation 1989, USEPA 1991), presently, the COE Manual is the method in use by the federal Section 404 review agencies: USCOE, NRCS, USFWS, and United States Environmental Protection Agency, USEPA.

Common in wetland definitions and delineation methods listed above is the use of a three parameter approach: hydrophytic vegetation, hydric soils, and hydrology. Positive indicators of all three parameters are required to qualify as a federal jurisdictional wetland. In order for hydrologic criteria to be met according to the COE Manual, federal jurisdictional wetlands must be inundated and/or saturated to within 30.48 cm (12 in.) of the soil surface for a minimum of five percent (as consecutive days) of the growing season. On site observations used as positive indicators of hydrology in the COE Manual, such as water lines, drift lines, sediment deposits, and drainage patterns in

wetlands, are evidence of a past flood event. However, the indicators do not address the timing, depth, and magnitude of the event. The USGS (Price 1977, Inman 1988, Stamey and Hess 1993, Inman 1994) developed regional curves and regression equations based on discharge and drainage area. However, the USGS curves stop short of addressing localized variation in channel capacity and levee elevation. One promising method of developing regional dimensionless rating curves that account for not only drainage area but also local variation in channel and levee geomorphology was recommended by Leopold et al. (1964), Dunne and Leopold (1978), and Rosgen (1996). However, the use of regional dimensionless rating curves were not applied to estimate flood frequency and magnitude for riverine wetlands until 1999 by the author of this paper. Pruitt et al. (1999) developed a dimensionless rating curve specific for low gradient riverine systems in the Western Kentucky Coalfield physiographic province. However, the western Kentucky curves were not tested within the physiographic province and are not considered by the author to be applicable to the Piedmont. Thus, development of a dimensionless rating curve specific to the Piedmont was one of the objectives of this study.

Historically, determination of the growing season length has been critical for both hydrology and hydric soils definition. The National Technical Committee for Hydric Soils (NTCHS) developed the following definition of hydric soils (US Department of Agriculture (USDA), Soil Conservation Service 1985, as amended by the NTCHS in December 1986):

> "A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation."

The growing season is defined as (US Department of Agriculture - Soil Conservation Service 1985 and Environmental Laboratory 1987 with clarification by Williams 1992 *italized*):

> "The portion of the year when the soil temperature at 19.7 inches (*20 inches*) below the soil surface is higher than biologic zero (5°C). For ease of

determination, this period can be approximated by the number of frost-free days. *Growing season starting and ending dates will generally be determined based on the 28 degrees F or lower temperature threshold at a frequency of 5 years in 10. In the south, at the discretion of the district, it may be more appropriate to use the 32 degree F threshold.*"

Three important questions arise from the definition of growing season (discussed below): 1) Is biologic zero a critical threshold of soil microbial activity?; 2) Does biologic zero occur at 20 inches (51 cm) for significant periods of time in the southeastern United States including the southern Piedmont to warrant establishment of a growing season applicable to federal jurisdictional wetland determination?; and 3) If biologic zero does occur in the Piedmont, does it have a significant impact on the oxidative status of the soil (hydric soil definition) and the expression of hydrophytic vegetation (wetland definition)?

Biologic zero is based on evidence that microbial activity is significantly reduced at temperatures below 5°C, and soil conditions are not favorable for key oxidation-reduction reactions responsible for the consumption of oxygen, reduction of iron and manganese compounds, and ultimately, the formation of redoximorphic features (Pickering and Veneman 1984, Evans and Franzmeier 1988, Megonigal et al. 1996). Previous investigators have shown that soil temperature at 50 cm at several locations in the southeastern United States was always above biologic zero (5°C) (Megonigal et al. 1993, Megonigal et al. 1996). In order to establish a microbial activity season, Megonigal et al. (1996) measured soil temperature and oxygen in South Carolina, Louisianna, Mississippi, and Georgia. The South Carolina, Louisanna, and Mississippi study sites were located in Gulf and Atlantic Coastal Plain soils and did not include the Piedmont. However, the Georgia study site was located in the Piedmont near Alpharetta, Georgia. Based on their findings, winter rates of soil respiration and oxygen consumption was sufficient to cause anaerobic conditions. Consequently, a 12-month microbial activity season was recommended for southeastern bottomland hardwood forests. However, the study did not address soil temperature at a regional scale or wetland class. In addition,

Megonigal et al. (1993) recognized the need to develop the relationship between temperature, soil saturation, and development of redoximorphic features in southeastern soils. That research need is the focus, in part, of this study.

The expression of the mobility of reduced iron and manganese in the form of redoximorphic features such as pore linings, concentrations, and concretions is critical in on-site identification of hydric soils and federal jurisdictional wetlands (Environmental Laboratory 1987, Vepraskas 1992). Reduction of iron and manganese is mediated by anaerobic bacteria under saturated soil conditions (Mitsch and Gosselink 1993, Mausbach and Richardson 1994). Measurement of redox potential in conjunction with pH has been widely utilized as a surrogate to establish anaerobic and reducing soil conditions, estimate the status of redox couples, and determine microbial activity (Dirasian 1968, Bricker 1980, Mueller et al. 1985, Faulkner et al. 1989, Mitsch and Gosselink 1993, Mausbach and Richardson 1994). Burke (1990) used soil redox potential measurements along a transect oriented orthogonally to the stream and extended across a broad levee in a bottomland hardwood forest in the Georgia Piedmont. Even though a high degree of variability in redox potential measurements was observed, Burke concluded that levee soils were oxidized year-round. However, redox potential did not correspond to either wetter or drier periods during the study. Somerville (1997) observed a negative relationship between water table and redox potential in a restored southern Piedmont wetland. Winger and Lasier (1993) investigated the influence of redox potential on pore water toxicity in sediments collected from the Savannah and Ogeechee Rivers. However, the measurements were not conducted *in-situ*, consequently, they may not be representative of field conditions. Megonigal et al. (1993) measured soil redox potential in conjunction with oxygen content, and water table depth at the Savannah River Site near Augusta, Georgia. The measurements were made along transects established perpendicular across the floodplains of the Savannah River and a tributary, Meyers Branch. The transect crossed dry sites on slightly raised terraces and wet sites in depressions. Minimum redox potential measured over a 6-month period ranged from 604

mV at 15 cm to -60 mV at 90 cm. However, it is assumed that the site was located on the Fall Line and not in the Piedmont, consequently, the data may not be applicable to Piedmont settings.

Another problem exists in Piedmont soils with high concentrations of hematite iron which weather from red parent material (personal communication with NTCHS 2001). Wheeler et al. (1999) conducted experiments using columns on brown soil material collected in Minnesota from soil profiles characterized with naturally occurring high soil organic carbon content as compared to red soil material collected from soil profiles low in organic carbon content and high in hematite iron. Soil temperature and water table conditions were controlled during the experiment. The redox potential in the brown soil material stabilized around 0.0 mV. In contrast, the redox potential of the red soil material reached an equilibrium in the range of 100 to 300 mV. The authors concluded that the difference in iron oxide mineralogy and bioavailable organic carbon contributed to the variation in redox potential between the two soils.

Critical to the federal wetland definition, correspondence between hydric regime and hydrophytic vegetation was required. In response to this need, the USFWS developed the *National List of Plant Species That Occur in Wetlands* (Reed 1988). The list included species that are typically adapted to wetland environments at various degrees of tolerances (status). The status of each listed species was based on the probability of occurrence in wetlands. In western riparian ecosystems, Castelli et al. (2000) reported that species found in wet meadows were most strongly associated with depth to water table and anaerobiosis. However, the correlation between the status of species, hydrologic indicators, and soil redoximorphic features has not been adequately addressed in the Piedmont.

Statement of Problem

Given the hydrologic and biogeochemical variability across wetland hydrogeomorphic settings, inadequate data exist on soil and hydrologic conditions (both temporally and spatially). Even less is known about soil temperature and reducing

conditions with application to growing season at the regional scale and within specific wetland classes. For instance, little is known about whether biologic zero (5°C) occurs at 51 cm for significant periods during the winter in specific wetland classes. If biologic zero does occur in Piedmont wetland classes, the effect on microbial activity has not been fully explored.

Even though vegetation, hydric soils, and hydrology are treated separately in the COE Manual, in reality the three should be fully integrated within specific wetland classes. In doing so, a means of estimating flood frequency and magnitude of riverine wetlands based on site-specific channel geomorphology needs to be developed and tested. In addition, there is a need to develop more appropriate scientifically-based correspondence between direct measures of soil properties, temperature, reducing conditions, and groundwater with indirect measures (indicators) such as redoximorphic features, evidence of flood events, and vegetation communities. In general, direct measures require long term intensive studies as compared to indirect measures which are an indicator, sign, or expression that the direct measure is presently occurring or has occurred in the recent past. All of these factors ultimately determine growing season, federal wetland jurisdiction, wetland functions, and are supportive of wetland protection under the Section 404 of the Clean Water Act (1977).

Goal and Objectives

The research goal was to identify the variation in hydrologic and soil conditions and controlling factors across hydrogeomorphic gradients in the southern Piedmont physiographic province. Specific objectives were to:

1. Classify a representative wetland population within the Piedmont;
2. Develop a means of estimating flood frequency and magnitude at the site-specific scale based on channel geomorphology;
3. Identify the correspondence between indicators of hydrology and soil redoximorphic features versus vegetation composition;

4. Determine the variability in groundwater, soil temperature and soil reducing conditions across wetland classes with application to growing season; and
5. Establish relationships between measured parameters and indicators of federal wetland jurisdiction.

Study Approach

In order to meet the research objectives, the study was divided into two parts, a regional study and an intensive study. The regional study was designed to sample a subset of wetlands representative of southern Piedmont riverine systems and address objectives 1 and 2 above. To accomplish this, the Ogeechee River Drainage Basin was chosen based on:

- Proximity to the planned instrumented sites (intensive study);
- Lack of disturbance particularly major impoundments other than historic mill dams;
- Representative of Piedmont riverine systems with predominantly agricultural land use;
- Similarity to USGS gaged streams used in regional dimensionless curve development (explained below); and
- Headwaters contained completely within the Piedmont, thus, not influenced by other physiographies.

The results of the regional study was used to establish relationships between measured parameters versus vegetation composition, hydrological indicators, and soil redoximorphic features.

The intensive study was designed to determine the temporal variability in groundwater, soil temperature and soil reducing conditions across wetland classes with application to growing season. In addition, the objective was to develop the relationship between air and soil temperature taking into account the effects of groundwater (if any). Also, the effects of air temperature and groundwater on soil reducing conditions as measured by redox potential were explored.

Objectives with testable, research hypotheses are addressed in more detail below in specific sections under Methods. In addition, methods pertaining to the regional and intensive studies have been segregated. For instance, the subheading, Study Area (Southern Piedmont), includes both the regional and intensive research sites. Regional and intensive study sites are described in more detail in regional and intensive study subheadings in Methods.

Study Area (Southern Piedmont)

The study area was located within the Piedmont physiographic province in Georgia, USA (Figure 1). Omernik (1987) described the area as the Southeastern Plains Ecoregion. This Ecoregion includes the Washington, Winder, and Greenville Slope areas. The Savannah River, Chattahoochee River, Flint River, Altamaha River, and a small portion of the Ogeechee River basins flow through this Ecoregion (Wharton 1978). Streams flowing to the southwest occupy shallow, open valleys with broad, rounded divides while those streams flowing southeast occupy narrow, deeper valleys with narrow, rounded divides. The streams flowing through the Winder and Washington Slope areas drain into the Atlantic Ocean while the Gulf of Mexico receives water flowing through the Greenville Slope area.

Much of the original topsoil has eroded away due to poor agricultural practices during the turn of the twentieth century, leaving red clay subsoils (i.e., B horizon) exposed in areas (Trimble 1969). There are numerous dome-shaped, granite surfaces in the Lower Piedmont. Prevalent geologic formations in the area are metamorphic in origin consisting of mafic gneisses, especially hornblende gneisses with intercalated amphibolites and biotite gneisses (Bennison 1975). Soils have developed from the parent material dominated with acid crystalline, metamorphic rock deposits formed from granites, gneisses, and schist, rich in iron and magnesium but low in nitrogen and phosphorus. Soil texture in the region ranges from sandy clay loam to sandy loam soils and contain mica schist and quartz.

The mean annual rainfall is 112 to 142 cm (44 to 56 inches) (Robertson 1968). Mean annual temperature ranges between 15 and 18°C (59 to 64°F). Mean midsummer maximum temperatures are 31 to 33°C (88 to 91°F), and midwinter minimum temperature falls between 0 and 2°C (32 and 36°F). The frost-free season is 210 to 240 days.

Less steep areas where the topsoil has not been as severely eroded are adapted to corn, cotton, soybean, and grain sorghum crops. About 70% of the subregion is woodland and 20% is dedicated to cropland and pastureland. However, sever impact from high urban densities (e.g., Atlanta) is growing steadily. Much of the subregion contains hardwood/mixed forests or pines.

Surface water mineral content is approximately 30 to 70 parts per million (ppm) (Robertson 1968). It is soft with a siliceous base. The pH ranges from 6.0 to 6.8. Iron concentrations are approximately 0.01 to 1.0 ppm.

Geomorphologically, the Piedmont consists of foothills and broad interstream areas (Perkins 1977). Cressler et al. (1983) described the stream network in the Piedmont area southeast of the Chattahoochee River as a superimposed dendritic drainage pattern. Elevations range from approximately 152 to 457 meters (500 to 1500 feet) above sea level.

Wharton (1978) describes this study area as the Piedmont physiographic province which is characterized by "alluvial river and swamp systems". Based on the Cowardin et al. (1979) classification system, most of the wetlands within the study area are classified as a Palustrine system dominated by forested classes. Utilizing a hydrogeomorphic classification, most of the wetlands are classified as middle gradient, riverine systems characterized by frequent flood events (Brinson 1993).

CHAPTER 2

METHODS

Regional Study Area Description

The regional study was conducted in the headwaters of the Ogeechee River Watershed, in Green, Hancock, Taliaferro, and Warren Counties, Georgia, USA (Figure 1). The Ogeechee River, which is approximately 402 km (250 river miles) in length (as measured from the mouth), begins within the Washington Slope (Wharton 1978) near Union Point in Greene County as two forks: the North Fork Ogeechee River; and the South Fork Ogeechee River. The two forks flow southeast into Taliaferro County where they merge at 380 km (river mile 236). From there, the river flows southeast through the Fall Line and Red Hills into the Vidalia Upland of the Coastal Plain, through the Coastal Marine Flatlands, and eventually, meets the Atlantic Ocean in Ossabaw Sound.

The regional study covered 53 assessment sites between July 14 and August 12, 1994 (Figure 2 and Table 1). Candidate wetland assessment sites were selected using the National Wetland Inventory (NWI) maps (USFWS 1995). An attempt was made to assess each mapped NWI polygon along the Ogeechee River and several of its tributaries within the Piedmont. Wetlands were characterized based on their hydrogeomorphic classification, botanical composition, hydrologic indicators, geomorphologic position, and soil redoximorphic properties as described below. Characterization of the 53 assessment sites was used to establish federal wetland jurisdiction under Section 404 of the Clean Water Act (1977) and recommend improvements in wetland delineation.

Regional Precipitation

Historic precipitation was assessed on a regional (northeast Georgia) and local scale (Athens/Watkinsville area, see Intensive Study below). The objective of analyzing

regional historic precipitation data was to establish normal monthly and annual climatic conditions and determine if normal precipitation conditions occurred during the study period. Within the northeast Georgia region, eleven records of daily observations were downloaded from Earthinfo® and reduced to monthly and annual statistics which included: number of observations, minimum, maximum, arithmetic mean, standard deviation (about the mean), median, and 25 and 75 percent quartiles.

Hydrogeomorphology

Fifty-three Piedmont assessment sites were classified using *A Hydrogeomorphic Classification for Wetlands*, or HGM (Brinsion 1993). The objective of this classification was two-fold. First, it grouped assessment sites based on common landscape and hydrological characteristics, thus reducing natural variability. Second, once classified, the relationship between indicators of hydrodynamics, hydric soils, and hydrophytic vegetation was assessed on each site during the regional study.

HGM classifies wetlands based on three components: (a) geomorphic setting, (b) water source and transport, and (c) hydrodynamics. The geomorphic setting was characterized by identifying land surfaces orthogonally to the valley in five distinct landscape positions: summit, shoulder, backslope, footslope, and toeslope. Water sources include direct precipitation, overbank flooding from the adjacent stream, and groundwater discharge. Hydrodynamics refers to vector flow (i.e., direction and magnitude or velocity).

Vegetation

A vegetation study was conducted on the 53 assessment sites in the study area. The objectives of the vegetation study were four-fold:

- Identify vegetation composition, diversity, relative dominance, and adaptations representative of Piedmont riverine hydrogeomorphic settings;
- Determine the vegetation status with respect to federal wetland jurisdiction;
- Determine the correspondence between vegetation, soils, and hydrologic characteristics of the hydrogeomorphic setting; and

- Use the results of the above to improve the confidence in the USFWS wetland vegetation status (Reed 1988).

In situ vegetation analysis included identification of vegetation adaptations in response to hydric conditions including buttressing, shallow root system, multi-trunks or stooling, pneumatophores, adventitious roots, hypertrophied lenticels, and floating leaves or stems. Buttressing is the enlargement or thickening of the tree trunk. Shallow root system or flared root system is the maintenance of roots near the soil surface usually in the surface horizon within twelve inches of the soil surface. Pneumatophores are extensions from the tree roots to the surface (e.g., cypress knees). Adventitious roots are extensions of the lower tree trunk into the soil. Hypertrophied lenticels are raised, and sometimes enlarged lenticels usually on the tree trunk. Floating leaves or stems refer to aquatic plants that have leaves or stems that float on the water surface in order to provide support and optimal conditions for photosynthesis.

Two methods were utilized to determine vegetation dominance on each assessment site. In general, these methods followed the routine and comprehensive methods described in COE Manual. The routine and comprehensive methods as outlined in the COE Manual were utilized to compare parameters measured directly during the Intensive Study against indicators used in the COE Manual. The routine versus comprehensive methods are described below.

Following a reconnaissance of each site, the top three dominant species using the routine method were identified in each of four strata: tree, shrub, herb, and woody vine. Strata were identified based on size classes as follows (Environmental Laboratory 1987):

- Vegetation greater than three inches in diameter were placed in the tree stratum;
- Vegetation less than three inches in diameter were placed in the shrub stratum;
- Vegetation less than one meter in height were placed in the herbaceous stratum; and
- Dominant woody vines were counted which included those attached to trees, unattached and erect, and/or unattached and trailing along the ground.

Initial site information included: hillslope position (summit, shoulder, backslope, footslope, or toeslope), an estimation of percent slope, and depth of leaf litter.

Based on the results of the reconnaissance and application of the routine method, a decision was made on whether to conduct a more detailed vegetation survey using the comprehensive method. Considerations included: 1) The uniqueness of the top three dominant species as compared to previously surveyed assessment sites; 2) Data richness within the three identified hydrogeomorphic subclasses; and 3) The uniqueness of the observed relationship of the dominant vegetation with soil and hydrologic characteristics of the assessment site.

If the comprehensive method was deemed necessary, a sample plot and two replicate plots were identified within each assessment site. The center point of the first plot was determined systematically by measuring 91.4 meters (300 feet) with a Keson™ tape from the nearest landmark (e.g, road, stream confluence). The center point of the two replicates were identified by measuring 30.5 meters (100 feet) from the first plot along a compass bearing parallel to the stream. The stream was paralleled in order to ensure vegetation analysis of the same vegetational "band" and landscape position orthogonal from the stream channel.

Within the three replicate plots, each of four strata were surveyed per size classes and form as described above. The following plot sizes and shapes were utilized for each strata: 1) Tree stratum (including snags): 21.3 meter (70-foot) diameter circular quadrat; 2) Shrub stratum: 21.3 meter diameter circular quadrat; 3) herbaceous: one-meter square quadrat; 4) Attached woody vines: 21.3 meter circular diameter quadrat; and 5) Unattached woody vines: one-meter square quadrat. From the center of each plot, four quadrants were identified within a Cartesian axis based on magnetic north with 21.3-meter axes. All trees, shrubs, and attached woody vines were identified and measured within the 21.3-meter circular quadrat. Tree diameter was measured at breast height (DBH, approximately 1.22 m from the ground), and shrubs were measured for height. For the herbaceous stratum, a one-meter square quadrat frame constructed from 1.9 cm

(¾-inch) diameter schedule 40 PVC pipe was randomly tossed within each of the four quadrants. Within each quadrat, percent coverage of each species was estimated.

Descriptive statistics were conducted on each vegetative stratum as follows:

- Trees: abundance, minimum, maximum, and arithmetic mean of the DBH, density relative density, dominance, and relative dominance;
- Shrubs: abundance, minimum, maximum, and arithmetic mean height, density, relative density, dominance, and relative dominance;
- Herbs: percent coverage, abundance, density, relative density, dominance, and relative dominance; and
- Woody vines: percent coverage, abundance, density, relative density, dominance, and relative dominance.

Soil Characterization

The objective of the soil characterization during this regional study was to determine the hydric condition of the soil. In general, soil profiles were described by excavating an unlined bore hole of adequate depth to describe the top three horizons or layers (approximately 0.5 to 1.0 meters) for the purpose of describing redoximorphic features in the upper part of the soil profile.

A soil pit was located in the center of the vegetation plot. The following soil properties were noted during the regional study:

- Presence or absence of leaf litter;
- Color (Munsell);
- Texture by feel;
- Structure;
- Odor (e.g., actinomycetes, hydric or rust, hydrogen sulfide);
- Presence or absence of roots (quantity and size);
- Moisture consistency;
- Presence or absence of rocks (size, shape, kind);
- Concretions (kind, quantity, size);

- Masses (quantity, size, color distinctness);
- Pore linings;
- Iron depletions;
- Clay depletions; and
- Horizon boundaries.

Hydrology and Geomorphology

The objectives of the hydrology and geomorphology study during the regional study were the following:

- Describe the hydrological condition of the population of riparian zones within the Ogeechee River watershed in the Piedmont;
- Determine the geomorphological condition of the stream channel and adjacent riparian area;
- Identify presence of surface and subsurface indicators of hydrology;
- Determine the predominant and secondary sources of hydrology to the wetland assessment site; and
- Determine if wetland hydrological criteria applicable to federal wetland jurisdiction were met.

In-channel geomorphological features included presence or absence of levees, crevasses, bar morphology, and channel width and depth. In-stream hydrological characterization included estimations of wetted surface width, water depth at identified bedforms (e.g., pool, run, riffle) and water velocity.

Geomorphological characterization of the riparian zone included macrotopography (oxbows, scrolls, side channels), microtopography (hummocks, depressions, floodways, sourways), and historic channel evidence (channel bed or channel lag). In general, topographic relief less than six inches was considered microtopography.

Indicators of surface hydrology within the riparian zone included silt-stained vegetation, water-stained leaves, lichen/bryophyte lines, sediment deposits, buried or scoured root or trunk collars, drainage patterns, ponding, and drift lines. Drainage

patterns are evidence of overbank flow in the form of leaf litter transported or sediment scour. Indicators of subsurface hydrology included surface water depth (if flooded or ponded), ground surface elevation (GSE) to the water table or soil saturation and oxidized rhizospheres. If any of the surface or subsurface indicators were observed, wetland hydrology were met based on the COE Manual. In addition, water sources (overland, overbank, direct precipitation, or groundwater discharge), inlet morphology (sheet, rill, crevasse, constricted, seep), and outlet morphology (sheet, crevasse, constricted, groundwater recharge) were identified.

Jurisdictional Wetland Determination

Federal jurisdictional wetland determinations were conducted using the three parameter approach outlined in the COE Manual. The COE Manual requires positive wetland indicators of all three parameters: hydrology, vegetation, and soils. In general, the routine method was utilized for all three parameters. However, the comprehensive method was conducted on several assessment sites as previously described.

Either one primary indicator or two secondary indicators of hydrology were required for the hydrological criterion to be met. Primary indicators of hydrology included inundation, saturated in the upper twelve inches, water marks, drift lines, sediment deposits, and drainage patterns in wetlands. Secondary indicators of hydrology included oxidized root channels in upper twelve inches, water-stained leaves, and local soil survey data. By definition, the rationale for all hydrological indicators is flooding, ponding, or soil saturation from groundwater such that soil saturation occurs within 30.48 cm (12 in.) of the soil surface for a minimum of five percent (as consecutive days) of the growing season (Environmental Laboratory 1987).

According to the COE Manual, a dominance of facultative species or wetter (facultative wetland or obligate wetland) was required before vegetation criteria were met. Indicator categories of vegetation (status) include the following (Reed 1988):

- Obligate Wetland (OBL). Occur almost always (estimated probability >99%) under natural conditions in wetlands;

- Facultative Wetland (FACW). Usually occur in wetlands (estimated probability 67% - 99%), but occasionally found in nonwetlands;
- Facultative (FAC). Equally likely to occur in wetlands or nonwetlands (estimated probability 34% -66%);
- Facultative Upland (FACU). Usually occur in nonwetlands (estimated probability 67% - 99%), but occasionally found in wetlands (estimated probability 1% - 33%); and
- Obligate Upland (UPL). Occur in wetlands in another region, but occur almost always (estimated probability >99%) under natural conditions in nonwetlands in the region specified. If a species does not occur in wetlands in any region, it is not on the National List.

The USFWS Region 2 (southeastern) list was used for this research (Reed 1988). In addition to indicator status, vegetation adaptations to hydric soil conditions were identified.

According to the COE Manual, only one indicator of hydric soils is required for hydric soil criteria to be met. Hydric soils indicators for non-sandy soils included: Histosol, histic epipedon, sulfidic material, aquic or peraquic moisture regime, reducing conditions, gleyed or low-chroma colors, and concretions. In addition, the detection of a fresh plowed odor (indicator of actinomycetes) was used to indicate recent non-hydric conditions. Actinomycetes are obligate aerobic bacteria which were used as evidence of aerobic conditions near the soil surface. Sulfidic material refers to the detection of a rotten egg odor of a freshly broken ped. It is assumed that sulfidic odor is only detected in soils that are highly reduced due to saturated conditions. An aquic moisture regime requires soil saturation on at least a semi-permanent basis. A peraquic moisture regime requires permanent soil saturation at or near the surface. Both moisture regimes require identification of redoximorphic features within a specific depth from the ground surface (Soil Survey Staff 1975). A positive α,α -dypridyl test was used to identify reducing conditions during the regional study. Gleyed or low-chroma colors are based on the

oxidative status of predominantly iron (Fe^{3+} or Fe^{2+}). Ferric iron (oxidized iron, Fe^{3+}) is usually yellow to red-orange to red and is indicative of oxidized or non-hydric conditions. In contrast, Ferrous iron (reduced iron, Fe^{2+}) is usually gray to blue-gray and is evidence of hydric conditions. Soil colors were determined using the Munsell Color Book (Munsell 1975) immediately below the A-horizon or ten inches below the soil surface (whichever was shallower). The soil color indicator was met for hydric soils in one of two ways (Environmental Laboratory 1987):

- Gleyed soils. Gleyed colors are identified on the gleyed Munsell page and are indicative of anaerobic conditions causing pronounced reducing conditions; or
- Gray soils with bright masses (mottles). Gray soils with bright masses refers to the reduced, gray matrix with microzones of oxidation or masses. A matrix chroma of two or less with masses or a matrix chroma of one or less with no masses is required for hydric soil determination.

Since a complete soil profile description to two meters deep was not conducted for the regional study, and the county soil survey for Taliaferro County was not published, the soils were not classified to Order. Consequently, the criteria for soil appearing on the hydric soils list was not used in this research. Concretions refers to iron and manganese oxides segregated into concretions, nodules, or masses. Concretions are products of successive oxidation and reduction processes and are evidence of soil saturation and anaerobiosis near the soil surface.

Local Study Area Description (Intensive Study)

Two sites were instrumented for long-term research. The first site was located in Whitehall Forest, School of Forest Resources, University of Georgia, Clarke County, Georgia, USA (N 33.882° latitude, W 83.362° longitude) (Figure 3). The site was located in the floodplain of the Middle Oconee River immediately downstream of Dean's Pond (hereafter, referred to as Dean's Pond Research Site, DPRS) (Figure 4). Automated instrumentation was installed September 8, 1997 and was monitored until February 5, 2001 for groundwater levels, air temperature, and soil temperature and redox potential.

Two hydrogeomorphic, riverine subclasses were monitored at DPRS, depression and overbank. Contributing sources of water to the depression were direct precipitation, a small stream from Dean's Pond, flood events from the Middle Oconee River, and possibly groundwater discharge in the form of saturated return flow from upland sources. Contributing sources of water to the overbank site were direct precipitation, flood events from the Middle Oconee River, and overflow from the depression.

The second site was located on the Plant Science Research Farm, University of Georgia, Oconee County, Georgia, USA (N 33.876° latitude, W 83.549° longitude) (hereafter, referred to as Plant Science Research Farm, PSRF) (Figure 5). PSRF was on a forested footslope down gradient from open fields used for agricultural research. Both a forested and emergent wetland site were instrumented at PSRF. Automated instrumentation was installed July 5, 1999 and was monitored until February 5, 2001 for groundwater level, air temperature, and soil temperature and redox potential. PSRF was located 17.2 kilometers (10.71 miles) nearly due east of DPRS.

Local Precipitation

Precipitation data were collected from two weather stations located near the research sites: 1) The Georgia Forestry Commission Weather Station (GRCWS, Whitehall Road, Athens, Georgia) which was 1.58 km (0.98 miles) from DPRS; and 2) The Plant Science Research Farm Headquarters Weather Station (PSRFWS, Watkinsville, Georgia) which was 1.27 km (0.79 miles) from PSRF research site (Figure 3). Both stations were equipped with tipping bucket rain gages. The objective of analyzing weather station data was to correlate precipitation and air temperature data with soil temperature and soil redox potential at the research sites.

Similar to regional data, local data were reduced to monthly and annual statistics and were compared against a 46-year record (1949-1994) collected by the College of Agriculture, University of Georgia, Athens, Georgia. For this research, 25 percent and 75 percent quartiles about the median precipitation were used as upper and lower boundaries, respectively, and were referred to in this research as normal.

Geomorphology

Instrumented sites and stream cross-sections were surveyed during the intensive study. The objectives of surveying were three-fold. First, the instrument nests at DPRS and PSRF were located with respect to the stream channel and landscape position (planform mapping). Second, cross-sections were surveyed to calibrate the hydraulic geometry of the stream channel at USGS gage stations (regional dimensionless rating curves as described below). Third, dimensionless rating curves were applied to selected cross-sections adjacent to the instrument nests at DPRS and PSRF (Oconee River Watershed) and at representative assessment sites identified during the regional study (Ogeechee River Watershed (dimensionless rating curve application).

Using a Topcon™ Total Station (Model 303D), traditional engineering surveying was employed including horizontal and vertical control and traditional horizontal traversing. For this specific study, horizontal angles were not corrected based on magnetic declination since only relative horizontal position was required. In addition, surveying did not include closing-the-loop between the cross section and the gage. However, horizontal and vertical control from the cross section to the gaging station was maintained.

Planform Mapping

Temporary bench marks (TBM) were established with 1.2 meter (4 ft.) long #4 (1.3 cm (½ ”) diameter) steel reinforcement bar at DPRS and PSRF instrument nests. The TBM were utilized to maintain on-site horizontal and vertical control for stream cross-sections and planform mapping. An accuracy of 0.91 cm (0.04 ft.) was maintained while back sighting between TBM. A total of 261 and 105 points were surveyed at DPRS and PSRF instrument nests, respectively (Figures 4 and 5).

Regional Curves

The objective of developing regional curves for the Piedmont physiography was to establish the flood frequency and discharge of streams adjacent to the study sites. Regional curves are an important component of assessing functions of riverine

hydrogeomorphic classes of wetlands and addressing predominant water sources (Pruitt et al. 1999).

Prior to field excursions, six USGS gaging stations were selected in the Piedmont that were representative of a range of watershed sizes. Drainage area sizes ranged from 47.4 to 2434.6 square kilometers (18.3 to 1430 square miles). Peak flow data and hydraulic geometry (USGS Summary of Discharge Measurement Data, 9-207 forms) for each of the seven gages were obtained from the State USGS office located in Doraville, Georgia. Peak flow data included the date of the observation, discharge (Q), and gage height or stage (S). Hydraulic geometry included width (W), cross-sectional area (A), mean velocity (V), and Q. Mean depth (D) was calculated by dividing cross-sectional area (A) by W. The data sets were downloaded into a computer spreadsheet for data reduction and graphical depiction of hydraulic geometry.

Bankfull Identification

Based on previous studies (Trimble 1969, Burke 1990), many Piedmont stream channels are degraded and enlarged such that the stream has been decoupled from its historic floodplain. For this reason, bankfull and channelfull stages were defined following the system of Pruitt et al. (1999): 1) Bankfull stage corresponds to the elevation that, on the long-term, does the most channel work such as channel maintenance, moving sediment, forming or removing bars, forming or changing bends and meanders (Dunne and Leopold 1978). In addition, it is the stage that corresponds with the effective discharge (Dunne and Leopold 1978, Knighton 1984, Rosgen 1996). In general, in the Southeast the bankfull stage is represented by the top of the point bar or the active floodplain and has a recurrence interval from 1 to 2 years; and 2) Channelfull corresponds to the stage and discharge required to flood the terrace or the historic (abandoned) floodplain.

Bankfull features vary with physiography based on geology, soil, bank material and sediment characteristics, vegetation, and location and form of bars (Williams 1978, Leopold 1994). For example, in the high gradient streams of the western United States,

bankfull indicators in general are represented by pronounced sediment berms, as evidenced by deposition of gravel to cobble particle sizes forming a distinct break in topography. In contrast, bankfull indicators in medium to low gradient streams of the southeastern United States are not as pronounced as western streams and are characteristically composed of sand or finer particle sizes including silt and clay. In addition, recognition of vegetative indicators, especially hydrophytes (Reed 1988), are important in establishing a stage that corresponds to bankfull discharge in southeastern streams. Also, in coastal plain settings, a break between bryophyte and lichen growth separated by a distinct tannic stain line on wetland trees (e.g., baldcypress and gum trees) often coincides with sediment features and may be used to confirm other primary bankfull indicators.

Identification of bankfull indicators included the following steps (adapted from Leopold 1994):

- A reconnaissance of the stream, upstream and downstream of the gage station, was conducted to identify a representative "natural" channel profile in cross section and planform. Typically, USGS gaging stations in the Piedmont are located at bridge crossings. In general, the stream is channelized and/or armored with rip-rap immediately below and upstream and downstream of the bridge. In addition, most bridge openings are under-sized and form an artificial knick point funneling water through the structure especially at higher stages. For this reason, representative cross sections were located an adequate distance away from the bridge to reduce "bridge-effect" (Pruitt et al. 1999);
- Once a representative stream reach was identified, bankfull indicators were identified and marked at several locations longitudinally along the channel;
- Utilizng a Topcon™ (Model 303D) and using traditional engineering surveying techniques, a representative cross section was surveyed across the valley flat which traversed one set (left and right banks) of the bankfull indicators identified above. A temporary bench mark (TBM) was installed to serve as a monument on

each end of the cross section with #4 (1.3 cm (½") diameter) by 1.2 meters (4 ft.) long steel steel reinforcement bars. Accurate observations were recorded of the channel and valley geomorphology including bars, levees, bankfull indicators, terraces, back swamps, and riparian zones and the site documented with photographs; and

- Features described in the cross section were correlated with the gage record by surveying the water surface elevation from the cross section to the bridge and vicinity of the USGS gage and/or staff plate. A parallel line was developed by surveying the additional bankfull indicators and channelfull stage indicators between the cross section and the bridge. The water surface and the parallel line created from the bankfull indicators was surveyed to the USGS gage datum at the bridge. The stages that coincided with the surface water elevation, bankfull, and channelfull were determined by either a tape down from a reference point, a USGS wire weight tapedown, a staff gage or an electronic display at the gage station depending on the specific equipment installed at the site.

USGS peak discharge data for each station (hereafter, referred to as at-station data) was sorted and ranked (m) by Q in descending order. The recurrence interval (RI) or return interval in years of each observation was calculated by (Dunne and Leopold 1978):

$$RI = (n+1)/m$$

where: m = the rank

n = number of observations

Probability of exceedence was calculated as the reciprocal of RI. Regression analysis on each at-station data set was conducted on several relationships including D vs. Q, W vs. Q, A vs. Q. Field-collected data were plotted to inspect for temporal trends and then transformed to linearize for best fit based on the regression coefficient (R^2).

Discharge, recurrence interval, and probabilities of exceedence were estimated by regression analysis from peak discharge data for each at-station data set based on the stages that represented bankfull and channelfull. In addition, discharges based on RIs of 1.5, 2.33, 10, 25, 50, and 100 years (hereafter referred to as standard RIs) were estimated by regression analysis. Mean depth at bankfull, channelfull, and standard recurrence intervals were estimated from discharge regressed against mean depth derived from the USGS Summary of Discharge Measurement Data (9-207 forms). Hydraulic geometry (width and cross sectional area) was also regressed against drainage area.

Discharges and mean depths corresponding to the bankfull and standard recurrence intervals of each at-station data set were utilized to develop a Piedmont regional dimensionless rating curve as follows:

$$Q / Q_{bkf} \text{ vs. } D / D_{bkf}$$

where : Q = the recurrence interval of the discharge at any topographic feature above the channel at a given mean depth (D)

Q_{bkf} = discharge that coincides with the bankfull stage

D_{bkf} = mean depth at bankfull

The Q and D of interest for this study was the channelfull flood event or the event that flooded the adjacent assessment or instrumented site.

Rating Curve Application

The Piedmont dimensionless rating curve was tested at six cross-sections. The cross-sections represented a range of drainage area sizes previously assessed during the Ogeechee River regional study. A suitable cross-section was identified which was representative of a relatively undisturbed cross-section and planform and located adjacent to the assessment site established during the regional study. The cross-section was surveyed perpendicular to stream flow and was extended across the levees and/or terraces. In addition, stream water surface and channel slopes were surveyed at the cross-section.

Groundwater Hydrology

Groundwater was monitored at the DPRS depression and overbank sites and at the PSRF forested and emergent seeps using automated wells manufactured by Remote Data Systems, Inc.™. The wells were constructed of screened, 10.2 cm (4 in.) schedule 40 PVC Pipe by 1.2 meters (4 ft.) long. Wells were installed at each of the four identified hydrogeomorphic settings using the following procedure:

- A suitable ground surface near the instrument nest for well installation as identified;
- A 10.2 cm (4 in.) diameter bore hole using a 10.2 cm auger was excavated;
- Depth to maintain adequate well height above ground surface elevation (GSE) was measured;
- The screened well was equipped with a nylon well sock;
- The well was inserted in the excavated hole, and the gap between the screen and bore hole was filled with silica sand;
- The well was sealed at ground surface with bentonite; and
- The well was calibrated to GSE by accurately surveying and averaging several GSEs around the well and presetting the manufacturer's calibration line.

Wells were programmed with a Hewlett-Packard™ Model 48G hand-held calculator to record at 8-hour intervals. Data were downloaded electronically once a month.

Soil Characterization (Laboratory Analysis)

Based on the results of the regional study, fifteen assessment sites were selected for intensive laboratory analysis that represented the range of variability and HGM subclasses. The subset was composed of nine overbank, three depressions (beaverponds), and three seeps.

Representative soil material was collected from each of the fifteen sites and transported to the Soil Characterization Laboratory of Crop and Soil Sciences and the School of Forest Resources for analysis. The soil material was collected from the surface

and subsurface horizons identified during the regional study. A subsample was collected from each soil sample, mixed thoroughly, and split analysis. Laboratory analysis included pH, bulk density, porosity, particle size distribution, percent total carbon, cation exchange capacity, and x-ray diffraction.

Bulk density and porosity was determined in the laboratory using the clod method 4A1 (USDA 1996). The method entailed the collection of a representative ped from each horizon, covering the clod with a fine-mesh, hair net, coating (by submergence) the clod with liquid Saran (Dow Saran F-310, Dow Chemical Co.™), repeated Saran coating and drying until waterproof, weighing the clod dry and then suspending it in water noting the water temperature, and weighing again following over-drying at 105°C. Bulk density (ρ_b) was calculated by:

$$\rho_b = \rho_w W_{ods} / [W_{sa} - W_{spw} + W_{pa} - (W_{pa\rho w} / \rho_p)]$$

where:

ρ_w = density of water at temperature of determination,

W_{ods} = oven-dry weight of soil sample (clod),

W_{sa} = net weight of clod in air,

W_{spw} = net weight of soil sample plus Saran in water,

W_{pa} = weight of Saran coating in air, and

ρ_p = density of Saran.

Porosity (φ) was calculated by:

$$\varphi = 1 - \rho_b / \rho_{qtz}$$

where:

ρ_b = bulk density of clod (determined in equation above), and

ρ_{qtz} = bulk density of quartz (2.65 g/cm^3)

Particle size determination (PSD) was measured using the pipette method (Gee and Bauder 1986). The method is based on Stoke's Law which is a relationship between the particle size and the density of the solution that the particle is falling through under the influence of gravity. For the pipette method, the clay fraction (<2 μm) was extracted

by pipette once adequate time (t) was allowed for the settling of silt (2 μm< silt < 62.5 μm) and given by the equation:

$$t = (18\nu x) / [(\rho_s - \rho_l)D^2 g]$$

where:

ν = viscosity of water

x = depth of the particle in the suspension beaker

ρ_s = density of the particle

ρ_l = density of water

D = diameter of the particle, and

g = force of gravity.

Percent total carbon was measured on a carbon analyzer equipped with an infrared detector (Shimarzo™ Model 550). Prior to combustion in the carbon analyzer, sample preparation included thoroughly mixing a representative sample of soil material, pulverizing the sample using a ball mill grinder, and oven drying the sample at 105°C for 24 hours. The carbon analyzer was calibrated against a certified soil reference material of known carbon content (1.2 percent).

Cation exchange capacity (CEC) and clay mineralogy were determined on soil material in the Soil Characterization Laboratory, Crop and Soil Sciences, University of Georgia. CEC was determined using an automatic extractor following the NH_4Cl, pH 7.0 procedure (procedure 5A9) (USDA 1996). Clay mineralogy was determined using a Philips x-ray defractometer (XRD). The XRD was equipped with a copper target and set at 35 kilovolts and 20 milliamps.

Soil Temperature

In conjunction with ambient air temperature, soil temperature was measured at three depths on DPRS and PSRF as described below. The objectives of measuring soil temperature were: 1) Determine the annual and seasonal variation in soil temperature at various depths across the four HGM subclasses; 2) Model the variation in soil temperature using time series analysis; 3) Determine the relationship between soil

temperature and ambient air temperature; 4) Determine the effects of groundwater on soil temperature; and 5) Determine if growing season, by definition, exists in the identified, wetland subclasses. The following hypotheses were tested:

Objective 1.

H_o : There is no significant difference in annual and seasonal soil temperature at three depths within a site and between sites (HGM subclasses)

H_a: There is a significant difference

Objective 2.

Hypotheses inappropriate

Objective 3.

H_o : There is no significant regression relationship between air and soil temperature (Pearson's r correlation)

H_a: There is a significant difference

Objective 4.

H_o : Groundwater does not exert a significant effect on soil temperature (regression analysis, positive or negative effect)

H_a: Groundwater does exert a significant effect on soil temperature

Based on the results of Objectives 1 and 3 above, Objective 5 can be accomplished.

Air and soil temperature was measured using thermocouples with 15.2 meter (50 ft.), shielded leads (Campbell™ Model 107-L for air and Model 107B-L for soil). Thermocouples were calibrated at a range of temperatures, which spanned the anticipated soil temperature ranges, and installed at three depths. With the exception of the air probe at the PSRF site ($R^2 = 0.98$), all calibration curves resulted in a regression coefficient of 0.99 (Appendix A, Figures 48 to 55).

For this research, growing season was defined as the period of the year when the soil temperature measured at 51 cm (20 inches) below the soil surface is greater than 5°C (41°F) (Environmental Laboratory 1987, Williams 1992). However, because site-specific, soil temperature data was not available, the starting and ending dates of the

growing season are determined based on a threshold of 28°F or lower air temperature at a frequency of 5 years in 10 (Williams 1992). This is the growing season criteria used in the Savannah District of the U.S. Army Corps of Engineers (personal communication, Richard Morgan 1997). Growing season was determined based on the Soil Survey of Clarke and Oconee Counties (Robertson 1968) as March 14 to November 20 which is equivalent to 251 days. Consequently, in order to meet hydrology criteria under the wetland manual (Environmental Laboratory 1987), federal jurisdictional wetlands must be inundated and/or saturated to within 30.48 cm (12 in.) of the soil surface for a minimum of five percent of the growing season as consecutive days. This is equivalent to 12.6 days for Clarke and Oconee Counties.

Soil Redox Potential

Oxidation-reduction potential (redox) was measured at three soil depths at DPRS and PSRF. The objectives of measuring soil redox were: 1) Determine the annual and seasonal variability in soil redox within a site at three depths and between HGM subclasses; 2) Determine the effects of soil temperature on redox; and 3) Determine the effects of soil temperature in conjunction with groundwater on redox. The following hypotheses were tested:

Objective 1.

H_o : There is no significant difference in annual and seasonal soil redox at three depths within a site and between sites (HGM subclasses)

H_a: There is a significant difference

Objective 2.

H_o: Soil temperature does not significantly affect soil redox

H_a: Soil temperature does affect soil redox

Objective 3.

H_o : Soil temperature in conjunction with groundwater does not significantly affect soil redox (annual and seasonal)

H_a: Soil temperature in conjunction with groundwater does affect soil redox

The results of the above objectives and hypotheses was used to test the Technical Standard described below.

Pankow (1991) described the negative logarithm of the electron activity (pe) as the master variable for describing the equilibrium position for all redox pairs in a given system:

$$pe \equiv - log \{e\}$$

According to Faulkner et al. (1989), redox is a quantitative measure of electron availability and is indicative of the intensity of oxidation or reduction in both chemical and biological systems. When based on a hydrogen scale, redox potential (E_H) is derived from the Nernst Equation (Stumm and Morgan 1981):

$$E_H = E_H^o + 2.3 \times ® \times T)/nF \times log (\prod_i \{ox\}^{ni}/\prod_j \{red\}^{nj})$$

where:

$\prod$ = product symbol

E_H^o = potential of reference, mV

R = gas constant = 81.987 cal deg^{-1} $mole^{-1}$

T = temperature, ^oK

n = number of moles of electrons transferred

F = Faraday constant = 23.061 cal/mole-mV

{ox} and {red} = activity of the oxidants and reductants, respectively

At standard conditions, pe can be estimated from E_H by:

$$pe = E_H / 0.05916$$

Variability in E_H can be attributed to spatial heterogeneity in texture, structure, organic matter, aeration, and moisture (Megonigal et al. 1993).

Typically, redox potential was reported in millivolts (mV) as referenced to a hydrogen probe, hence E_H. A saturated calomel electrode (E_{SCE}) was used in this study and in the following example. Silver chloride reference probes (E_{AgCl}) would have a different correction factor. *In situ* redox potential (E_{sce}) needs to be corrected in the following steps:

1) corrected to calibration curves specific to the electrode:

$$Corrected\ E_{sce} = b + m\ (Observed\ E_{sce})$$

2) normalized to a predetermined soil pH (e.g., pH 7) for comparison between sample populations:

$$E_{sce,\ pH5} = Corrected\ E_{sce} + 59.16\ (Field\ pH - 7)$$

and

3) corrected to a hydrogen probe using the Nernst Equation and accounting for a calomel reference electrode and soil temperature (Pankow 1991):

$$E_H = E_{sce,\ pH5} + 0.268 - (2.303 \times RT)/2F\ \log\ (\{Hg_{(l)}\}^2\ \{Cl^-\}^2)/\{Hg_2Cl_{2(s)}\})$$

In general, the correction from a E_{SCE} and E_{AgCl} is +244 mV and +222 mV, respectively.

Forty redox potential probes (18 for DPRS and 22 for PSRF) were referenced to a standard reference probe (E_{SCE}) against three quinhydrone standards (3-point calibration curve, Appendix B, Figures 56 to 75). A significant difference (t-test, p=0.005) was observed by comparing probes calibrated prior to wiring assembly through the Campbell™ CR-10X as compared to complete wiring. Consequently, the post-wiring calibration results were used to correct the field redox values. With the exception of probe 7 ($R^2 = 0.94$), an R^2 of 0.98 or greater resulted from the 3-point calibration curve.

An interim calibration of ten probes from the DPRS instrument nest was conducted on 27 May 1998 following equipment removal during the extreme flood event of 6 February 1998. The probes were rinsed with deionized water prior to calibration and checked for accuracy against the three redox potential standards referred to above. No significant difference (t-test, p=0.883) was observed between the calibration prior to the initial installation and the interim calibration.

DPRS was instrumented prior to the release of the draft technical standard by the National Technical Committee for Hydric Soils NTCHS. Thus, following recommended installation (Dirasian 1968), three, replicate probes were installed at each of three depths, 15 cm, 30 cm, and 51 cm (see procedure in Appendix B).

PSRF was instrumented following the release of the draft technical standard by the NTCHS. Consequently, the probes were installed as follows: 1) three replicate probes each at 15 cm and 51 cm; and 2) five replicate probes at 25 cm (as recommended by NTCHS for clayey soils).

The dataloggers were downloaded to a portable computer once a month. Field redox values were corrected to the calibration curve, soil pH, and to the hydrogen probe standard as outlined in the procedure above. An average of the three replicates was taken or if the redox potential recorded was extremely different from the other replicates, the outlier was discarded (Dirasian 1968).

Technical Standard

The *Draft* Technical Standard for Hydric Soils (NTCHS 2000) was utilized to determine hydric soil conditions at the instrumented stations. The standard requires identification of anaerobic and saturated conditions. Anaerobic conditions are confirmed by redox potential and reduced iron. Saturated conditions are confirmed by piezometric or groundwater well data. *In-situ* pH data and precipitation are required for determination of both anaerobic and saturated conditions. A E_H versus pH stability diagram was constructed to establish the boundary between aerobic or anaerobic conditions (Figure 6). The technical standard requires the following (adapted for use in Piedmont soils):

- Five redox potential electrodes installed at 25 cm for loamy/clayey soils;
- Field testing using α,α- dipyridyl (test for reduced iron, ferrous Fe^{2+}) of three replicate samples at 25 cm; and
- One soil pH measurement at 25 cm.

Based on the technical standard, for the soil to meet the anaerobic conditions, E_H measurements of less than or equal to 175 mV at pH 7 on a curve with a slope of negative 60 must exist within the 25 cm. Soil pH is used to identify the point on the E_H versus pH curve that separates aerobic from anaerobic conditions. Based on the technical standard, for a soil to meet the anaerobic conditions, a positive α,α- dipyridyl test for reduced iron is the dominant (60% or more) condition of a layer at least 10.2 cm (four

inches) thick within 30.5 cm (twelve inches) or 5.1 cm (two inches) within 15.2 cm (six inches) for the mineral soil surface for at least 2 of the 3 required samples. The test for ferrous iron was not used in the intensive study.

The National Technical Committee for Hydric Soils (NTCHS 2000) recommended a minimum sample period that captures a dry and wet cycle usually over one year. For the saturation requirement, fully automated wells were installed and programed to record three readings daily (once every eight hours). Free water must be observed in the well.

The technical standard requires a minimum frequency and duration of saturation and anaerobic conditions as follows:

- A duration of 14 or more consecutive days (saturation and anaerobic conditions overlapping); and
- A frequency of fifty percent (more than 1 out of 2 years). Frequency is assumed if data are collected during normal precipitation periods (30 to 70 percent precipitation probability). For this study, the range of normal precipitation was between 25 and 75 percent quartiles.

According to the technical standard, growing season is when soil microbes are active. The technical standard assumes that growing season is throughout the year in most of the United States. For this research, growing season was not assumed and was measured using soil thermocouples at three depths.

CHAPTER 3

RESULTS

Regional Precipitation

Mean regional precipitation (northeast Georgia) ranged from 123.8 cm (48.75 inches) in Athens, Georgia to 180.3 cm (70.99 inches) in Clayton, Georgia (Table 2). A near-normal, frequency distribution of annual total precipitation was observed from the 46 years of data collected from the Athens station (Figure 7, skewness = 0.10 and kurtosis = -0.16). Minimum and maximum precipitations were 72.7 cm (28.61) and 181.3 cm (71.39 inches), respectively. During the same period of record, 25 percent and 75 percent quartiles were 105.5 cm (41.54 inches) and 137.8 cm (54.27 inches), respectively. For the objectives of this research, the 25 and 75 percent quartiles represent the range of precipitation conditions and are referred to as normal.

Hydrogeomorphology

All 53 regional assessment sites were classified as riverine (Brinson 1993). In addition, appropriate subclasses based on the presence of indicators of hydrodynamics, geomorphic position, and predominant water source were observed in each of the 53 assessment sites during the regional study as follows:

- Overbank: silt lines on trees, drift and/or wrack lines, sediment deposition, leaf/sediment layering (i.e., stratified layering), directionally bent vegetation, buried or scoured root collars, floodways, side channels, and large woody debris movement;
- Depression: submerged aquatic vegetation (SAV), macrotopographic surfaces, beaver activity (e.g., lodges and dams, cut and chewed plants, beaver tracks, slides and/or scat), prevalence of emergent vegetation and snags, water-stained leaves,

ponding, oxbows, aquic or peraquic conditions (e.g., gleyed matrix and/or strong redoximorphic features in surface horizon); and

- Seep: footslope geomorphic position, iron floc (ferric hydroxide), organic sheen, lush winter growth of emergent vegetation, and ponded or saturated conditions at footslope.

The above subclasses of riverine wetlands had been previously recommended for the Piedmont of Georgia and the Carolinas (Brinson et al. 1996). However, the riverine seepage subclass was subdivided based on soil particle size distribution, mineralogy, and hydrodynamics into fine-textured seep and course-textured seep (see Soil Characterization Results). Fine-textured seeps were characterized with higher amounts of silt and clay fractions (D_{50} = 0.002 to 0.05 mm, silt particle size class) and did not produce obvious surface water flow. In contrast, course-textured seeps had higher sand fractions (D_{50} = 0.5 to 1.0 mm, coarse sand particle size), were lithologically controlled, and in general, produced surface water flow.

Vegetation

A total of 67 different taxa of plants were identified across the 32 assessment sites (Tables 3 to 5). Tree taxa accounted for 31of the total taxa observed. Tree density and basal area across all assessment sites for all taxa averaged 23 trees per hectare (range = 1 to 190) and 34.05 m^2/hectare (range = 0.35 to 302.93), respectively (Table 6). Across all assessment sites, sweetgum (*Liquidambar styraciflua*) was dominant by frequency (24), abundance (217), average density (190/hectare), and basal area (302.93 m^2). Green ash (*Fraxinus pennsylvanica*) was the second most dominant with frequency, abundance, average density, and basal area values of 19, 84, 73, and 134.4 m^2, respectively. Red maple (*Acer rubrum*) and winged elm (*Ulmus alata*) were the third most frequent (14 sites out of 32). Box elder (*Acer negundo*) was the third most abundant across sites (75 individuals recorded). However, by basal area, river birch (*Betula nigra*) was the third most dominant tree species across sites (76.92 m^2).

Plant species occupying the shrub strata accounted for twelve of the different taxa observed during the regional study (Table 6 and 7). Ironwood (*Carpinus caroliniana*) and winged elm were the most frequent species observed (16 of the 32 sites) in the shrub strata. However, the abundance of ironwood (233) exceeded the abundance of winged elm (93). The second most frequent species observed in the shrub strata was box elder (14 of the 32 sites, abundance = 65). However, the abundance of box elder was exceeded by red maple (74) and sweetgum (72).

Plant species occupying the herbaceous strata accounted for fourteen of the different taxa observed during the regional study. *Microstegium virmineum* was the most frequent species observed (16 of the 32 sites) (Table 7). Total abundance (by cover) for *Microstegium* was estimated at 18.75% across the 32 sites. The second most frequent herbaceous species was a species of sedge (*Carex* spp.). Sedges were observed in thirteen of the 32 sites with a total percent cover of 6.72.

Vines accounted for ten of the different taxa observed during the regional study. Poison ivy (*Toxicodendron radicans*) was the most frequently observed species in the vine strata (23 of the 32 sites) (Table 7). The second and third most frequently observed species were Virginia creeper (*Parthenocissus quinquefolia*) and Japanese honeysuckle (*Lonicera japonica*) with frequency values of 19 and 16, respectively. Snags were observed at 30 of the 32 sites at a total abundance of 185 individuals and total basal area of 106.43 m^2 (Table 7).

Vegetation and Hydric Soil Correspondence

In order to determine similarity between assessment sites and correspondence of vegetation with environmental factors (redoximorphic features and hydrologic characteristics), plant species identified in each of four strata were ordinated against environmental factors using three ordination methods to determine which analysis was sensitive to the vegetative gradient. The objective was to identify the ordination axes that maximally reveal the common structure of the two matrices (Gauch 1982).

Tree abundance per species was ordinated using Principle Components Analysis (PCA) to determine similarity and dissimilarity between assessment sites. With the exception of nine sites (1, 8, 18, 24, 37, 42, 45, 47, and 48), all sites grouped near the centroid of the plot. By inspection of species composition, these sites were composed of predominantly facultative species. However, assessment sites 1, 8, 18, 24, 37, 42, 45, 47, and 48 were observed to have different species composition as compared with the other sites (Figure 8). A gradient along each axis was identified by inspection of species composition of each assessment site which was outside of the centrally located group as follows:

- Assessment sites to the left of negative two on Axis 1 (sites 37, 47 and 48) were composed of trees that included species considered facultative upland or not normally associated with wetland ecosystems. These species included pignut hickory (*Carya glabra*), mockernut hickory (*Carya tomentosa*), flowering dogwood (*Cornus florida*), white ash (*Fraxinus americana*), and sugar maple (*Acer saccharum*);
- Assessment sites less than -2 on Axis 2 (sites 1 and 8) were composed of facultative to facultative upland species such as sweetgum, red maple, yellow poplar (*Liriodendron tulipifera*), hop hornbeam (*Ostrya virginiana*), water oak (*Quercus nigra*), and winged elm; and
- Assessment sites above positive two on Axis 2 (sites 24 and 42) were composed of trees which included facultative plus to facultative wetland species such as river birch (*Betula nigra*), green ash, and sugarberry (*Celtis laevigata*), and cottonwood (*Populus deltoides*).

In order to determine the relationship between plant species and hydric soil properties (redoximorphic features), two ordination methods were tested for applicability, reciprocal averaging (RA) and canonical correlation analysis (CCA). Two matrices were required: 1) assessment sites by species; and 2) assessment sites by redoximorphic features. Redoximorphic features included matrix chroma of 2 or less, concretions,

masses, pore linings, and iron depletions. RA revealed a strong gradient in a negative direction on Axis 1 and positive direction on Axis 2 (Figure 9). By inspection, the majority of the species which grouped in this area are associated with upland environments (pignut and mockernut hickories, flowering dogwood, sugar maple, and white ash). Tree species that plotted outside of this group are commonly associated with wetlands and floodplain environments. The CCA was conducted on the same two matrices, but also included vectors calculated from the second matrix (redoximorphic features). A strong gradient along Axis 1 was observed (Figure 10) and was in response to the association between redoximorphic features and wetland tree species. Tree species generally associated with upland environments plotted to the left (negative) along Axis 1. Those species included pignut hickory, flowering dogwood, white ash, loblolly pine, and sugar maple. In contrast, tree species generally associated with wetland or floodplain environments plotted to the right (positive) and were associated with one or more of the five redoximorphic features. Those species included box elder, red maple, river birch, persimmon (*Diospyros virginiana*), green ash, honey locust (*Gleditsia triacanthos*), black walnut (*Juglans nigra*), sweetgum, red mulberry (*Morus rubra*), hop hornbeam, sycamore (*Platanus occidentalis*), cottonwood, overcup oak (*Quercus lyrata*), water oak, willow oak (*Quercus phellos*), and red oak (*Quercus rubra*). CCA was found to be the most sensitive to the relationship between vegetation and environmental factors (soil redoximorphic features and hydrologic indicators). Consequently, it was used exclusively in the other vegetative strata.

Similar results observed within the tree strata using CCA were also observed within the shrub strata. A gradient along Axis 1 extended (left to right) from species generally associated with uplands to wetland species (Figure 11). By inspection of species composition, the following observations were made:

- Seven upland shrub species grouped to the extreme left: sugar maple, pignut hickory, redbud (*Cercis canadensis*), flowering dogwood, silverberry (*Elaeagnus umbellata*), *white oak (Quercus alba),* and cane (*Arundinaria gigantea*);

- Eight shrubs grouped to the extreme right and generally, are associated with wetland environments: river birch, swamp dogwood (*Cornus amomum*), black willow (*Salix nigra*), huckleberry (*Vaccinium stamineum*), sycamore, box elder, and green ash; and
- The remaining shrubs not listed above grouped around the centroid and in general are considered facultative species.

Similar to the results of the tree and shrub stratum, plants identified within the herbaceous strata followed a gradient from upland species to wetland species (left to right) on Axis 1 of the CCA plot as follows (Figure 12):

- Species within the herbaceous strata generally associated with uplands were located to the extreme left on Axis 1 of the CCA plot, included sugar maple, dayflower (*Commelina communis*), elephant's-foot (*Elephantopus carolinianus*), and Christmas fern (*Polystichum acrostichoides*). As evidenced by closeness to species located to the extreme left, other upland species included paw paw (*Asimina parviflora*), Spikegrass (*Chasmanthium latifolium*), Japanese honeysuckle (*Lonicera japonica*), Jack-in-the-pulpit (*Arisaema triphyllum*), clearweed (*Pilea pumila*), wild strawberry (*Fragaria virginiana*), cane, box elder, and poison ivy;
- In contrast, species within the herbaceous strata generally associated with wetlands were plotted to the right on Axis 1 of the CCA and included *Microstegium*, bog hemp (*Bohenmeria cylindrica*), green ash, Virginia creeper, jewel-weed (*Impatiens capensis*), knotweed (*Polygonum punctatum*), and green briar (*Smilax laurifolia*).

In contrast to results of the tree and shrub stratum, plants identified within the woody vine strata did not follow a well-defined gradient from upland species to wetland species (left to right) on Axis 1 of the CCA plot (Figure 13). Seven of the nine species plotted close to the centroid. However, as compared with all other species, kudzu (*Pueraria lobata*) plotted to the extreme left, and green briar plotted to the right.

Vegetation and Hydrology Correspondence

Similar to addressing the relationship between vegetation and redoximorphic features, plant species identified in each of four strata were ordinated against hydrological indicators using CCA. Even though not as strong of a relationship as tree species versus redoximorphic features, the interpretation of the plot of hydrological indicators overlaying tree species follows (Figure 14):

- Facultative upland tree species (white ash, flowering dogwood, sugar maple, pignut hickory) and one facultative species (yellow popular) plotted in the negative quadrant and were associated with buried root collars; and
- Several tree species (willow oak, red maple, sugarberry, green ash, box elder, hawthorne (*Crataegus* sp.), honey locust, and cottonwood (*Populus deltoides*) were associated with water-stained leaves, drift lines, and sediment deposition. These species are considered facultative or wetter.

Since tree species were addressed above, interpretation of species identified in the shrub strata is limited to plants which do not normally mature to heights beyond 30 feet (middle canopy) (Figure 15). The results of the CCA ordination follows:

- With the exception of spicebush (*Clycanthus floridus*), three facultative wetland species (stiff dogwood, swamp dogwood, elderberry) plotted to near or to the right of the centroid and were associated with water-stained leaves, silt-stained trees, drift lines, and exposed roots. In addition, silverberry which has not been assigned a status (Reed 1988) plotted in the same area; and
- Five facultative upland shrub species (Carolina silverbell - *Halesia carolina*, beauty-berry - *Callicarpa americana* , huckleberry, flowering dogwood, and redbud) plotted to the left of the centroid. Three of the species (flowering dogwood, huckleberry, and redbud) were associated with buried root collars, and two species were not associated with any hydrological indicator (Carolina silverbell and beauty-berry).

Similar to the analysis performed on true shrubs, ordination (CCA) was conducted on true herbs which was defined as groundcover which usually does not grow taller than one meter at maturity. No distinct pattern was observed (Figure 16). However, two facultative wetland herbs (cane and knotweed) were displaced along Axis 1 from the other eleven species.

The ordination (CCA) of the woody vine strata also resulted in no distinct pattern (Figure 17). However, three species (kudzu, climbing hydrangea - *Decamaria barbara*, and trumpet creeper - *Campsis radicans*) were displaced from the other six species. In addition, all nine vine species were disassociated with buttressing and scoured roots.

Precipitation (Intensive Study)

Precipitation records during the study period were provided by the Plant Science Research Farm Headquarters Weather Station, Watkinsville, Georgia, USA (PSRFWS, Figure 3) and the Georgia Forestry Commission Weather Station, Athens, Georgia, USA (GFCWS, Figure 3). The PSRFWS and GFCWS was used to assess local precipitation at PSRF and DPRS research sites, respectively. Normal precipitation (25 to 75 percent quartiles) at PSRF and DPRS was determined by comparing the local weather stations with a 46-year historic record for Athens, Georgia, USA (College of Agriculture) (Figure 7). During the 46-year period of record for Athens, consecutive years of below normal precipitation conditions were observed between 1954 and 1955 and between 1985 and 1988.

Total annual precipitation during the period of 1997 to 2000, collected from PSRFWS was 154.6 cm (60.85 in.), 115.9 cm (45.61 in.), 95.7 cm (37.66 in.), and 80.8 cm (31.81 in.), respectively. The annual total precipitation for 1998 was within normal precipitation conditions. In contrast, the annual total precipitation for 1997 was above normal, and the annual totals for 1999 and 2000 (consecutive years) were below normal.

Corresponding observations of total annual precipitation for 1997 to 2000 collected from GFCWS were 143.5 cm (56.50 in.), 115.7 cm (45.53 in.), 110.1 cm (43.33 in.), and 81.5 cm (32.07 in.), respectively. Similar to the observations at PSRFWS, the

annual total precipitation for 1997 and 2000 were above normal and below normal, respectively. Also, similar to PSRFWS, the annual total precipitation for 1998 at GFCWS was normal. In contrast to the PSRFWS, the annual total precipitation for 1999 at GFCWS was within a normal range but exceeded the lower 25 percent quartile by only 4.8 cm (1.89 in.).

Regional Curves

The Piedmont regional dimensionless rating curve was developed from the calibration of six gage records: North Fork Broad River, South Fork Ogeechee River, Hudson River, Beaverdam Creek, and Oconee River. Surveyed cross sections and hydraulic geometry are presented in Table 8. Drainage areas varied in size from 47.4 to 2434.6 square kilometers (18.3 to 940 square miles). Excellent correlation (regression coefficient > 0.98) was observed when stage was regressed against discharge (rating curve) on all gage records with the exception of the North Fork Broad River. The rating curve of the North Fork Broad River had the lowest regression coefficient ($R^2 = 0.66$, on transformed data, typical unless otherwise noted). This observation could be explained by either the quality of the gaging station, age of the record, or the instability of the substrate resulting in a variation in cross-sectional area during discharge measurements (e.g., hysteresis).

Discharges at bankfull (Q_{bkf}) and channelfull (Q_{chf}) stage at the USGS gaging station with the smallest drainage area (47.40 km^2), the North Fork Broad River, were12.5 and 31.39 $m^3 s^{-1}$, respectively. In contrast, discharges at bankfull (Q_{bkf}) and channelfull (Q_{chf}) stage at the USGS gaging station with the largest drainage area (2434.60 km^2), the Oconee River, were 246.66 $m^3 s^{-1}$ for both Q_{bkf} and Q_{chf}. Since bankfull and channelfull stage and discharge at the Oconee River were the same, overbank occurs during a bankfull discharge event at the site. Recurrence intervals (RI) at bankfull stage (RI_{bkf}) ranged from 0.82 years at the North Fork Broad River to 1.40 years at the Ogeechee River. However, flood frequency at bankfull (RI_{bkf}) was not related to drainage area size or Q_{bkf} due to variation in channel geomorphology and capacity.

At-station data was tabulated and formatted for regression analysis in preparation for regional hydraulic curve development (Table 9 and 10). Hydraulic geometrical parameters (mean depth at bankfull (D_{bkf}), width at bankfull (W_{bkf}), and cross-sectional area at bankfull (A_{bkf})) were plotted against drainage area (DA). Excellent regression correlation was observed between D_{bkf} and A_{bkf} versus DA (R^2 = 0.94 and 0.86, respectively) (Figures 18a and 19a, respectively). In contrast, the regression correlation between W_{bkf} and DA was observed to be fair (R^2 = 0.71) (Figure 18b).

At-station data were combined to produce a dimensionless rating curve. The dimensionless rating curve was developed by normalizing discharge (Q) at standard RIs to Q_{bkf} versus mean depth (D) at standard recurrence intervals normalized to D_{bkf} (Table 9 and 10) as:

$$Q/Q_{bkf} \quad vs. \quad D/D_{bkf}$$

and as regressed and substituting discharge at channelfull (Q_{chf}) and mean depth at channelfull (D_{chf}) (Figure 19b):

$$Q_{chf} = 0.975 \; X \; (D_{chf}/D_{bkf})^2 \; X \; Q_{bkf}$$

Excellent regression correlation was observed between Q_{chf}/Q_{bkf} and D_{chf}/D_{bkf} (R^2 = 0.93). The RIs at bankfull and standard RIs were plotted against Q for each at-station data set (Figure 20a). By inspection of the resulting RI verus Q plots, at-station data sets were paired based on DA size. Consequently, the RIs were grouped based on the following drainage area size classes (in square kilometers): < 130; 130 to 518 ; and >518 (Figures 20b, 21a and 21b, respectively). Drainage size classes 130 to 518 km^2 and greater than 518 km^2 were observed to have the best fit (R^2 = 0.98) as compared with the less than the 130 km^2 drainage size class (R^2 = 0.83). The discharge from the resulting regression equations of each paired set was compared against the discharges derived from the at-station regression equations. No significant difference was observed between discharges derived from the at-station data and discharges derived from the paired regional data (t-test, α = 0.05).

Application of Regional Curves

In order to test the Piedmont regional curves and estimate flood frequency, six stations in the Ogeechee River watershed, MC15, SFOR13, NFOR25, NFOR30, OR24, and OR46, were selected that represented a range of drainage areas from 7.8 to 331 square kilometers (3.0 to 127.8 square miles) (Table 11). The six stations were a subset of the original assessment sites characterized during the regional study. With the exception of OR24, channelfull RI at the representative cross sections were less than two years. The channelfull RI at Station OR24 was 2.4 years. This station was located just below the confluence of the North Fork Ogeechee River with the South Fork Ogeechee River. As evidenced by a relatively high width to depth ratio (12.5) and cross-sectional area at channelfull, the channel was enlarged at this point, consequently, capable of carrying a large volume of stormflow.

In addition to the six cross sections within the Ogeechee River Basin, three cross-sections on the Middle Oconee River and on an unnamed creek (DPRS and PSRF, respectively), were surveyed to determine hydraulic geometry and channel capacity, test the accuracy of identifying bankfull dimensions, and estimate flood frequency. Average D_{bkf} ranged from 2.0 to 2.2 meters (6.7 to 7.3 feet) on the Middle Oconee River and 0.5 to 0.6 meters (1.7 to 1.9 feet) on the unnamed creek.

As evidenced by the range of average D_{chf} (2.8 to 3.6 meters (9.3 to 11.9 feet)) on the Middle Oconee River, the elevation of the levee adjacent to the research site varied considerably. The D_{chf} of 2.8 meters (9.3 feet) was observed at the inlet/outlet to the depression. Flood recurrence intervals were estimated at 1.3 years at the inlet/outlet as compared to 1.6 and 1.9 years at the other two cross sections. The instrument nest located in the depression was only 0.03 meters (0.11 feet) above the inlet, consequently, it was flooded on a RI of approximately 1.3 years. However, the overbank instrument nest was located 0.5 meters (1.59 feet) above the inlet and was estimated to flood at a RI of 1.6 years.

Geomorphological and hydrological parameters calculated from the cross-sectional data from the regional assessment sites were overlaid onto the regional hydraulic geometry curves (Figures 22 and 23). All data points measured at the regional assessment sites plotted within the 95% confidence intervals of the regional hydraulic geometry curves. Excellent correspondence was observed between the assessment sites with all hydraulic geometry relationships (D_{bkf}, W_{bkf}, and A_{bkf}) and with the regional dimensionless rating curve.

Soil Characterization

Bulk density, porosity, percent total carbon, particle size distribution (PSD), CEC, and mineralogy were compared between the four riverine subclasses: overbank, beaver, coarse seep, and fine seep (Table 12). Similar bulk densities were observed between overbank and coarse seep subclasses and between beaver and fine seep subclasses (Figure 24a). However, as evidenced by standard error bars, the overbank and coarse seep subclasses were significantly different from the beaver and fine seep subclasses. Since porosity is calculated from bulk density, similar results were observed between subclasses with porosity as with bulk density (Figure 24b). Consequently, the beaver and fine seep subclasses were observed to have higher porosity as compared to the overbank and coarse seep subclasses.

Percent total carbon was observed to be highly variable in the beaver and fine seep subclasses as compared to the overbank and coarse seep subclasses (Figure 25). Given the variability, the beaver and fine seep subclasses were not determined to be significantly different from either each other or the overbank and coarse seep subclasses. However, the coarse seep subclass was observed to be significantly higher in percent total carbon as compared to the overbank subclass.

Subclasses were compared using the PSD observed in both the surface and subsurface horizon (Figure 26a and 26b, respectively). The coarse seep was dramatically different from the other three subclasses as follows:

- The percent PSD of the coarse seep was skewed right (positive) as compared to other subclasses which were skewed left (negative). Thus, the coarse seep had a higher percentage of coarse sand in both horizons; and
- On a cumulative percent scale, the D_{50} of the coarse seep was coarse sand (0.5 to 1.0 mm) in the surface horizon and medium sand (0.25 to 0.5 mm) in the subsurface horizon as compared to the other subclasses which varied from a D_{50} of silt to very fine sand (0.002 to 0.125 mm) in the surface and subsurface horizons.

Similar mineralogy was observed in the overbank, beaver, and fine seep subclasses and were dominated by kaolinite, hydroxyl-interlayed-vermiculite, and mica (Table 12). In contrast, the coarse seep was dominated by quartzite. Mean CEC values were 2.3, 8.8, 12.7, and 15.5 NH_4 - meq/100g in the coarse seep, beaver, overbank, and fine seep subclasses, respectively.

Surface and Ground water (Dean's Pond Research Site - DPRS)

Variation in precipitation during the study period was reflected in the fluctuation observed in the overbank groundwater well at DPRS (Figure 27). Surface water was observed on the overbank site twice during 1998, once during the extreme flood event which occurred February 6 - 9, 1998, and once in July 1998. During the extreme flood event that occurred in February 1998, the floodplain was flooded to approximately 1.5 meters (5 feet) above the floodplain surface. During 1999 and 2000, groundwater on the overbank site remained below 40 cm. In contrast to the overbank, with the exception of the extreme drought of 1999 (i.e., precipitation below normal), surface water or groundwater in the depression was above or within 40 cm of the soil surface during the extent of the study period. The above observations do not take into account surface and ground water conditions during periods of equipment malfunctions.

Surface and Ground water (Plant Science Research Farm - PSRF)

Similar variation in surface and ground water levels was observed at both the forested and emergent seeps at PSRF during the study period (Figure 28). However, groundwater was generally higher in the emergent seep than in the forested seep.

Groundwater was measured below 30 cm in both seeps during extreme drought periods (i.e., precipitation below the 25% quartile of normal) between August 1999 and October 1999 and again between May 2000 and September 2000. However, between October 1999 and May 2000 and between November 2000 and February 2001 during periods of normal rainfall, groundwater was within 10 cm or above the soil surface in both seeps.

Soil Temperature (Dean's Pond Research Site - DPRS)

Air temperature at the Georgia Forestry Commission Weather Station (GFCWS, Figure 3) during the study period averaged 17.0°C (range -6.3 to 29.1°C) over all seasons (Appendix C, case-wise deletion of missing data, Tables 15 to 19, abbreviations listed in Table 13). Mean air temperature (°C) observed during winter, spring, summer, and fall was 4.8 (range -6.3 to 15.5), 19.5 (range 6.7 to 27.6), 24.1 (range 14.9 to 29.1), 11.6 (range -6.1 to 24.1), respectively.

Significant difference between air temperature and soil temperature observed in the time series (discussed below) was tested using t-tests ($p<0.05$, typical, unless noted). Mean air temperature was significantly higher than soil temperature at every depth in both the depression and overbank sites (all data). With the exception of soil temperature at 15 and 30 cm in the depression, mean air temperature was significantly different from soil temperatures at every depth in both the depression and the overbank sites during each of the four seasons as follows: 1) During the winter and fall, mean air temperature was lower than mean soil temperature; 2) In contrast, during the spring and summer, mean air temperature was higher than mean soil temperature; and 3) Mean soil temperature at 15 and 30 cm in the depression was not significantly different from mean air temperature during the spring.

Significant correlations were observed between mean daily air versus mean, minimum, and maximum soil temperatures at all depths measured in both the depression and overbank sites (all data, Pearson-r range = 0.85 to 0.95 at $p<0.05$, $n = 385$). Mean daily air temperature is more readily available locally than minimum and maximum daily air temperature, and estimation of minimum daily soil temperature is preferred for

determination of growing season. Consequently, minimum daily soil temperature at each of the three depths in both the overbank and depression was estimated from mean daily air temperature by untransformed linear regression of annual data (Figures 29 to 34). Toy et al. 1978) observed that mean annual, seasonal, and monthly soil temperatures could be estimated by linear regression, with reasonable accuracy, using only air temperature data.

The combined effects of air temperature and groundwater on soil temperature was assessed using multivariate regression analysis. On an annual basis (all seasons), a significant, positive relationship with air temperature and a significant, negative relationship with groundwater was observed when mean daily soil temperature at each depth (depression and overbank) was regressed against mean daily air temperatures and mean daily groundwater. In contrast, on a seasonal basis, a significant effect of groundwater on soil temperature was not consistently observed:

- With the exception of soil temperature at 51 cm in the depression, groundwater did not exert a significant effect on soil temperature at any depth on either the depression or overbank in the winter;
- In the spring, groundwater in the depression exerted a significant, negative effect on soil temperature at 15 and 30 cm but not at 51 cm. In contrast, groundwater did not significantly affect soil temperature at the three depths on the overbank site;
- In the summer, groundwater exerted a significant, negative effect on soil temperature at 15 cm in the depression but not at the other five soil temperatures in both the depression and the overbank; and
- In the fall, groundwater exerted a significant, negative effect on soil temperature at 15 and 51 cm in the depression but not at the other four soil temperatures in both the depression and the overbank.

Soil Temperature (Plant Sciences Research Farm - PSRF)

Air temperature at the Plant Science Research Farm Weather Station (PSRFWS, Figure 3) during the study period averaged 16.3°C (range -4.1 to 29.5°C) over all seasons

(Appendix C, case-wise deletion of missing data, Tables 20 to 24, abbreviations listed in Table 14). Mean air temperature (°C) observed during winter, spring, summer, and fall was 5.9 (range -4.1 to 17.0), 19.4 (range 7.6 to 28.4), 24.3 (range 16.7 to 29.5), 15.1 (range 0.0 to 26.0), respectively.

Similar to the DPRS dataset, significant difference between air temperature at PSRF and soil temperature observed in the time series (discussed below) was tested using t-tests ($p<0.05$, typical, unless noted). With the exception of mean daily soil temperature at 51 cm, mean daily air temperature was significantly different from soil temperature at every depth in both the forested and emergent seeps (all data) as follows: 1) Mean air temperature was higher than soil temperature at 15 cm at the forested seep and all soil depths at the emergent seep; 2) Mean air temperature was lower than soil temperature at 25 cm at the forested seep; and 3) Mean air temperature (16.5°C) was the same as mean soil temperature at 51 cm at the forested seep.

With the exception of soil temperature at 51 cm in the forested seep during the fall, mean air temperature was significantly different from soil temperatures at every depth in both the forested and emergent seeps during each of the four seasons as follows: 1) During the winter and fall, mean air temperature was lower than mean soil temperature; 2) In contrast, during the spring and summer, mean air temperature was higher than mean soil temperature; 3) During the fall, mean soil temperature at 15 and 25 cm in the forested seep was lower than mean air temperature; 4) In contrast in the fall, mean soil temperature at all three depths in the emergent seep was higher than air temperature; and 5) Soil temperature at 51 cm in the forested seep during the fall was not significantly different from mean air temperature.

Significant correlation (all data, Pearson-r range = 0.84 to 0.96 at $p<0.05$, $n = 202$) was observed between mean daily air temperature and mean daily, minimum, and maximum soil temperatures at all depths measured in both the forested and emergent seeps. Consequently, similar to DPRS, minimum daily soil temperature at each of the

three depths was estimated from mean daily air temperature by untransformed linear regression of annual data (Figures 35 to 40).

Similar to the DPRS site, the combined effects of air temperature and groundwater on soil temperature was assessed using multivariate regression analysis. On an annual basis (all data), a significant, positive relationship was observed between mean daily air temperature and mean daily soil temperature in all depths at both seeps. However, groundwater only exerted a significant effect at 25 and 51 cm on the forested seep and had no effect at any depth on the emergent seep. In contrast with Dean's Pond, the influence of groundwater on soil temperature across seasons was highly variable as follows:

- In the winter, groundwater did not exert a significant, negative effect on soil temperature at any depth with the exception of 51 cm on the forested seep. No significant effect was observed at any depth on the emergent seep;
- In the spring, groundwater in the depression exerted a significant, negative effect on soil temperature at 25 cm on the forested seep and at all depths on the emergent seep;
- In the summer, groundwater exerted a significant, negative effect on soil temperature at 15 and 25 cm on the forested seep but not at the other four soil temperatures in both seeps; and
- In the fall, groundwater exerted a significant, negative effect on soil temperature at all six depths in both seeps.

Soil Temperature (Time Series Analysis)

The objective of time series analysis was to stage the data for interpretation of seasonal fluctuations, make comparative analysis, and model forecasting. This objective was accomplished by transforming the data set such that the variability in air temperature is reduced and the phases between air and soil temperatures are synchronized. Mean air and soil temperatures (untransformed) were plotted over time during the study period (Figure 41 and 42, DPRS and PSRF, respectively). By inspection, a seasonal pattern was

observed in the plots of the time series. Soil temperature exhibited a high degree of variability (noise) relative to corresponding air temperatures. In addition, the general pattern of higher air temperature versus soil temperature during the spring and summer and lower air temperature versus soil temperature during the fall and winter was depicted in the time series. Also, soil temperature was observed to be out of phase (i.e., lag time) with air temperature.

A series of transformations were preformed on both the DPRS and PSRF datasets in the following steps:

1. Mean daily air temperature was smoothed using a moving average width of two (n=2) (Figures 43 and 44, DPRS and Figure 45, PSRF);
2. The mean daily air temperature plot was synchronized with plots of mean daily soil temperature by identification of seasonal minimum and maximum soil temperatures (sine wave troughs and peaks) followed by trial and error; and
3. Mean daily air and soil temperatures were modeled using Auto-Regressive Integrated Moving Average (ARIMA).

Prior to model runs using ARIMA, several transformations were performed on the datasets including powers, natural logarithm, log base ten, square root, exponential, differencing, autoregression, moving average, and lag (phase) shift. Before and after each transformation and combination of transformations, changes in autocorrelation and the partial autocorrelation correlogram and a histogram of the residuals were inspected and used to identify transformations resulting in the best fit of the data for ARIMA input.

Power, natural logarithm, log base ten, square root, and exponential transformations did not produce significant improvement in curve fit. However, differencing, autoregression, moving average, and lag produced the best model fit resulting in lag spikes within one standard error autocorrelation and a near normal distribution of residuals. The results of autocorrelation and distribution of residuals of pre- and post-transformation of the mean daily air temperature are presented in Figures 46

and 47, respectively. Similar results were observed in mean daily soil temperature at all depths.

The following ARIMA model parameters resulted in the best fit suitable to forecast temperature (p,d,q)(ps,ds,qs):

(2,1,2) (1,1,1)

where:

p = non-season autoregressive of 2;

q = differencing of 1;

q = moving average of 2;

ps = season autocorrelations of 1;

ds = seasonal differencing of 1; and

qs = seasonal moving average of 1.

Hence, the ARIMA model is described as having two autoregressive parameters (p), two regular moving average parameters (q), one seasonal autocorrelation parameter (ps),and one seasonal moving average (qs). These parameters are computed for the series after it is differenced once with lag 1 (d), and once seasonally differenced (ds).

The autoregressive process addressed the serial dependence of time series data. Each observation was dependent on a linear combination of prior observations (Box and Jenkins 1976, Montgomery et al. 1990). Regular moving average parameters reduced the variability observed specially in mean daily air temperature. Seasonal autocorrelation removed the seasonal trends that occur on a 12-month basis. Differencing removed the first-order autocorrelation and the trend component. Based on the results of ARIMA, future mean daily air and soil temperatures can be predicted with a moderate degree of confidence (90%).

Minimum Soil Temperature and Growing Season

Growing season was defined above as the period of the year where the soil temperature as measured at 51 cm (20 in.) below the soil surface is greater than 5°C (41°F) (Environmental Laboratory 1987, Williams 1992). During the winter of 1998,

2000, and 2001, minimum air temperature of 5°C or less was recorded 63, 38, and 25 days, respectively, at DPRS and 23, 22, and 1 days at PSRF, respectively. Corresponding minimum soil temperatures of 5°C or less occurred during winters of 1998, 2000, and 2001 as follows (days correspond to consecutive years):

- 25, 3, and 22 days, respectively, at 15 cm at the DPRS depression site and zero days at the DPRS overbank site;
- 1, 1, and zero days, respectively, at 15 cm at the PSRF emergent seep and zero days at the PSRF forested seep;
- 1, zero, and 1 days at 30 cm, respectively, at the DPRS depression site and zero days at the DPRS overbank site;
- Zero days at 30 cm over the two years at either of the PSRF sites;
- 3, zero, and 3 days at 51 cm, respectively, at the DPRS depression site and zero days at the DPRS overbank site; and
- Zero days at 51 cm over the two years at either of the PSRF sites.

Relative to the depression (DPRS) and emergent (PSRF) sites, a lower air temperature was required to reduce soil temperature to 5°C at the overbank (DPRS) and forested (PSRF) sites.

Even though the water table was not accounted for in the above univariate analysis, mean water table depths recorded during the study period were -40.2 and -92.2 cm, respectively, at the depression and overbank (DPRS), and 13.6 and -25.9 cm, respectively, at the emergent and forested seeps (PSFR) (Appendix C, Tables 15 to 24). Generally, the 5°C standard was obtained more often in the sites with higher water tables as compared with sites with lower water tables. Consequently, bivariate regression analysis was performed with air temperature and water table as independent variables and soil temperature at all depths as the dependent variable.

As with univariate regression above, a significant, positive relationship between air and soil temperature was observed in all cases using bivariate regression analysis. In contrast, a significant, negative relationship between water table elevation and

temperature was observed in all cases with the exception of: 1) Daily minimum soil temperature at 15 cm in the depression (DPRS); and 2) Mean daily soil temperature at 15, 25, and 51 cm in the emergent seep (PSRF). Consequently, in general, soil temperature decreased with increasing water table.

Redox (Dean's Pond Research Site - DPRS)

Unless otherwise noted in this section, redox refers to mean daily oxidation-reduction potential in positive millivolts (mV), air temperature refers to mean daily air temperature, and significance was determined using t-tests ($p<0.05$). Over the entire study period (all seasons), redox in the depression was significantly lower than the overbank at all soil depths (paired datasets, case-wise deletion of missing data, Appendix D, Tables 25 to 29, abbreviations listed in Table 13). Redox in the depression averaged 227, 197, and 33 mV at soil depths of 15, 30, and 51 cm, respectively. Corresponding redox recorded at the overbank site were 619, 722, and 787 mV. Consequently, highly reducing conditions were observed in the depression as compared to oxidized conditions in the overbank site.

Similar results were observed when the dataset was stratified temporally by season. Within each season, redox in the depression was significantly lower than the overbank at all soil depths (15, 30, and 51 cm, reported consecutively below) as follows:

- During the winter, redox in the depression was 283, 265, and 84 mV as compared to 590, 692, and 762 mV at the overbank site;
- During the spring, redox in the depression was -132, -105, and -194 mV as compared to 609, 692, and 790 mV at the overbank site;
- During the summer, redox in the depression was 289, 205, and 85 mV as compared to 635, 742, and 823 at the overbank site; and
- During the fall, redox in the depression was 315, 331, and 120 mV as compared to 619, 740, and 809 mV at the overbank site.

The lowest redox was recorded in the spring in the depression when the combined effects of relatively high water table and adequate temperature for microbial activity was present.

Also, by inspection of the above mean seasonal daily redox, redox in the depression during the winter, summer, and fall were very similar. And, redox at the overbank site during all seasons was similar.

Bivariate regression analysis was performed by regressing redox as the dependent variable against air temperature and water table as the independent variants. Over the entire study period (all seasons), a significant negative relationship was observed between water table and redox at all depths and in both the depression and overbank. With the exception of 30 and 51 cm in the depression, a significant positive linear regression was observed between air temperature and redox in both the depression and overbank. However, the regression coefficients (R^2) of the regressed depression dataset were higher, in general, as compared to the overbank. When the dataset was stratified by season, redox responded negatively to water table and positively to air temperature (unless otherwise noted) as follows:

- During the winter, with the exception of redox at 30 cm in the overbank, a significant relationship was observed at all soil depths at both sites between water table and redox and air temperature and redox;
- During the spring, both water table and air temperature exerted a significant influence on redox in the depression at 15 and 30 cm both not at 51 cm. Water table and air temperature accounted for 66 to 71 percent of the variability in redox. In contrast as evidenced by the low R^2 values, only 9 to 13 percent of the variability in redox on the overbank site could be explained by water table and air temperature;
- During the summer, both water table and air temperature exerted a significant influence on redox in the depression at 15 cm. However, air temperature did not significantly influence redox at 30 and 51 cm. At all depths on the overbank site, redox was influenced by water table but not by air temperature. However, corresponding R^2 values were relatively low (0.50, 0.17, and 0.15 at 15, 30, and 51 cm, respectively);

- During the fall, water table exerted a significant influence on redox in the depression at all depths. However, air temperature significantly influenced redox at 51 cm only. Corresponding R^2 values were relatively low (0.14, 0.13, and 0.19 at 15, 30, and 51 cm, respectively). With the exception of redox at 15 cm, both water table and air temperature exerted a significant influence on redox on the overbank site. At 15 cm, a positive relationship between redox and water table was observed, but air temperature did not influence redox. Corresponding R^2 values were 0.41, 0.21, and 0.59 at 15, 30, and 51 cm, respectively).

Redox (Plant Science Research Farm - PSRF)

Unless otherwise noted in this section, redox refers to mean daily oxidation-reduction potential in positive millivolts (mV), air temperature refers to mean daily air temperature, and significance was determined using t-tests ($p<0.05$). Over the entire study period (all seasons), redox in the forested seep was significantly higher than the emergent seep at all soil depths (paired datasets, case-wise deletion of missing data, Appendix D, Tables 30 to 34, abbreviation listed in Table 14). Redox in the forested seep averaged 339, 385, and 311 mV at soil depths of 15, 25, and 51 cm, respectively. Corresponding redox recorded in the emergent seep were 207, 228, and 232 mV.

When stratified temporally by season, comparative redox was observed to be depth-dependent as follows (compared by consecutive depths of 15, 25, and 51 cm):

- During the winter, redox in the forested seep was significantly higher (275, 329, and 282 mV) than corresponding redox in the emergent seep (164, 271, and 221 mV);
- Similar to the winter, with the exception of 51 cm, redox during the spring in the forested seep was significantly higher (302 and 303 mV) than corresponding redox in the emergent seep (110 and 244 mV). Redox at 51 cm in the forested seep (228 mV) was not significantly different from redox at 51 cm in the emergent seep (245 mV);

- Similar to winter and spring, redox recorded during the summer in the forested seep was significantly higher (430, 474, and 371 mV) as compared to the emergent seep (254, 192, and 235 mV); and
- Similar to winter, spring, and fall redox recorded in the fall in the forested seep was significantly higher (357, 407, and 346 mV) than the emergent seep (253, 211, and 247 mV).

Similar to DPRS, bivariate regression analysis was performed by regressing redox as the dependent variable against air temperature and water table as the independent variables. Over the entire study period (all seasons), a significant negative relationship was observed between water table and redox at all depths in the forested seep. In others words, as the water table increased, redox potential decreased (i.e., increasing reducing conditions). In contrast, in the emergent seep, water table was positively related to redox at all depths, but air temperature was negatively related. However, the regression coefficients (R^2) of the forested seep were higher, in general, as compared to the emergent seep. When the dataset was stratified by season, redox responded to water table and air temperature as follows (compared by consecutive depths of 15, 25, and 51 cm, unless noted):

- During the winter, no significant relationship was observed between redox versus water table and air temperature in either seep at any depth (based on inspection of p-values of F-test and t-test and R^2);
- During the spring, water table exerted a negative effect on redox in the forested seep at all depths, and air temperature exerted a positive effect on redox at 15 and 51 cm. Water table and air temperature accounted for 72, 44 and 68 percent of the variability in redox within the forested seep at all depths. The effect of water table and air temperature was not conclusive in the emergent seep during the spring and may have been due to equipment failure;
- During the summer, both water table and air temperature exerted a significant negative effect on redox in the forested seep at all depths. Corresponding R^2

values were relatively low (0.31, 0.20, and 0.38 at 15, 25, and 51 cm, respectively); In contrast, water table exerted a significant positive effect on redox in the emergent seep at all depths. Air temperature also exerted a significant positive effect but only at 25 cm. Similar to the forested seep, corresponding R^2 values were relatively low (0.32, 0.39, and 0.22 at 15, 25, and 51 cm, respectively);

- During the fall, water table exerted a significant negative effect on redox in the forested seep at all depths, and air temperature exerted a significant positive effect on redox at 15 and 25 cm, similar to results measured in the spring. However, only water table exerted a significant (negative) influence redox at 51 cm. Corresponding R^2 values were relatively low (0.32, 0.22, and 0.27 at 15, 25, and 51 cm, respectively). Both water table and air temperature significantly influenced redox at 25 cm, but not at either 15 or 51 cm. However, the R^2 was relatively low (0.15).

Soils (NTCHS, Technical Standard)

In order to meet the technical standard (NTCHS 2000) a redox of +265 mV or less (based on mean soil pH of 5.5) is required for anaerobic conditions at 25 cm in clayey soils. The DPRS depression met the technical standard at all depths (15, 30, and 51 cm) during the spring, at two depths (30 and 51 cm) during the winter and summer, and only at one depth (51 cm) in the fall. The DPRS overbank did not meet either requirement during any season. Hence, based on mean redox at 30 cm, it is assumed that the technical standard was met at 25 cm in the DPRS depression during the spring, winter, and summer.

The PSRF emergent seep met both requirements at two depths (15 and 51 cm) during the winter but not at 25 cm. During the spring, summer, and fall, the emergent seep met both requirements at all depths (15, 25, and 51 cm). In contrast to the emergent seep, mean redox in the PSRF forested seep, did not drop below +265 mV at any depth during any season with the exception of 51 cm. During the spring, redox in the PSRF

forested seep averaged +244 mV (range +97 to +409 mV). Hence, the technical standard at 25 cm was met in the PSRF emergent seep during the all seasons with the exception of the winter. The technical standard was not met in the PSRF forested seep during any season.

Jurisdictional Wetlands

Federal wetland jurisdiction was determined on the 53 sites plus research sites (DPRS and PSRF) using indicators specified in the COE Manual (Environmental Laboratory, 1987) and outlined above under Methods. All 53 sites met hydrophytic vegetation criteria by having a prevalence of facultative or wetter species in each strata. In contrast, 43 of the 53 sites met hydrology criteria, and 28 of the 53 sites met hydric soils criteria. Groundwater was observed in twelve of the sites in the unlined, excavated soil pit. Twenty-one of the sites had silt stains on either tree trunks or leaves. Fourteen of the sites had sediment deposits on around tree trunks or in drainage ways. Twenty-nine of the sites had drift lines (detritus), and twenty-four of the sites had water-stained leaves predominantly in microtopographic depressions or side channels. Twenty-one of the sites had a Munsell (1975) chroma of two or less. Three sites had concretions. Twenty-nine of the sites had either pore linings (oxidized rhizospheres) or masses. Twenty-one of the sites had iron depletions usually associated with dead root zones or organic matter depositions, and seven sites had hydrogen sulfide odor. Presence or absence of hydric soils was the primary determinant in federal jurisdictional wetland determination. Overall, 28 of the 53 sites were determined to be federal jurisdictional wetlands and in all cases, the presence or absence of hydric soils was the most limiting criterion.

A minimum of 12.6 consecutive days of inundation or saturation within 30.48 cm (12 in.) of the soil surface during the growing season (March 14 to November 20) was required to meet hydrologic criteria in Clarke and Oconee Counties, Georgia (Robertson 1968). Hydrologic criteria was met during the study period at the instrumented sites as follows (observed number of consecutive days in parentheses):

DPRS:

- At both the depression (48 days) and overbank (20 days) during 1998;
- At the depression (57 and 58 days) but not the overbank during 1999 and 2000, respectively;

PSRF:

- At both the forested (101 days) and emergent (22 days) during 1999; and
- At both the forested (117 days) and emergent (97 days) during 2000.

Hence, the only year when the DPRS overbank site met hydrologic criteria was 1998 which followed a year of above normal precipitation (143.5 cm in 1997). In addition, hydrologic criteria was met early in the calendar year of 1998 prior to the influence of transpiration. The DPRS depression met hydrologic criteria in normal and below normal precipitation years during 1998 through 2000. Both the PSRF forested and emergent seeps met hydrologic criteria in below normal precipitation years in 1999 and 2000.

CHAPTER 4

DISCUSSION

Soil temperature and moisture are the key rate-determinants in oxidation-reduction processes mediated by microbes in wetland environments (Soil Survey Staff 1975 and 1999, Mitsch and Gosselink 1993). Ultimately, under adequate temperature and moisture conditions in wetland soils, the products of microbial activity are expressed in the formation of redoximorphic features. Temperature controls seed germination, plant growth and development, and soil formation (Soil Survey Staff 1975).

The results of this research showed that mean annual and seasonal soil temperature in wetland environments was affected by mean annual and seasonal air temperature. The relationship between mean annual air and soil temperature in upland environments has been previously reported (Soil Survey Staff 1975). However, previous to this research, the combined effects of air temperature and soil moisture on soil temperature in wetland environments had not been adequately addressed especially in specific physiographies such as the Piedmont. Even less is known about soil temperature, redox potential, and groundwater with application to reducing conditions and growing season in riverine wetland subclasses.

In general, the results of this research showed that mean daily and seasonal soil temperature was not only influenced by air temperature but also by soil moisture as measured by water table. Mean daily and seasonal soil temperature increased with air temperature and decreased with soil moisture. Soil temperature fluctuated more with air temperature near the soil surface as compared to soil temperature at depth (i.e., damping effect). The resistence to heat conduction dampens the temperature cycle at greater depths (Coutts 1955, Hanks and Ashcroft 1980) Also, within a given HGM setting,

moisture played an important role in reducing soil temperature fluctuations by increasing thermal conductivity. The specific heat of water is approximately five times that of mineral soils (Soil Survey Staff 1975). Consequently, air temperature is conducted through the soil matrix more rapidly when the soil is moist or saturated as compared to a relatively dry soil. The evidence of this phenomenon was demonstrated at both the DPRS depression and PSRF emergent seep. The water table was near the surface for relatively prolonged periods resulting in a higher mean daily air temperature required to reduce the mean daily and minimum soil temperature to 5°C at 51 cm. In contrast, a lower mean daily air temperature was required at DPRS overbank to achieve the same effect, since the water table was below 51 cm for most of the study period.

Marked seasonal fluctuations in mean daily soil temperature was observed at all sites. For example, the difference in mean daily soil temperature between winter and summer at DPRS depression at 51 cm was 16.7°C as compared to 12.8°C at DPRS overbank at 51 cm. Corresponding mean daily air temperature was 4.8°C and 24.1°C (winter and summer, respectively) resulting in a flux of 19.3°C. Hanks and Ashcroft (1980) related the seasonal flux in soil temperature to the annual cycle of incoming solar radiation. This seasonal effect was also observed in soil temperature records from Belgrade, Yugoslavia (Soil Survey Staff 1975). The results of that study showed that seasonal temperature fluctuations penetrated to a depth of 14 meters which was considered the stratum of constant temperature. However, because water has a high specific heat, the stratum of constant temperature is reduced in moist or saturated soils. Based on temperature records of well-water in the 48 conterminous United States, the stratum of constant temperature occurred at approximately nine meters (Soil Survey Staff 1975).

In addition, Soil Survey Staff (1975) reported that the amplitude of seasonal soil temperature fluctuations is affected by other factors including the angle of the sun’s rays, clouds, rain, irrigation water, snow cover, bodies of water, aspect, water table, and

organic matter content (i.e., insulation). Soil color (i.e., albedo) also exerts an influence on soil temperature by affecting net radiation (Hanks and Ashcroft 1980).

With the exception of three consecutive days, a soil temperature of 5°C or less at 51 cm was not observed for extended periods during the study period. Hence, growing season occurred year-round during the study period. It is unlikely that this requirement is achieved anywhere in the southern Piedmont (NTCHS 2000) and is considered a short-coming of the wetland delineation method (Envronmental Laboratory 1987, Williams 1992) presently used by Section 404 (Clean Water Act 1977) federal review agencies. A promising technical standard has been proposed by the NTCHS (2000). According to the technical standard, the growing season includes that period when soil microbes are active. The technical standard assumes that growing season is throughout the year in most of the United States. Microbial activity is assumed by establishing anaerobic and reducing conditions using redox potential and a positive α, α-dipyridyl test, respectively. However, one disadvantage to this method is the need to measure directly redox potential over one dry and one wet season. As this research demonstrated, consecutive years of drought may result in either a false negative conclusion based on the technical standard or delay the Section 404 permit application until normal climatic conditions return. This obviously poses a problem on controversial federal wetland jurisdictions (i.e., problem areas) when positive indicators of hydrology, hydric soils, and hydrophytic vegetation are not decisive. However, once scientifically-based surrogates (e.g., redoximorphic features) are established using the technical standard, improvements in federal wetland jurisdiction can be made.

Soil redox potential was consistently lower in the depression as compared to the other subclasses. During normal precipitation years, permanent inundation and soil saturation coupled with microbial activity were responsible for reducing conditions as measured with redox potential (Gambrell and Patrick 1978, Mausbach and Richardson 1994, Mendelssohn et al. 1995). In addition, the lowest mean daily redox potential was recorded in the depression during the spring when the combined effects of relatively high

water table and adequate temperature for soil microbial activity were present. Excellent correlation between mean daily air temperature, water table, and redox potential was observed during this time. Consequently, measurements of water table, soil temperature, and redox potential need to include the spring for application to federal wetland jurisdiction and the technical standard.

In riverine systems, estimation of flood frequency is critical in federal wetland jurisdiction and assessing wetland functions. The use of the dimensionless rating curves to map areas subject to flooding has been suggested in the past (Dunne and Leopold 1978, Knighton 1984, Rosgen 1996). However, until now, the use of dimensionless rating curves with application to assessing water source and federal wetland jurisdiction had not been adequately explored. The regional dimensionless rating curve provides estimates of channel-full flows based upon measurements of channel depth at a particular wetland site or within a particular reach. The dimensionless curve developed in this research used stream hydraulic geometry relationships from USGS records at gaging stations. Development of the curve requires data acquisition/manipulation, and field calibration. However, once developed, the dimensionless curve and the bankfull depth and flow curves could be used with minimal effort and in a rapid assessment context to estimate the stream flow needed to inundate the surface of the wetland. This technique is more accurate than wetland hydrologic indicators (e.g. drift wrack, silt lines, water marks) for determining depth and frequency of flooding in making federal wetland jurisdictional delineations. It also fills a void left by other techniques in relating the depth of the channel at a site with the flood discharge and recurrence interval of flooding. Consequently, the use of regional dimensionless rating curves is recommended for assessing flood depth and frequency federal wetland jurisdiction and hydrogeomorphic wetland functional assessment models (e.g., Ainslie et al. 1999).

The following are recommendations for future research:

- The use of wetland classifications designed to reduce natural variability, improve wetland inventories, assess wetland functions and values, and develop restoration

or enhancement criteria need to be explored in other Ecoregions or physiographies;

- Assessment of soil function with application to wetland assessment needs to be developed and included in future hydrogeomorphic wetland functional assessment models;
- In Ecoregions where federal wetland jurisdiction is not decisive due to inadequate data on groundwater and hydric soils, the technical standard needs to be applied and appropriate surrogates identified;
- A scientific-based relationship between effective discharge and bankfull indicators needs to be developed on a regional scale; and
- The definition of growing season with respect to soil temperature at an arbitrary soil depth needs to be revised based on actual microbial activity and reducing conditions that occur in wetland environments. This research is needed throughout the country.

CHAPTER 5

CONCLUSIONS

The goal of the study was to identify the variation in hydrologic and soil conditions and controlling factors across hydrogeomorphic gradients in the southern Piedmont physiographic province. Five objectives were identified as follows: 1) classify a representative wetland population within the Piedmont; 2) develop a means of estimating flood frequency and magnitude at the site-specific scale based on channel geomorphology; 3) identify the correspondence between indicators of hydrology and soil redoximorphic features versus vegetation composition; 4) determine the variability in groundwater, soil temperature and soil reducing conditions across wetland classes; 5) based on the finding of the above objectives, establish relationships or surrogates between measured parameters versus indicators of federal wetland jurisdiction. In addition, the results of the above objectives were utilized to determine if growing season is applicable to federal jurisdictional wetland determination.

Four subclasses, overbank, depression, fine seep and coarse seep, were identified during the study that spanned the variability in the 53 assessment sites representative of Piedmont riverine hydrogeomorphic settings. The subclasses were classified based on indicators of hydrodynamics, geomorphic position, predominant water source, and soil properties as follows:

- Overbank: silt lines on trees, drift and/or wrack lines, sediment deposition, leaf/sediment layering (i.e., stratified layering), directionally bent vegetation, buried or scoured root collars, floodways, side channels, large woody debris movement, dominance of kaolinite, hydroxyl-interlayered vermiculite, and mica,

silt to very fine sand particle size class, range of porosity of 0.3 to 0.4, percent mean total carbon of 1.15, and mean cation exchange capacity of 12.7 meq $100g^{-1}$;

- Depression: submerged aquatic vegetation (SAV), macrotopographic surfaces, beaver activity (e.g., lodges and dams, cut and chewed plants, beaver tracks, slides and/or scat), prevalence of emergent vegetation and snags, water-stained leaves, ponding, oxbows, aquic or peraquic conditions (e.g., gleyed matrix and/or strong redoximorphic features in surface horizon), dominance of kaolinite, hydroxyl-interlayered vermiculite, and mica, silt to very fine sand particle size class, range of porosity of 0.0 to 0.1, percent mean total carbon of 2.72, and mean cation exchange capacity of 8.8 meq $100g^{-1}$;
- Fine seep: footslope geomorphic position, iron floc (ferric hydroxide), organic sheen, lush winter growth of emergent vegetation, ponded or saturated conditions at footslope, dominance of kaolinite, hydroxyl-interlayered vermiculite, and mica, silt to very fine sand particle size class, range of porosity of 0.15 to 0.20, percent mean total carbon of 0.57, and mean cation exchange capacity of 2.3 meq $100g^{-1}$; and
- Coarse seep: footslope geomorphic position, iron floc (ferric hydroxide), organic sheen, lush winter growth of emergent vegetation, ponded or saturated conditions at footslope, dominance of quartzite and medium to coarse sand particle size class, range of porosity of 0.15 to 0.20, percent mean total carbon of 1.74, and mean cation exchange capacity of 15.5 meq $100g^{-1}$.

With the exception of the woody vine stratum, vegetation across subclasses in all strata was dominated by hydrophytes (i.e., facultative to obligate wetland species, Reed 1988). Dominant vegetation in tree, shrub, and herbaceous strata included sweetgum, green ash, red maple, ironwood, winged elm, box elder, *Microstegium*, and *Carex*. Wharton (1978) reported similar vegetation species in Piedmont alluvial river and swamp systems.

Predominant hydric soil indicators across the 53 assessment sites were Munsell chroma of two or less, pore linings (oxidized rhizospheres), and iron depletions associated with organic matter (e.g., dead roots and buried leaf litter). Predominant hydrological indicators included water-stained leaves, silt stains on tree trunks or leaves, and drift lines. All 53 assessment sites met hydrophytic vegetation criteria for federal wetland jurisdiction. However, 43 of the assessment sites and only 28 of the sites met hydrology and hydric soils criteria, respectively. Since positive indicators of all three parameters are required, only 28 of the 53 assessment sites met federal wetland jurisdiction.

Excellent correspondence was observed between vegetation composition and hydric soil indicators. Using ordination techniques, a strong gradient was observed between hydrophytic vegetation and soil redoximorphic features. A predominance of hydrophytes were more often associated with soil matrix chroma two or less, pore linings, and iron depletions.

In contrast to hydric soil indicators, the correspondence between vegetation composition and hydrologic indicators was not as strong. However, upland species were generally associated with buried root collars. In addition, several hydrophytes (facultative and facultative wetland species) were associated with water-stained leaves, drift lines, and sediment deposition.

Good correspondence was observed between herbaceous vegetation and redoximorphic features and hydrological indicators. However, poor correspondence was observed between woody vines when ordinated with redoximorphic features and hydrologic indicators.

In order to establish the contribution of flood events on the floodplain of the assessment areas and instrumented research sites (DPRS and PSRF), a Piedmont regional dimensionless rating curve was developed. Six USGS gages were calibrated to bankfull and channelfull dimensions. Once the dimensionless rating curve was constructed, flood discharge and frequency at any watershed position within the Piedmont could be

estimated by the watershed size and the average depth at channelfull (levee). Watershed sizes at the six USGS gages ranged from 47.4 to 2434.6 square kilometers. Corresponding channelfull discharges at USGS gaging stations ranged from 31.39 to 246.66 $m^2 s^{-1}$. Flood frequency at channelfull ranged from recurrence intervals of 1.1 to 20.8 years and did not correspond to the range of channelfull discharges and, was related to channel geomorphology and capacity. The estimated recurrence interval of 20.8 years was on the Ogeechee River immediately below the confluence of the North Fork and South Fork Ogeechee River at a cross section where channel capacity was increased due to the influence of the two forks.

Bankfull discharge and flood frequency was estimated from the dimensionless rating curve at six of the 53 assessment sites which represented a range of watershed sizes from 7.8 to 331.0 square kilometers. Corresponding channelfull discharges ranged from 8.16 to 181.71 $m^2 s^{-1}$. Flood frequency at channelfull ranged from recurrence intervals of 0.9 to 2.4 years and did not correspond to the range of channelfull discharges and, similar to the USGS gaging stations, was related to channel geomorphology and capacity.

Watershed sizes at DPRS and PSRF were 1216.1 and 0.8 square kilometers, respectively. Three cross-sections were surveyed on the Middle Oconee River adjacent to DPRS and on the unnamed stream adjacent to PSRF. Channelfull discharge at DPRS varied from 185.79 $m^2 s^{-1}$ at the bidirectional outlet to the depression to 293.11 $m^2 s^{-1}$ at the levee adjacent to the overbank site. Corresponding recurrence intervals were estimated at 1.3 to 1.9 years. Channelfull discharge at PSRF varied from 7.14 to 10.35 $m^2 s^{-1}$ at a recurrence interval of 0.9 years. Excellent concurrence was observed between the hydraulic geometry of all twelve cross-sections (regional and intensive assessment sites) overlaying Piedmont regional hydraulic curves and the dimensionless rating curve. Hence, regional hydraulic and dimensionless rating curves provided an accurate means of estimating flood frequency and discharge at the site-specific scale where channel geomorphology (channel capacity and levee elevation and geomorphology) varied considerably.

Higher soil bulk densities were observed in the overbank and coarse seep subclasses as compared to depression (beaver) and fine seep subclasses. Consequently, porosity was higher in depression and fine seep subclasses as compared to depression and coarse seep subclasses. As evidenced by standard error about the mean, percent total carbon was highly variable in the depression and fine seep subclasses as compared to the overbank and coarse seep subclasses. However, the coarse seep was significantly higher in percent total carbon as compared to the overbank subclass.

A significantly higher percentage of medium to coarse sand was observed in both the surface and subsurface horizon of the coarse seep (D_{50} = 0.25 and 0.5 mm, respectively) as compared to the other three subclasses which had higher percentages of silt (D_{50} = 0.002 to 0.05 mm). The overbank, depression, and fine seep subclasses were dominated by kaolinite, hydroxyl-interlayed vermiculite, and mica as compared to quartzite in the coarse seep. In addition, the iron mineral, lepidocrocite (γ-FeOOH), was identified in samples collected on ped faces in the DPRS depression. Lepidocrocite has been associated with "now-time" hydrological conditions (Vepraskas 1992). The results of well data (discussed below) are supportive of this association.

Determination of normal annual precipitation was important in groundwater response, soil temperature, and redox potential on the instrumented research sites, DPRS and PSFR. In order to determine the deviation of annual precipitation at the instrumented sites from historic conditions, precipitation measured at the weather stations adjacent to the instrumented was compared against 46 years of record for Athens, Georgia. Mean annual precipitation over the period of record was 123.8 cm (48.75 in.). Normal annual precipitation was defined as the range between the 25% and 75% quartiles or 105.5 cm (41.54 in.) and 137.8 cm (54.27 in), respectively. During the study period, the annual total precipitation measured at DPRS and PSFR was above normal in 1997, was normal in 1998, and below normal in 2000. Below normal precipitation was recorded at PSFR, and normal precipitation was recorded at DPRS during 1999. However, precipitation at DPRS exceeded the 25% quartile by only 4.8 cm (1.89 in.).

Variation in precipitation during the study period was reflected in a widely fluctuating water table (flashiness) at the DPRS overbank site as evidenced by the steep rise and fall in response to rain events. In addition, the only year when the DPRS overbank site met hydrologic criteria was 1998 which followed a year of above normal precipitation (143.5 cm in 1997). In contrast, the DPRS depression met hydrologic criteria in normal and below normal precipitation years during 1998 through 2000. This finding was supportive of the identification of lepidocrocite along ped faces in the soil profile at the DPRS depression. Lepidocrocite has also been identified in peraquic conditions on the coatings of rice roots (Bacha and Hossner 1977, Chen et al. 1980).

Both the PSRF forested and emergent seeps met hydrologic criteria (federal wetland jurisdiction, Environmental Laborabory 1987) during below normal precipitation years in 1999 and 2000. Dominant water source to seepage wetlands in footslope positions are an expression of groundwater (i.e., saturated return flow) and may provide water even during periods of prolonged drought as reported above in hydrologic criteria.

By inspection of time series analysis, a high degree of variability between air temperature and the resulting soil temperature was observed. In general, soil temperature was out-of-phase with air temperature and lagged behind air temperature by approximately two days. However, during the spring and summer, air temperature was higher than soil temperature at both DPRS and PSRF. In contrast, during the fall and winter, air temperature was lower that soil temperature. Consequently, inversions in the temperature profile occurred in April and August.

Mean annual air temperature was observed to be 17.0°C and 16.3°C at DPRS and PSFS, respectively. The observed mean annual air temperatures at the research sites fell within the reported range of 15 to 18°C for the region (Robertson 1968). Mean air temperature over the study period was significantly higher than mean soil temperature at all depths in both the depression and overbank instrumented nests at DPRS. Even though the PSRF dataset was not as robust as DPRS, mean air temperature over the study period was significantly higher than mean soil temperature at all depths at the PSRF emergent

site. However, the relationship between mean air temperature and mean soil temperature at the three depths was observed to be highly variable in the PSRF forested seep. This phenomena may have been related to an imbalance of seasonal data.

Growing season is defined as a soil temperature of greater than 5°C at 50 cm below the soil surface (Environmental Laboratory 1987, Williams 1992). Hydrology criteria is met by inundation or saturation to within 30.48 cm (12 in.) of the soil surface for a minimum of five percent of the growing season as consecutive days. This is equivalent to 12.6 days for Clarke and Oconee Counties (Robertson 1968). During the winters of 1998 and 2000, a soil temperature of 5°C or less (i.e., non-growing season) at 51 cm below the soil surface only occurred three consecutive days at DPRS depression and did not occur at any of the other instrumented HGM subclasses. During the winter of 1999, non-growing season did not occur at any of the HGM subclasses. Consequently, the non-growing season was not observed for a significant period of time during the study period at either DPRS or PSRF to warrant a designated growing season applicable to hydric soils definition and jurisdictional wetland determination. In addition, this conclusion does not account for the time lag observed between air and soil temperature. Minimum temperature does not occur at depth until a temperature gradient is established resulting in vertical flow of colder temperature through the soil profile (Hanks and Ashcroft 1980). This time lag was also observed by Gupta et al. (1980) on a diurnal scale, in that, the time lag was more apparent at 30 cm than at the soil surface.

Soil redox potential at DPRS during the study period (all seasons) and during each of four seasons was significantly lower in the depression as compared to the overbank. The lowest redox was recorded in the PSRF depression during the spring when the combined effects of relatively high water table and adequate temperature for soil microbial activity was present. In addition, redox during the winter, summer, and fall in the DPRS depression and during all seasons in the DPRS overbank was relatively constant within the same soil depths.

With the exception of 51 cm, soil redox potential at soil depths of 15, 25, and 51 cm at PSRF during the study period (all seasons) and during each of four seasons was significantly higher in the forested seep as compared to corresponding redox in the emergent seep.

In general, a positive relationship was observed between soil redox and mean daily air temperature, and a negative relationship was observed between soil redox and water table (bivariate regression). Hence, soil redox potential decreased with increasing air temperature and water table. As compared to DPRS overbank (R^2 = 0.09 to 0.13), PSRF forested (R^2 = 0.20 to 0.38), and PSRF emergent (R^2 = 0.22 to 0.39) sites, air temperature in combination with water table accounted for a relatively high percentage of the variability in soil redox at DPRS depression during the spring (R^2 = 0.66 to 0.71). This is strong evidence of the effects of prolonged soil saturation (i.e., peraquic conditions) resulting in highly reducing conditions as measured by low redox potential. Megonigal et al. (1993) also observed a strong correlation between redox potential, oxygen content, chroma, and soil saturation near the surface when averaged across annual time scales.

A soil redox potential of +265 mV or less was required for anaerobic conditions. Neither DPRS overbank nor PSRF forested seep met the requirement of the technical standard during any season. In contrast, DPRS depression met the standard at all soil depths during the spring, at two depths during winter and summer (30 and 51 cm), and only one depth during the fall (51 cm). PSRS emergent seep met the requirements of the technical standard at all three soil depths during the spring, summer, and fall but at two depths during the winter (15 and 51 cm).

DPRS depression and PSRF forested and emergent seeps met the requirements of federal wetland jurisdiction (Environmental Laboratory 1987). DPRS overbank did not meet the requirements of federal wetland jurisdiction. Based on the results of this research, federal wetland jurisdiction was confirmed at the DPRS depression and the PSRF forested and emergent seeps in two ways: 1) the water table was within 30.48 cm

of the soil surface for a minimum of five percent of the growing season (12.6 consecutive days); and 2) reducing conditions, as measured by redox potential, existed for prolonged periods of time during the year to produce anaerobiosis (redox less than +265 mV).

In summary, the following findings were identified in this study:

- Based on geomorphic setting, water source and transport, hydrodynamics, particle size distribution, and mineralogy, four subclasses of Piedmont riverine systems were identified: overbank, depression, fine seep, and coarse seep;
- Excellent correspondence was observed between hydrophytic vegetation and redoximorphic features. Fair correspondence was observed between hydrophytic vegetation and hydrologic indicators;
- Piedmont regional dimensionless rating curves were developed and were utilized to estimate flood frequency and discharge onto adjacent wetlands. In general, Piedmont floodplains were estimated to flood on a one to two year recurrence interval depending on channel capacity and levee elevation above the channel adjacent to the wetland assessment site;
- Higher bulk densities were observed in overbank and coarse seep subclasses as compared to depression and fine seep subclasses. Higher medium to coarse sand percentages were observed in the coarse seep as compared to the other subclasses. In addition, the coarse seep was dominated by quartzite as compared to kaolinite, hydroxyl-interlayed vermiculite, and mica in the other subclasses;
- Extreme fluctuation in the water table of the overbank site mimicked precipitation and was more flashy as compared to the other subclasses. In addition, the overbank site did not meet hydrologic criteria for federal wetland jurisdiction in normal rainfall years during the study period. In contrast, the other subclasses exhibited moderate fluctuation following precipitation and met hydrologic criteria even during below normal rainfall years;

- Soil temperature lagged behind air temperature, and the lag time varied with soil depth. However, mean, minimum, and maximum soil temperature could be estimated by linear regression with a moderate to high degree of accuracy at all depths across all subclasses;
- With the exception of the forested seep, mean annual air temperature was significantly higher than mean annual soil temperature at all depths across subclasses;
- Non-growing season, by definition, only occurred for three consecutive days at the depression during the winters of 1998 and 2000 and did not occur during 1999. Non-growing season did not occur at the other subclasses. A lower air temperature was required to produce a soil temperature of 5°C at 51 cm below the soil surface at the overbank as compared to the other subclasses;
- Water table was lower and soil redox potential was higher at the overbank as compared to the other subclasses. Optimal soil temperature in combination with adequate water table resulting in the lowest redox potential was recorded in the depression during the spring. Within the same soil depths, redox potential fluctuated the least during the winter, summer, and fall in the depression and during all seasons in the overbank site;
- Soil redox potential decreased with increasing air temperature and water table in all subclasses but was most evident in the depression;
- The depression and emergent seep met the requirements of the Technical Standard. The depression, forested seep, and emergent seep met the requirements of federal wetland jurisdiction based on water table and redox potential; and
- Based on the seasonal variation in water table, soil temperature, and redox potential, application of the NTCHS technical standard should include periods of normal precipitation conditions over several seasons with emphasis placed on late winter and early spring before transpiration exerts a significant effect on the water table.

Table 1. Coordinates of regional and intensive study assessment sites, Georgia, USA.

Station[§]	Decimal Degrees		Station[§]	Decimal Degrees	
	Latitude	Longitude		Latitude	Longitude
Regional Study Assessment Sites (Ogeechee River Watershed):					
NFOR01	33.600	83.080	NFOR30	33.550	82.957
TNFOR09	33.588	83.076	NFOR31&32	33.547	82.950
NFOR07&08	33.602	83.050	GHB33	33.538	82.925
NFOR06	33.601	83.048	NFOR34	33.535	82.922
NROR02	33.592	83.012	NFOR35&36	33.529	82.919
NFOR05	33.593	83.038	OR24	33.520	82.909
NFOR03	33.588	83.009	OR43	33.516	82.903
TNFOR04	33.574	82.999	OR42	33.512	82.896
SFOR10&11	33.551	83.042	OR41	33.476	82.871
SFOR12	33.549	83.041	PC39	33.447	82.873
SFOR13&14	33.527	83.017	OR38	33.435	82.845
MC15&16	33.518	83.013	OR37	33.433	82.843
MC17	33.519	83.014	OR44	33.419	82.826
MC18	33.512	83.028	OR45	33.421	82.824
MC19	33.511	83.024	OR46	33.425	82.827
SFOR20	33.521	82.986	BC50	33.403	82.870
SFOR22	33.517	82.979	BC47	33.408	82.868
SFOR21	33.516	82.977	BC48	33.400	82.865
SFOR23	33.513	82.955	BC49	33.402	82.853
NFOR25	33.576	82.993	BC51	33.403	82.846
NFOR26	33.575	82.989	BC32	33.399	82.861
NFOR27	33.562	82.974	BC53	33.404	82.881
NFOR28	33.557	82.964	BC52	33.403	82.876
NFOR29	33.556	82.960			
Intensive Study Assessment Sites (Oconee River Watershed):					
Plant Science Research Farm (PSRF)			Dean's Pond Research Site (DPRS)		
Weather Station	33.873	83.535	Weather Station	33.896	83.366
Instrumented Site	33.876	83.549	Instrumented Site	33.882	83.362

[§]NFOR = North Fork Ogeechee River, TNFOR = Tributary (unnamed) North Fork Ogeechee River, SFOR = South Fork Ogeechee River, MC = Moores Creek, GHB = Gunn Hill Branch, OR = Ogeechee River (main stem), BC = Beaverdam Creek, PC = Powell Creek.

Table 2. Summary of northeast Georgia annual precipitation listed by cities.

Parameter	Toccoa	Hartwell	Carnesville	Elberton	Cornelia	Commerce
Number	64	55	41	40	43	29
Minimum (cm)	103.28	85.32	79.93	80.04	99.67	89.84
Maximum (cm)	214.25	182.07	170.64	172.57	192.74	171.02
Arithmetic mean (cm)	151.90	128.51	129.27	123.54	151.81	133.94
Standard deviation	25.79	23.78	22.79	21.58	25.24	22.48
25% Quartile (cm)	133.96	109.96	116.87	106.47	131.28	120.65
Median (cm)	148.58	125.50	131.04	123.69	149.91	135.23
75% Quartile (cm)	167.94	137.64	143.81	138.64	172.10	150.44

	Lexington	Clayton	Bowman	Athens	Helen
Number	35	61	43	43	29
Minimum (cm)	67.44	118.19	86.94	72.67	121.18
Maximum (cm)	168.73	262.92	168.66	181.33	223.22
Arithmetic mean (cm)	121.26	180.32	119.59	123.19	185.58
Standard deviation	22.77	32.06	20.37	23.73	28.62
25% Quartile (cm)	106.72	152.65	104.51	105.82	160.96
Median (cm)	120.98	172.36	118.21	125.91	195.71
75% Quartile (cm)	134.24	201.70	132.41	137.43	205.05

Table 3. Regional study, vegetation species key, Ogeechee River basin, Georgia, page 1 of 3.

All Species	Tree	Shrub	Herb	Vine	Abbreviation	Scientific Name	Common Name	Status
1	1				ACNE	*Acer negundo*	box elder	FACW
2	2				ACRU	*Acer rubrum*	red maple	FACW
3	3				ACSA	*Acer saccharum*	sugar maple	FACU-
4				1	ANCA	*Anisostichus capreolata*	cross vine	Upland
5			1		ARGI	*Arundinaria gigantea*	cane	FACW
6			2		ARTR	*Arisaema triphyllum*	Jack-in-the-pulpit	FACW-
7			3		ASPA	*Asimina parviflora*	Paw Paw	FACU
8	4				BENI	*Betula nigra*	river birch	FACW
9			4		BOCY	*Boehmeria cylindrica*	bog hemp	FACW+
10		1			CACAM	*Callicarpa americana*	beauty-berry	FACU-
11		2			CAFL	*Calycanthus floridus*	spicebush	FACU+
12				2	CARA	*Campsis radicans*	trumpet creeper	FAC
13	5				CACA	*Carpinus caroliniana*	ironwood	FAC
14	6				CAGL	*Carya glabra*	pignut hickory	FACU
15	7				CATO	*Carya tomentosa*	mockernut hickory	Upland
16		3			CECA	*Cercis canadensis*	redbud	FACU
17	8				CELA	*Celtis laevigata*	sugarberry	FACW
18			5		COCO	*Commelina communis*	dayflower	FAC
19		4			COAM	*Cornus amomum*	swamp dogwood	FACW+
20	9				COFL	*Cornus florida*	flowering dogwood	FACU
21		5			COST	*Cornus foemina*	stiff dogwood	FACW-
22	10				CRSP	*Crataegus spathulata*	hawthorne	FAC

Table 4. Regional study, vegetation species key, Ogeechee River basin, Georgia, page 2 of 3.

All Species	Tree	Shrub	Herb	Vine	Abbreviation	Scientific Name	Common Name	Status
23				3	DEBA	*Decumaria barbara*	climbing hydrangea	FACW
24	11				DIVI	*Diospyros virginiana*	persimmon	FAC
25		6			ELUM	*Elaeagnus umbellata*	silverberry	FACU
26			6		ELCA	*Elephantopus carolinianus*	elephant's-foot	FAC
27			7		FIAU	*Fimbristylis autumnalis*	beak rush	OBL
28		7			FRVI	*Fragaria virginiana*	wild strawberry	FAC-
29	12				FRAM	*Fraxinus americana*	white ash	FACU
30	13				FRPE	*Fraxinus pennsylvanica*	green ash	FACW
31	14				GLTR	*Gleditsia triacanthos*	honey locust	FAC-
32		8			HACA	*Halesia carolina*	Carolina silverbell	FACU+
33		9			ILDE	*Ilex decidua*	deciduous holly	FACW-
34			8		IMCA	*Impatiens capensis*	jewel-weed	FACW
35	15				JUNI	*Juglans nigra*	black walnut	FACU
36		10			LISI	*Ligustrum sinense*	privet	FAC
37	16				LIST	*Liquidambar styraciflua*	sweetgum	FAC+
38	17				LITU	*Liriodendron tulipifera*	yellow poplar	FAC
39				4	LOJA	*Lonicera japonica*	Japanese honeysuckle	FAC-
40			9		MIVI	*Microstegium virmineum*	Microstegium	NL
41	18				MORU	*Morus rubra*	red mulberry	FAC
42	19				NYSY	*Nyssa sylvatica*	blackgum	FAC
43	20				OSVI	*Ostrya virginiana*	hop hornbeam	FACU-
44				5	PAQU	*Parthenocissus quinquefolia*	Virginia creeper	FAC

Table 5. Regional study, vegetation species key, Ogeechee River basin, Georgia, page 3 of 3.

All Species	Tree	Shrub	Herb	Vine	Abbreviation	Scientific Name	Common Name	Status
45			10		PIPU	*Pilea pumila*	clearweed	FACW+
46	21				PITA	*Pinus taeda*	loblolly pine	FAC
47	22				PLOC	*Platanus occidentalis*	sycamore	FACW-
48			11		POAC	*Polystichum acrostichoides*	Christmas fern	FAC
49	23				PODE	*Populus deltoides*	cottonwood	FAC+
50			12		POPU	*Polygonum punctatum*	knotweed	FACW+
51	24				PRSE	*Prunus serotina*	black cherry	FACU
52				6	PULO	*Pueraria lobata*	kudzu	Upland
53	25				QULY	*Quercus lyrata*	overcup oak	OBL
54	26				QUNI	*Quercus nigra*	water oak	FAC
55	27				QUPH	*Quercus phellos*	willow oak	FACW-
56	28				QURU	*Quercus rubra*	red oak	FACU
57			13		RUAR	*Rubus argutus*	blackberry	FAC-
58	29				SANI	*Salix nigra*	black willow	OBL
59		11			SACA	*Sambucus canadensis*	elderberry	FACW-
60				7	SMLA	*Smilax laurifolia*	green briar	FACW+
61				8	SMRO	*Smilax rotundifolia*	green briar	FAC
62				9	TORA	*Toxicodendron radicans*	poison ivy	FAC
63	30				ULAL	*Ulmus alata*	winged elm	FACU+
64	31				ULAM	*Ulmus americana*	American elm	FACW
65			14		UNLA	*Chasmanthium latifolium*	Spikegrass	FACU
66		12			VAST	*Vaccinium stamineum*	huckleberry	FACU
67				10	VIRO	*Vitus rotundifolia*	muscadine	FAC

Table 6. Regional study, vegetation statistics by species, Ogeechee River basin, Georgia, page 1 of 2.

Trees [§]	ACNE	ACRU	ACSA	BENI	CACA	CAGL	CATO	CELA	COFL	
Frequency	12	14	3	6	13	4	5	11	3	
Abundance	75	42	10	33	51	22	11	35	7	
Density (number ha^{-1})	66	37	9	29	45	19	10	31	6	
Dominance (m^2 ha^{-1})	56.09	75.20	4.37	76.92	14.45	36.87	4.88	56.23	1.08	
Trees	CRSP	DIVI	FRAM	FRPE	GLTR	JUNI	LIST	LITU	MORU	OSVI
Frequency	1	1	1	19	1	2	24	7	2	3
Abundance	2	5	2	84	1	3	217	14	2	8
Density (number ha^{-1})	2	4	2	73	1	3	190	12	2	7
Dominance (m^2 ha^{-1})	0.35	2.13	0.55	134.42	0.69	4.06	302.93	37.89	2.30	2.53
Trees	PITA	PLOC	PODE	QULY	QUNI	QUPH	QURU	ULAL	ULAM	
Frequency	1	7	1	2	9	1	1	14	11	
Abundance	2	9	1	2	20	1	1	53	30	
Density (number ha^{-1})	2	8	1	2	17	1	1	46	26	
Dominance (m^2 ha^{-1})	7.37	14.09	6.86	2.47	58.08	5.11	0.48	19.29	25.60	
Shrubs	ACNE	ACRU	ACSA	AESY	ARGI	ASPA	BENI	CACAM	CACA	CAFL	CAGL
Frequency	14	12	3	1	1	6	1	2	16	5	1
Abundance	65	74	19	2	13	75	11	2	233	51	2
Density (number ha^{-1})	57	65	17	2	11	66	10	2	204	45	2
Shrubs	CATO	CECA	CELA	COAM	COFL	COST	CRSP	DIVI	ELUM	FRPE	HACA
Frequency	5	1	9	4	5	3	2	2	1	11	2
Abundance	14	2	18	19	11	5	8	2	4	39	5
Density (number ha^{-1})	12	2	16	17	10	4	7	2	3	34	4

[§]See Figures 4 - 6 for vegetation key.

Table 7. Regional study, vegetation statistics by species, Ogeechee River basin, Georgia, page 2 of 2.

Shrubs [§]	LITU	LISI	LIST	LOJA	MORU	NYSY	OSVI	PITA	PLOC	PRSE	
Frequency	1	10	13	1	1	2	6	0	2	2	
Abundance	1	54	72	2	4	2	35	0	5	3	
Density (number ha^{-1})	1	47	63	2	3	2	31	0	4	3	
Shrubs	QUAL	QULY	QUNI	QUPH	ROCO	SACA	SANI	ULAL	ULAM	VAST	
Frequency	1	1	9	0	1	3	1	16	6	2	
Abundance	2	1	13	0	1	8	3	93	9	4	
Density (number ha^{-1})	2	1	11	0	1	7	3	81	8	3	
Herbs	ACNE	ACSA	ANCA	ARGI	ARTR	ASPA	BOCY	CARA	COCO	ELCA	FIAU
Frequency	4	2		3	3	2	10	2	1	1	
Abundance (% cover)	1.09	0.94		2.19	0.94	0.31	3.28	1.25	0.31	0.31	
Herbs	FRPE	FRVI	IMCA	LISI	LIST	LOJA	MIVI	PAQU	PIPU	POAC	POPU
Frequency	1	2	2	2		8	16	5	2	3	1
Abundance (% cover)	0.16	0.78	0.31	0.20		5.33	18.75	2.22	0.47	0.94	0.16
Herbs	QUNI	RUAR	SMLA	TORA	UNLA	VIRO	unk. grass	*Carex* spp.			
Frequency	2	9	2	3	5	4	10	13			
Abundance (% cover)	0.31	4.06	0.31	2.50	1.80	0.63	4.53	6.72			
Snags, vines	Snags	ANCA	CARA	DEBA	LOJA	PAQU	PULO	SMLA	TORA	VIRO	
Frequency	30	14	9	4	16	19	1	10	23	15	
Abundance	185	14	9	4	16	19	1	10	23	15	
Density (number ha^{-1})	162	12	8	3	14	17	1	9	20	13	
Dominance (m^2 ha^{-1})	106.43										

[§]See Figures 4 - 6 for vegetation key.

Table 8. Piedmont hydraulic geometry data.

Parameter	USGS Gaging Station					
	North Fork Broad	South Fork Ogeechee	Hudson	Beaverdam	Ogeechee	Oconee
Drainage area (km^2)	47.40	81.07	157.73	186.48	626.78	2434.60
Bankfull discharge ($m^3\ s^{-1}$)	12.5	22.9	14.4	29.4	117.5	246.66
Bankfull depth (m)	0.84	1.28	1.18	1.35	2.04	3.15
Bankfull recurrence interval (yr)	0.8	1.2	0.9	1.4	1.4	1.1
Bankfull width (m)	24.01	17.98	18.43	25.27	40.84	66.27
Bankfull square area (m^2)	22.77	21.22	21.35	35.12	93.38	176.13
Channelfull discharge ($m^3\ s^{-1}$)	31.39	43.66	103.05	50.46	211.44	246.66
Channelfull depth (m)	1.43	1.77	2.58	1.95	2.95	3.15
Channelfull recurrence interval (yr)	2.5	2.5	4.3	2.0	20.8	1.1

Table 9. Piedmont dimensionless rating curve calibration, page 1 of 2.

Parameter [§] / Stream	RI (years)	Q ($m^3 s^{-1}$)	Q/Q_{bkf} (unitless)	D (m)	D/D_{bkf} (unitless)
North Fork	0.8	12.53	1.00	0.84	1.00
Broad River	1.5	23.45	1.87	1.36	1.62
USGS Station No. 02189500	2.3	30.79	2.46	1.54	1.83
	5.0	43.52	3.47	1.80	2.15
	10.0	55.07	4.39	2.00	2.39
	25.0	70.35	5.61	2.24	2.67
	50.0	81.90	6.54	2.40	2.87
	100.0	93.46	7.46	2.55	3.04
South Fork	1.2	22.90	1.00	1.28	1.00
Ogeechee River	1.5	31.16	1.36	1.54	1.21
USGS Station No. 02199700	2.3	43.33	1.89	1.80	1.40
	5.0	64.44	2.81	2.15	1.68
	10.0	83.61	3.65	2.42	1.90
	25.0	108.94	4.76	2.74	2.14
	50.0	128.10	5.59	2.95	2.30
	100.0	147.26	6.43	3.14	2.46
Hudson River	0.9	14.35	1.00	1.18	1.00
USGS Station No. 02191200	1.5	47.09	3.28	1.86	1.58
	2.3	72.92	5.08	2.28	1.93
	5.0	117.69	8.20	2.83	2.40
	10.0	158.33	11.03	3.24	2.75
	25.0	212.06	14.77	3.71	3.15
	50.0	252.70	17.61	4.02	3.41
	100.0	293.35	20.44	4.30	3.65

[§]RI = recurrence interval, Q = discharge at a given mean depth (D), Q_{bkf} and D_{bkf} = bankfull discharge at and bankfull depth, respectively.

Table 10. Piedmont dimensionless rating curve calibration, page 2 of 2.

Parameter / Stream	RI (years)	Q ($m^3 s^{-1}$)	Q/Q_{bkf} (unitless)	D (m)	D/D_{bkf} (unitless)
Beaverdam Creek	1.4	29.38	1.00	1.35	1.00
USGS Station No. 02188500	1.5	33.14	1.13	1.48	1.10
	2.3	56.43	1.92	1.98	1.47
	5.0	96.81	3.30	2.65	1.97
	10.0	133.47	4.54	3.16	2.34
	25.0	181.92	6.19	3.73	2.77
	50.0	218.58	7.44	4.12	3.06
	100.0	255.24	8.69	4.48	3.32
Ogeechee River	1.4	117.49	1.00	2.04	1.00
USGS Station No.02200000	1.5	142.36	1.21	2.73	1.34
	2.3	278.61	2.37	3.68	1.81
	5.0	514.86	4.38	4.84	2.38
	10.0	729.31	6.21	5.66	2.78
	25.0	1012.80	8.62	6.56	3.22
	50.0	1227.26	10.45	7.14	3.51
	100.0	1441.71	12.27	7.68	3.77
Oconee River	1.1	246.66	1.00	3.15	1.00
USGS Station No. 02218300	1.5	338.97	1.37	3.62	1.15
	2.3	451.19	1.83	4.09	1.30
	5.0	645.74	2.62	4.77	1.51
	10.0	822.34	3.33	5.29	1.68
	25.0	1055.81	4.28	5.88	1.87
	50.0	1232.41	5.00	6.29	2.00
	100.0	1409.02	5.71	6.66	2.11

[§]RI = recurrence interval, Q = Discharge at a given mean depth (D), Q_{bkf} and D_{bkf} = bankfull discharge at and bankfull depth, respectively.

Table 11. Hydraulic geometry data and application of piedmont regional dimensionless rating curve, regional and intensive study assessment sites.

		Regional Study[¶]						Intensive Study - DPRS[¶]			Intensive Study - PSRF[¶]		
Parameter[§]	Units	MC15	SFOR13	NFOR25	NFOR30	OR24	OR46	MOR01	MOR02	MOR03	PSRF01	PSRF02	PSRF03
DA	km^2	7.8	26.2	38.1	55.9	159.8	331	1216.1	1216.1	1216.1	0.8	0.8	0.8
D_{bkf}	m	0.49	0.73	0.85	1.16	1.55	1.89	2.04	2.07	2.23	0.52	0.58	0.58
W_{bkf}	m	6.37	6.95	9.57	10.49	19.48	16.67	41.82	59.25	47.98	3.96	7.62	5.27
A_{bkf}	m^2	2.79	4.92	8.64	11.43	32.05	32.79	85.66	117.71	135.64	1.67	2.97	2.42
Q_{bkf}	$m^3\ s^{-1}$	2.46	7.08	10.45	22.54	46.75	76.23	95.37	98.57	117.97	3.00	3.82	3.91
RI_{bkf}	yrs	0.8	0.9	0.8	1.2	0.7	0.7	0.9	1.0	1.0	0.7	0.7	0.7
D_{chf}	m	0.91	1.19	1.55	1.71	1.83	2.93	3.63	3.26	2.83	0.98	0.79	0.85
W_{chf}	m	7.04	9.11	14.63	13.99	26.09	29.87	70.01	77.11	64.25	6.68	11.86	13.96
A_{chf}	m^2	5.95	10.78	19.23	22.30	45.15	71.07	177.54	222.50	219.72	5.48	8.73	8.27
Q_{chf}	$m^3\ s^{-1}$	8.16	17.47	33.44	47.74	64.34	181.71	293.11	240.13	185.79	10.25	7.14	7.87
RI_{chf}	yrs	0.9	1.1	1.4	1.8	2.4	1.3	1.9	1.6	1.3	0.9	0.9	0.9

[§]DA = drainage area, D_{bkf} and D_{chf} = mean depth at bankfull and channelfull, respectively, W_{bkf} and W_{chf} = width at bankfull and channelfull, respectively, A_{bkf} and A_{chf} = cross-sectional area at bankfull and channelfull, respectively, Q_{bkf} and Q_{chf} = discharge at bankfull and channelfull, respectively, RI_{bkf} and RI_{chf} = recurrence interval at bankfull and channelfull, respectively.

[¶]MC = Moores Creek, SFOR = South Fork Ogeechee River, NFOR = North Fork Ogeechee River, OR = Ogeechee River (main stem), MOR = Middle Oconee River at Dean's Pond Research Site (DPRS), PSRF = Plant Science Research Farm.

Table 12. Comparison of soil properties across hydrogeomorphic subclasses, regional study.

Hydrogeomorphic Subclass	Soil Properties				
	Porosity	Mineralogy	Total Carbon (%)	CEC (meq $100g^{-1}$)	PSD (Median)
Overbank	0.3 to 0.4	Kaolinite, Hydroxyl-Interlayered-Vermiculite, Mica	1.15	12.7	Silt to Very Fine Sand
Beaver	0.0 to 0.1	Kaolinite, Hydroxyl-Interlayered-Vermiculite, Mica	2.72	8.8	Silt to Very Fine Sand
Coarse Seep	0.15 to 0.20	Quartzite	0.57	2.3	Median Sand to Coarse Sand
Fine Seep	0.15 to 0.20	Kaolinite, Hydroxyl-Interlayered-Vermiculite, Mica	1.74	15.5	Silt to Very Fine Sand

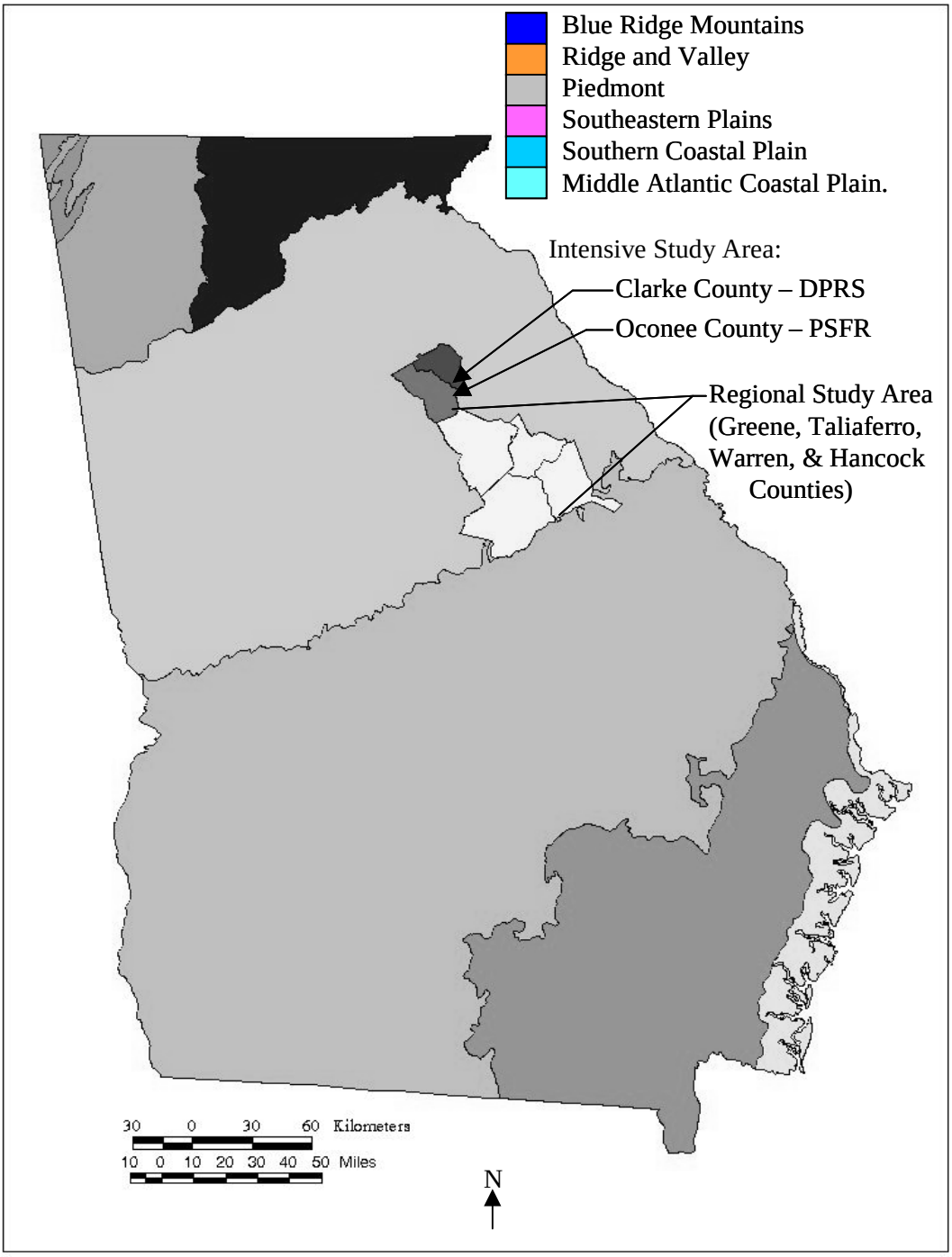

Figure 1. Ecoregion map of Georgia, USA, with study areas (DPRS = Deans Pond Research Site, PSRF = Plant Science Research Farm).

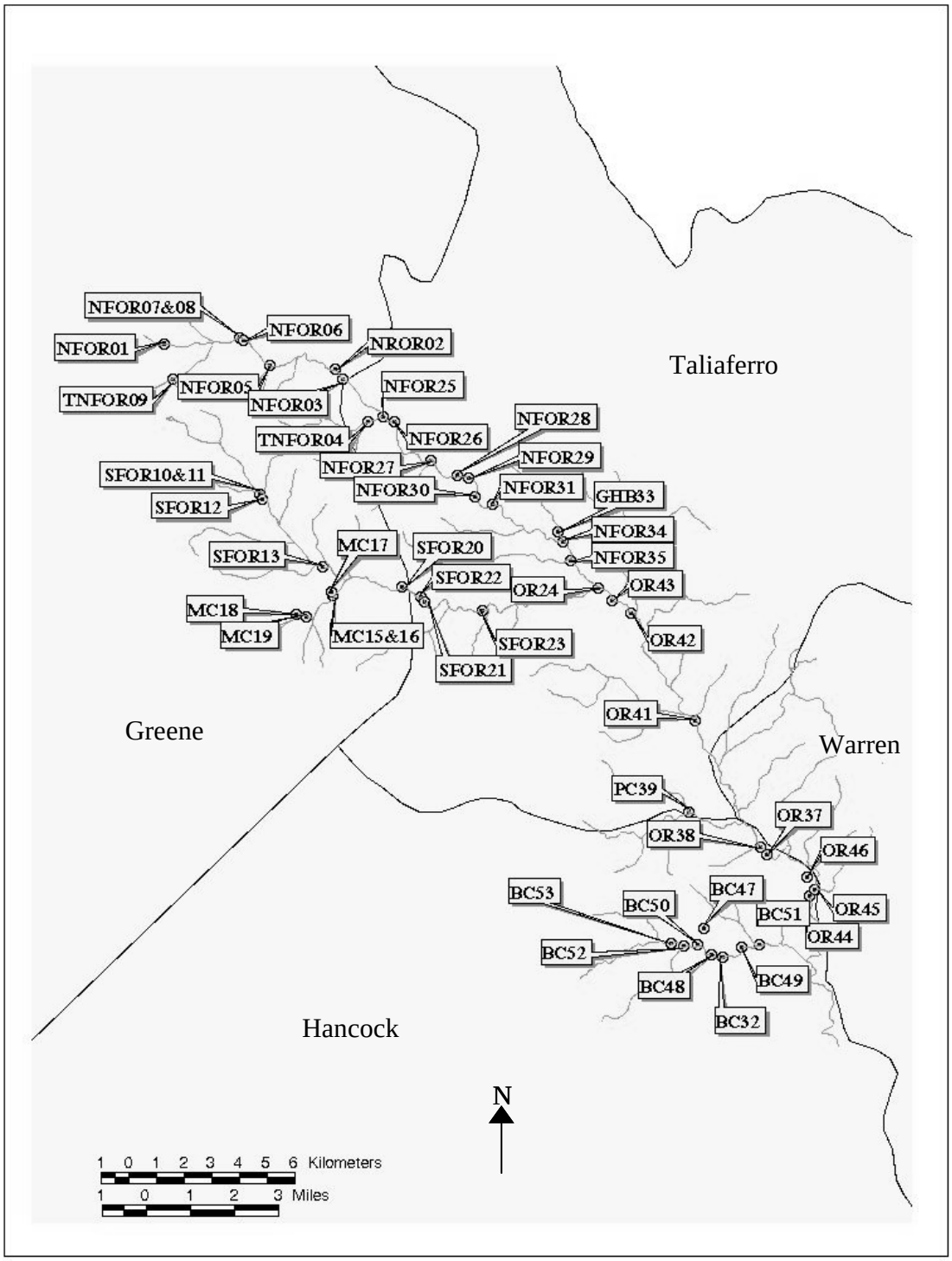

Figure 2. Regional study, wetland assessment sites (Greene, Hancock, Taliaferro, Warren Counties, Georgia, USA).

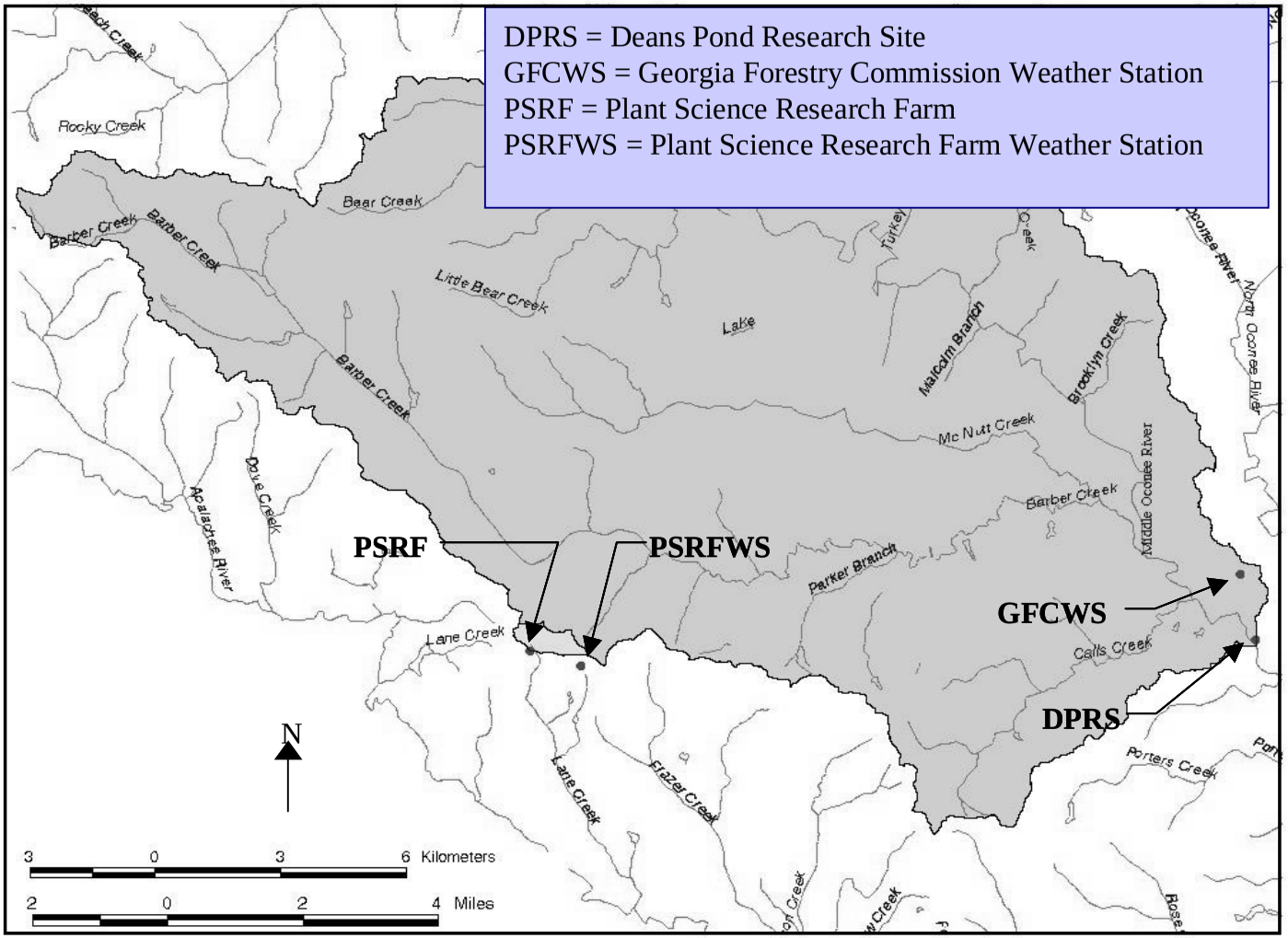

Figure 3. Watershed map with intensive research sites and weather stations, Georgia, USA.

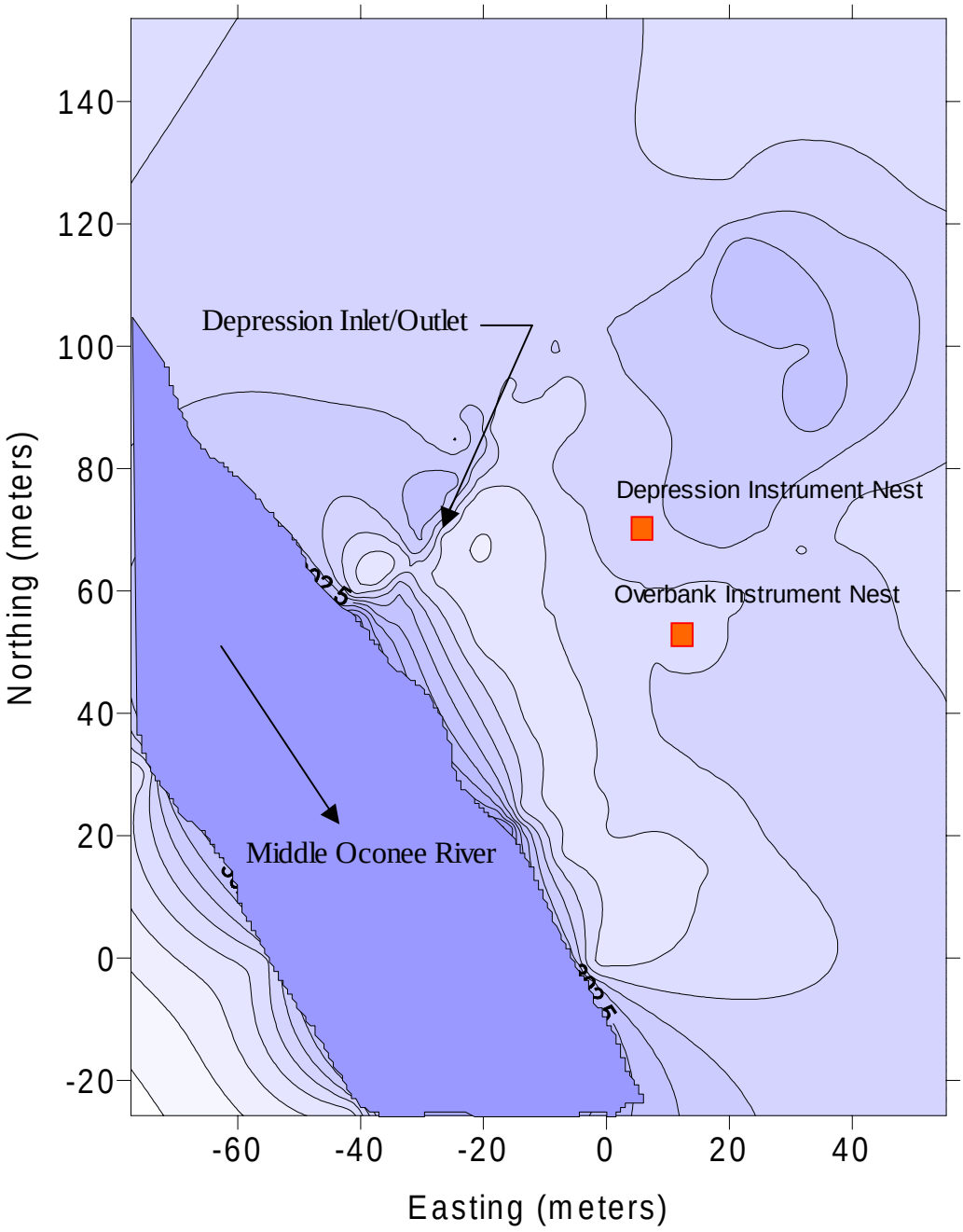

Figure 4. Deans Pond Research Site (DPRS), Whitehall Forest, Athens, Athens-Clarke County, Georgia, USA.

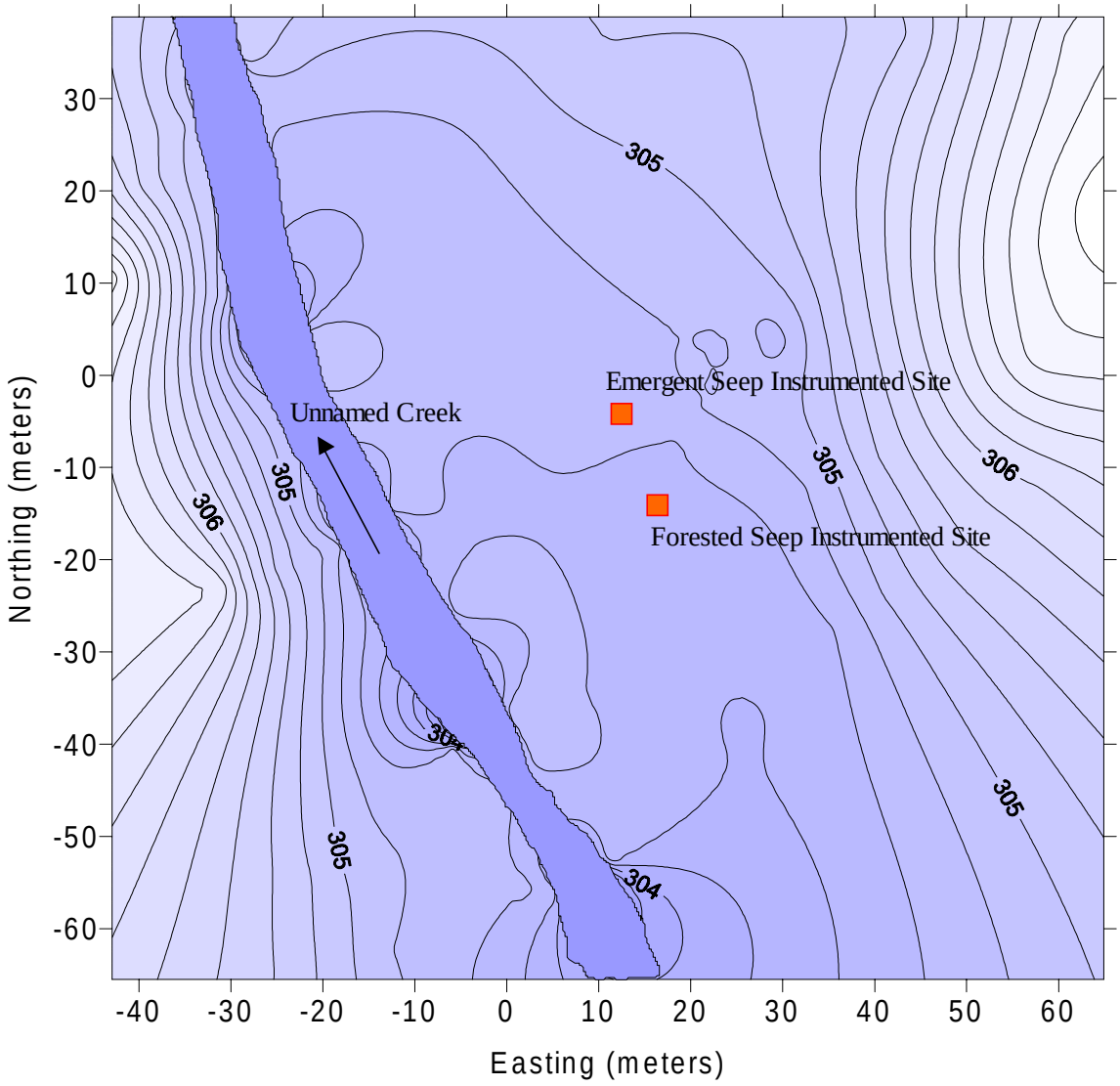

Figure 5. Plant Science Research Farm Instrumented Site (PSFR), Plant Science Research Farm, Watkinsville, Oconee County, Georgia, USA.

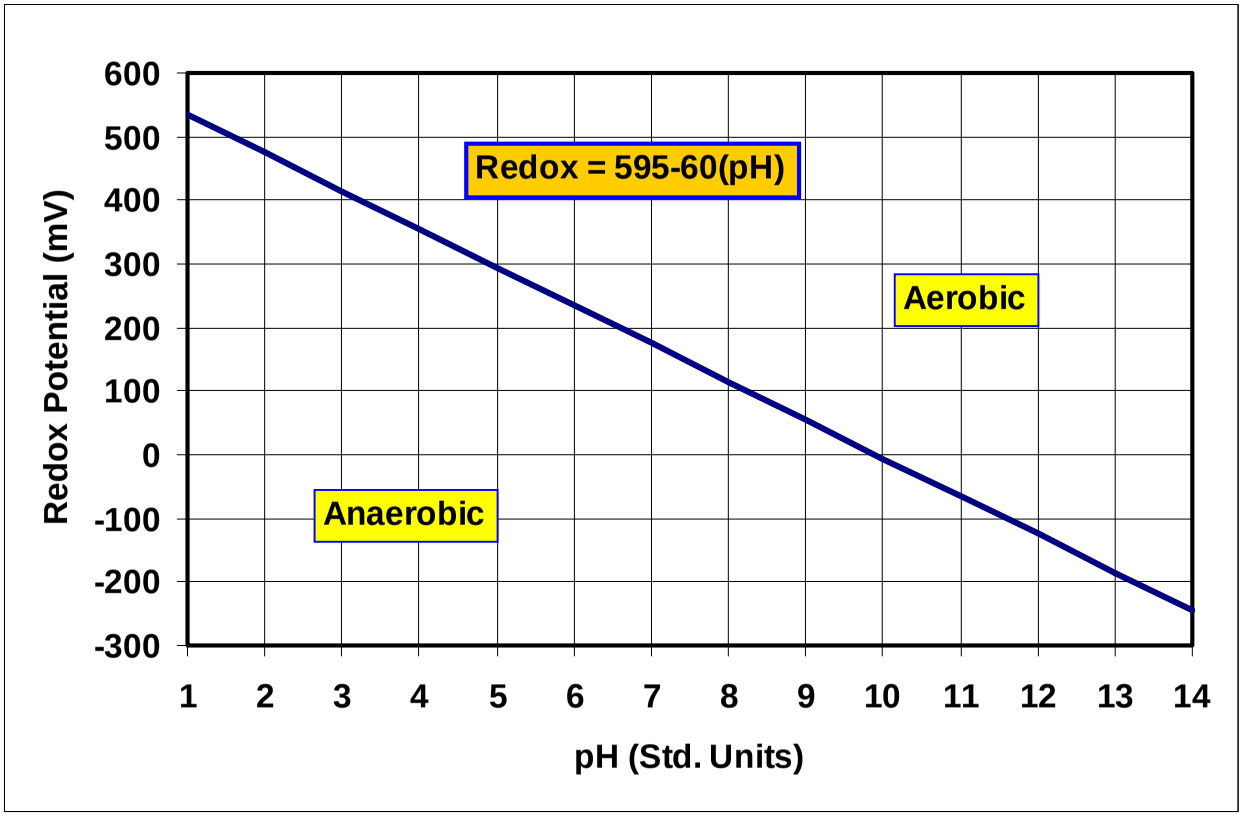

Figure 6. Redox potential versus pH stability diagram (After NTCHS 2000).

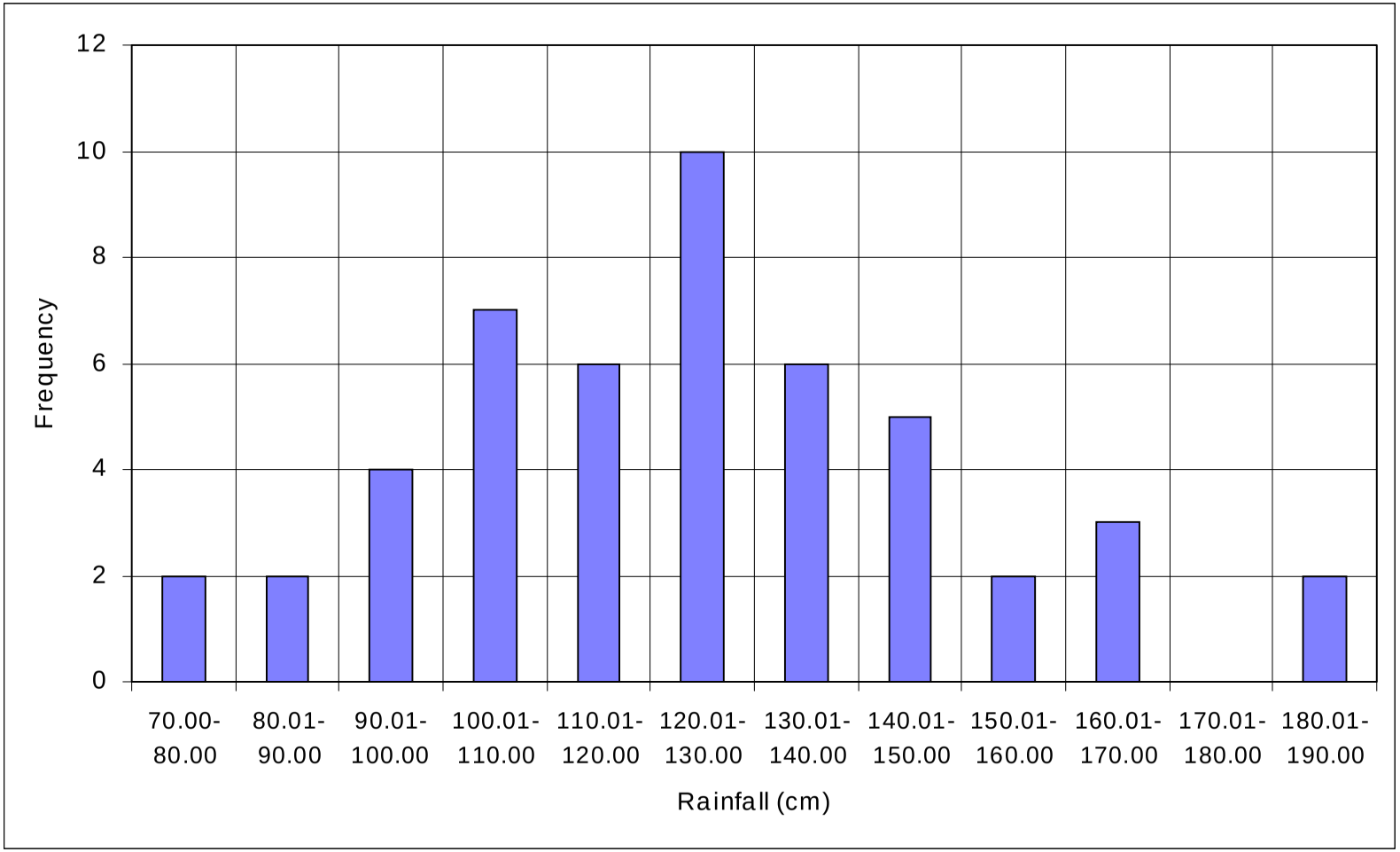

Figure 7. Frequency distribution of historic annual rainfall for Athens, Georgia, USA (1949 to 1994).

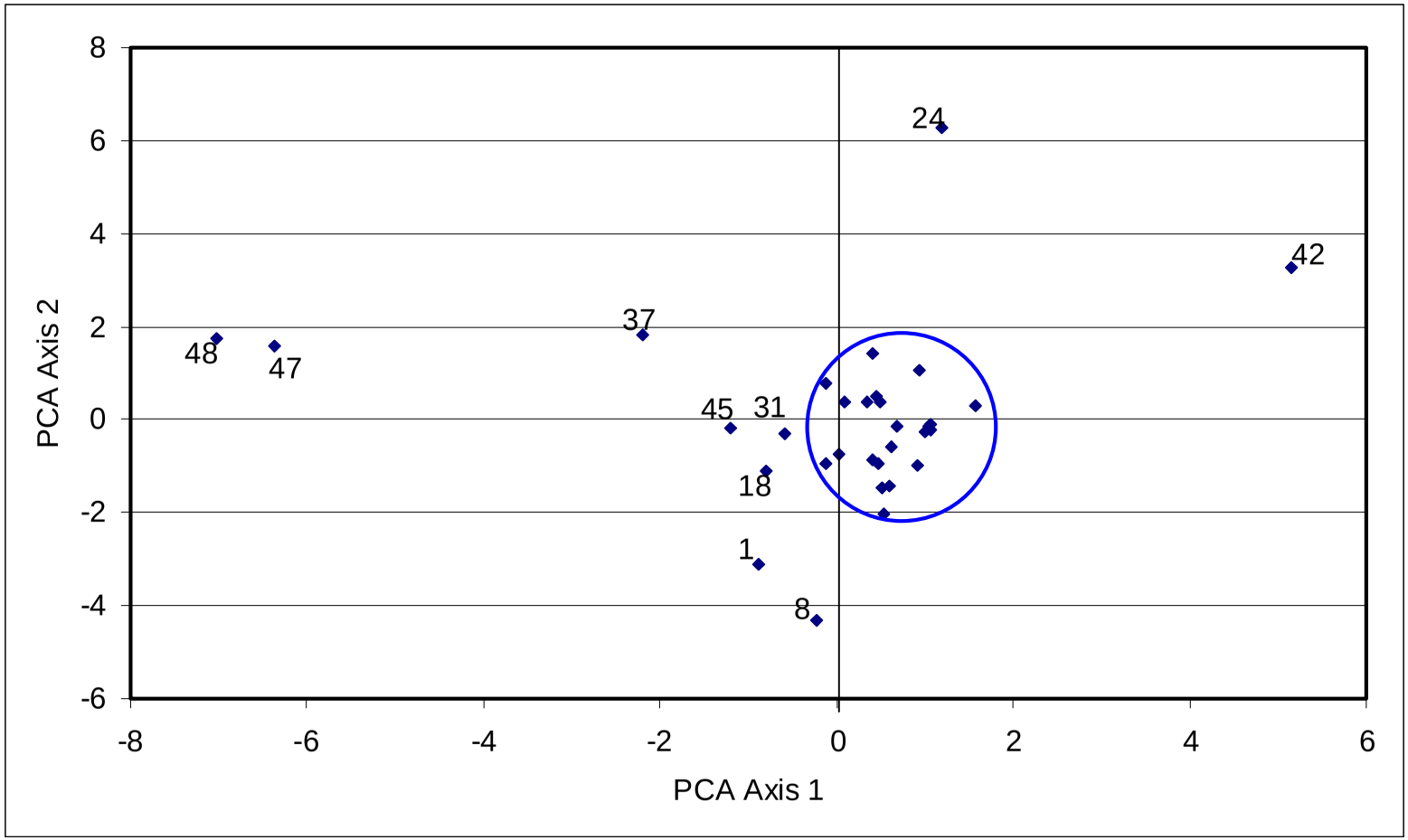

Figure 8. Principle components analysis (PCA) on tree abundance per species across regional assessment sites, assessment sites within the circle had similar species composition and were dominated by facultative species as compared with sites outside the circle.

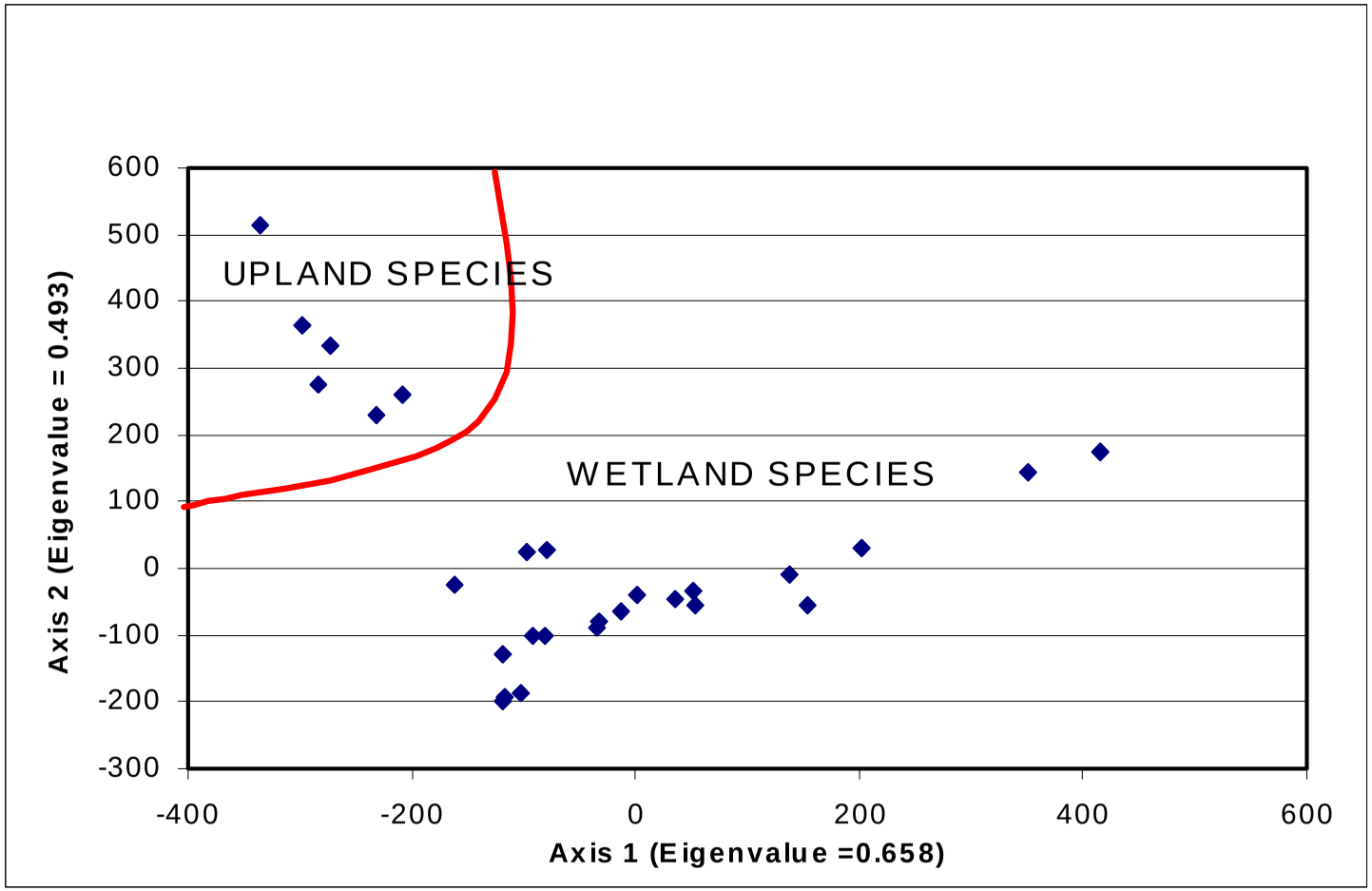

Figure 9. Redoximorphic features overlaying tree abundance using reciprocal averaging (RA), solid line separates wetland species from upland species.

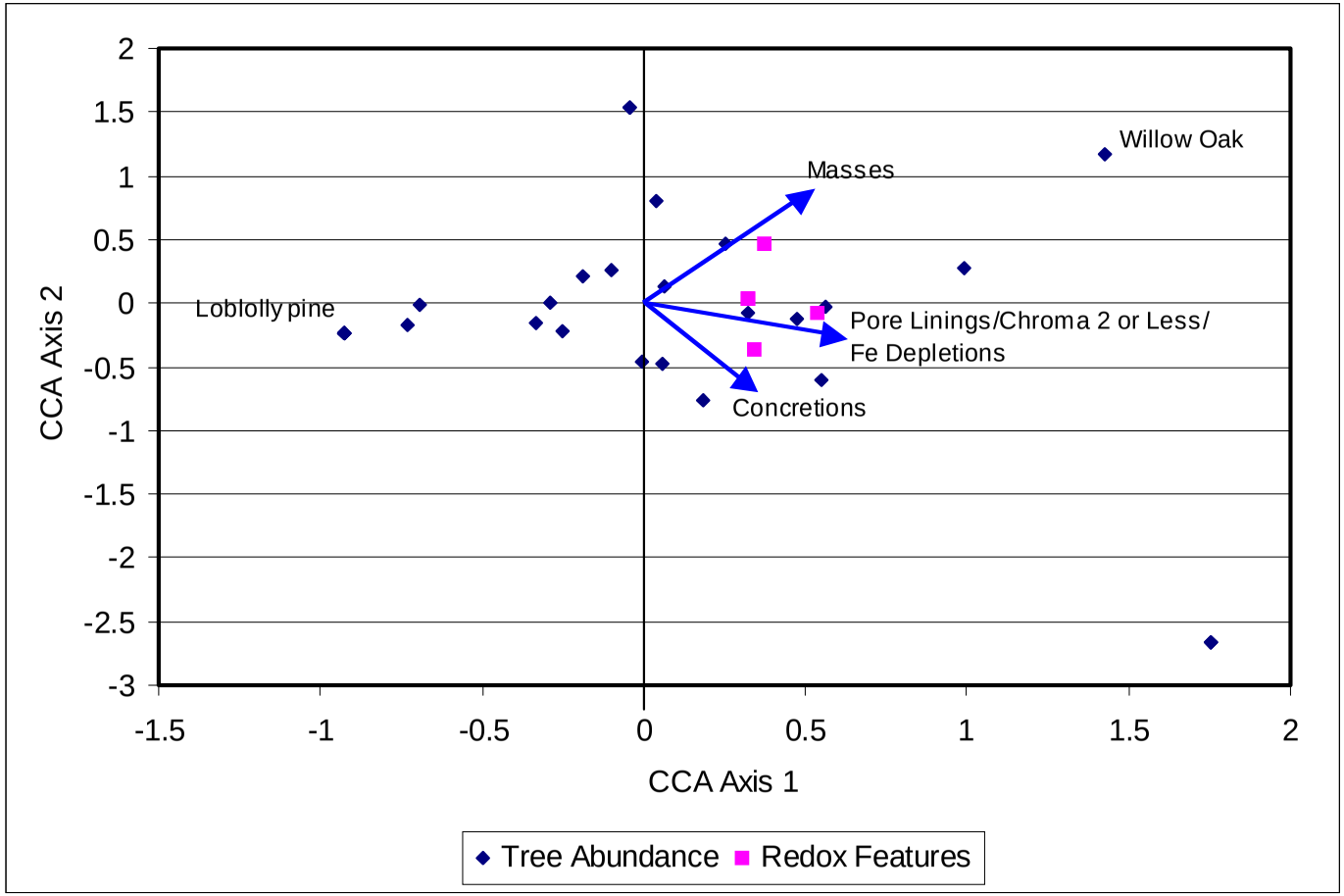

Figure 10. Redoximorphic features overlaying tree abundance by species using canonical correlation analysis (CCA), arrows represent direction of redoximorphic features with corresponding tree species, willow oak (facultative wetland species) and loblolly pine (facultative species) shown to illustrate gradient.

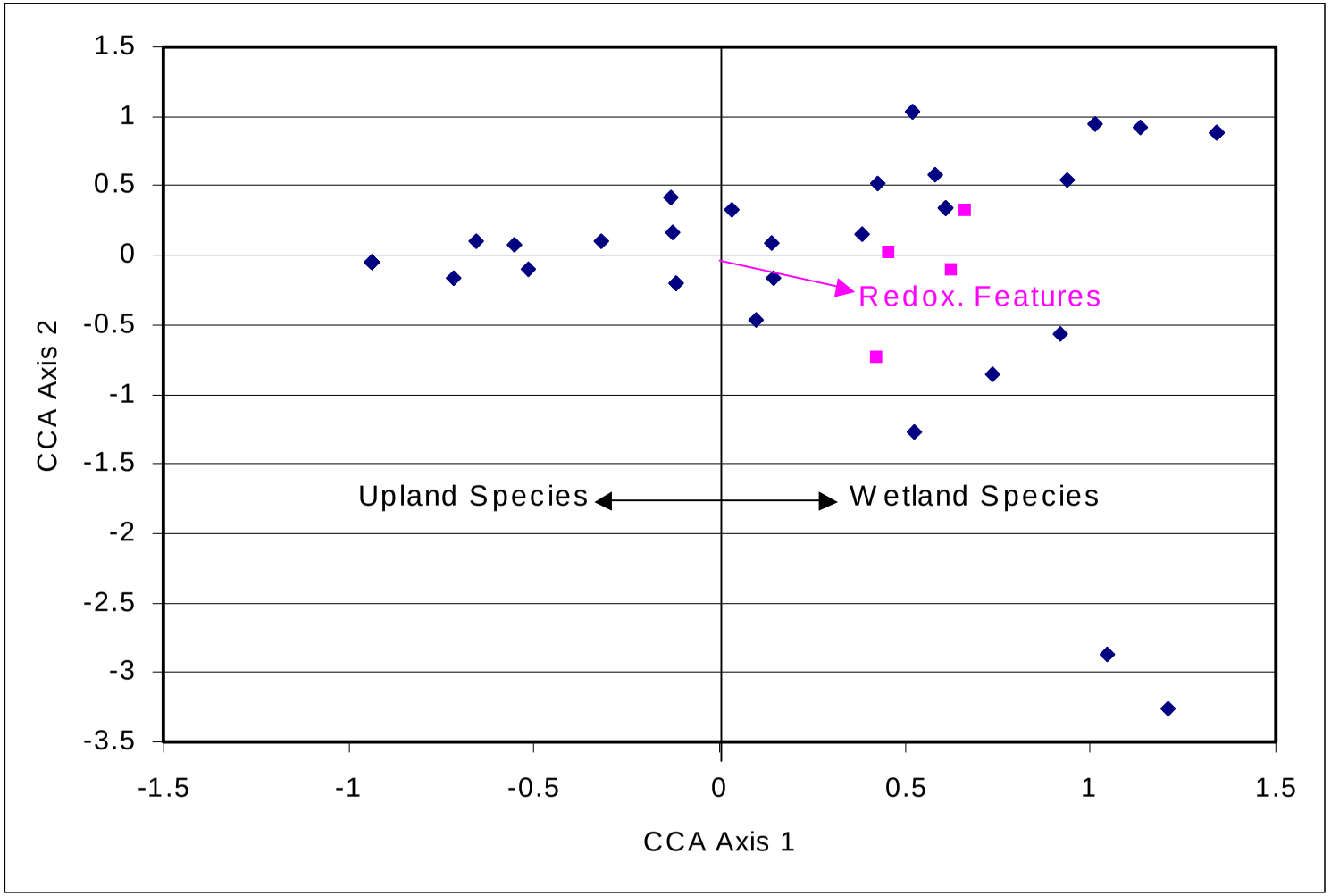

Figure 11. Redoximorphic features overlaying shrub abundance using canonical correlation analysis (CCA), arrow from centroid represents direction of redoximorphic features, zero on axis 1 represents break between upland and wetland shrub species.

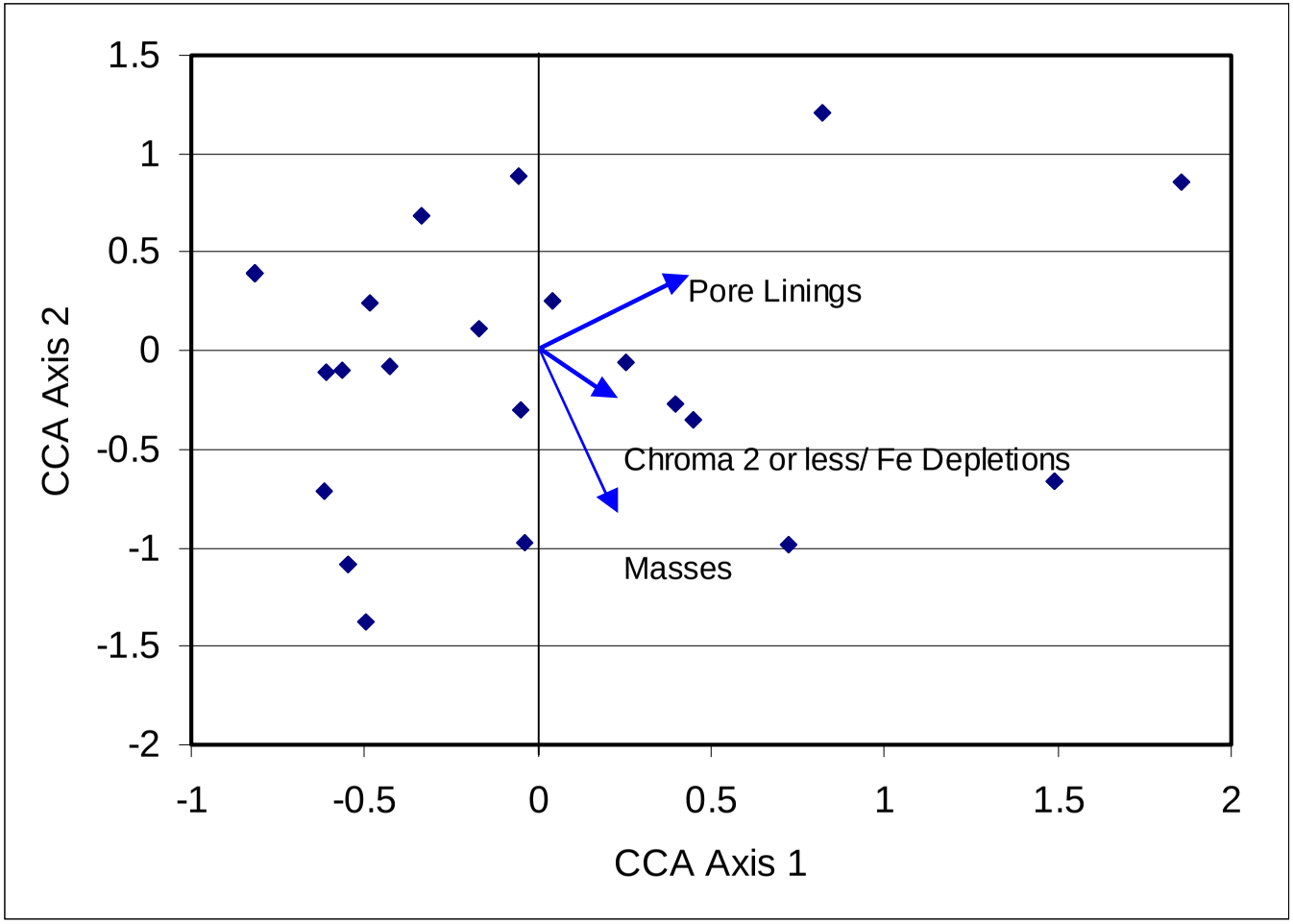

Figure 12. Redoximorphic features overlaying herbaceous abundance by coverage using canonical correlation analysis (CCA), arrows represent direction of redoximorphic features with corresponding herbaceous species.

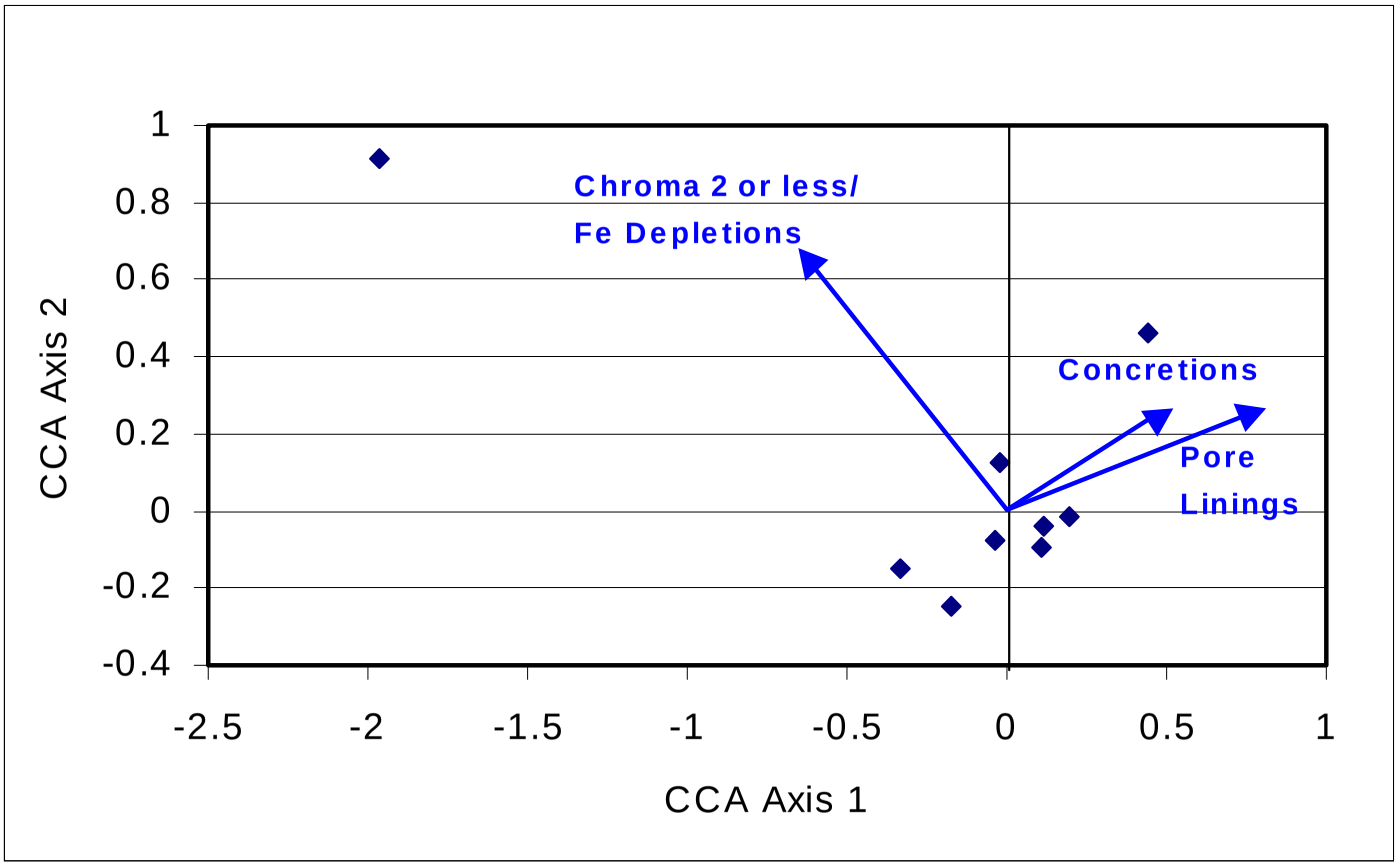

Figure 13. Redoximorphic features overlaying woody vines by abundance using canonical correlation analysis (CCA), arrows represent direction of redoximorphic features with corresponding woody vine species.

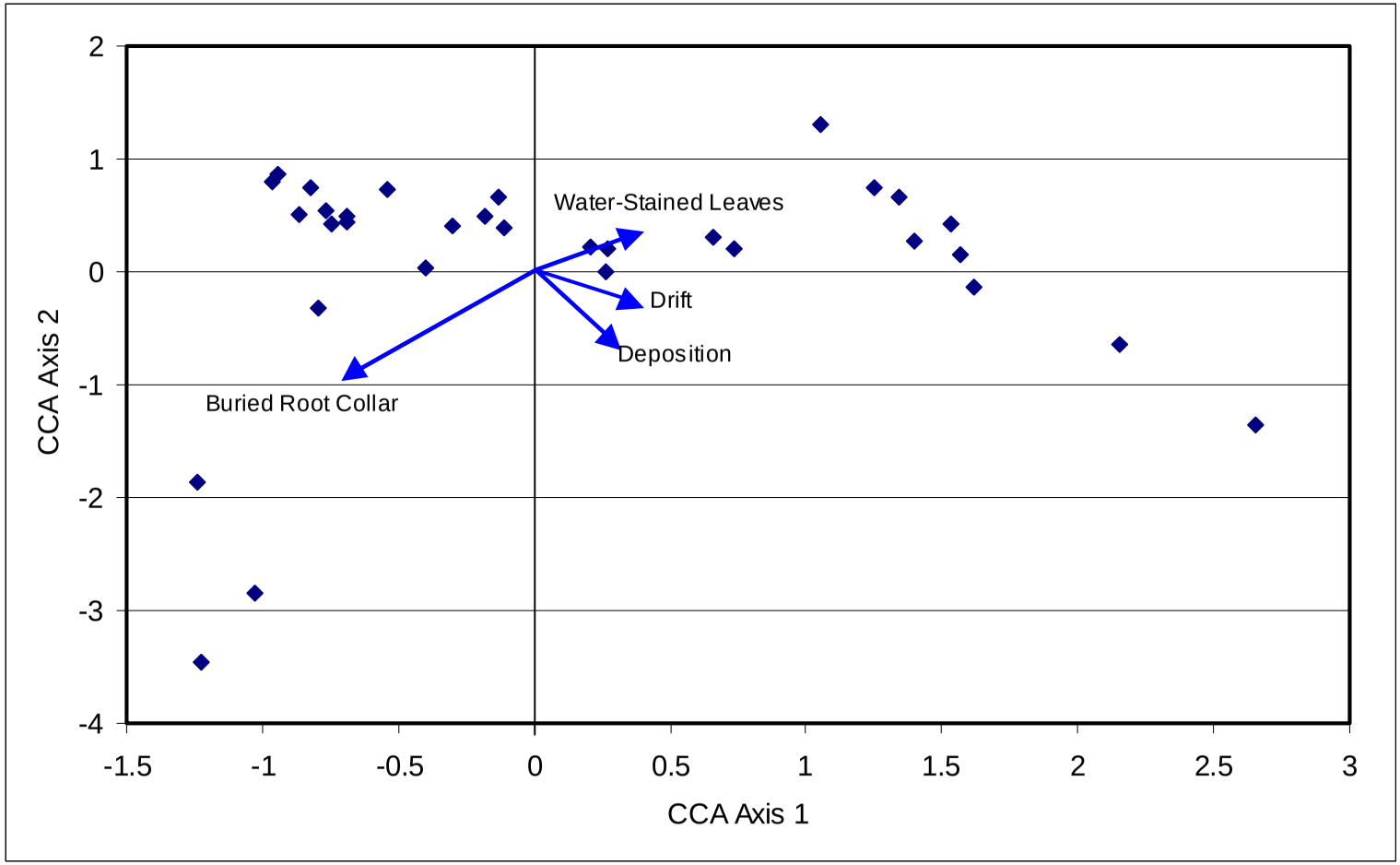

Figure 14. Hydrologic indicators overlaying tree species by abundance using canonical correlation analysis (CCA), arrows represent direction of hydrologic indicators with corresponding tree species.

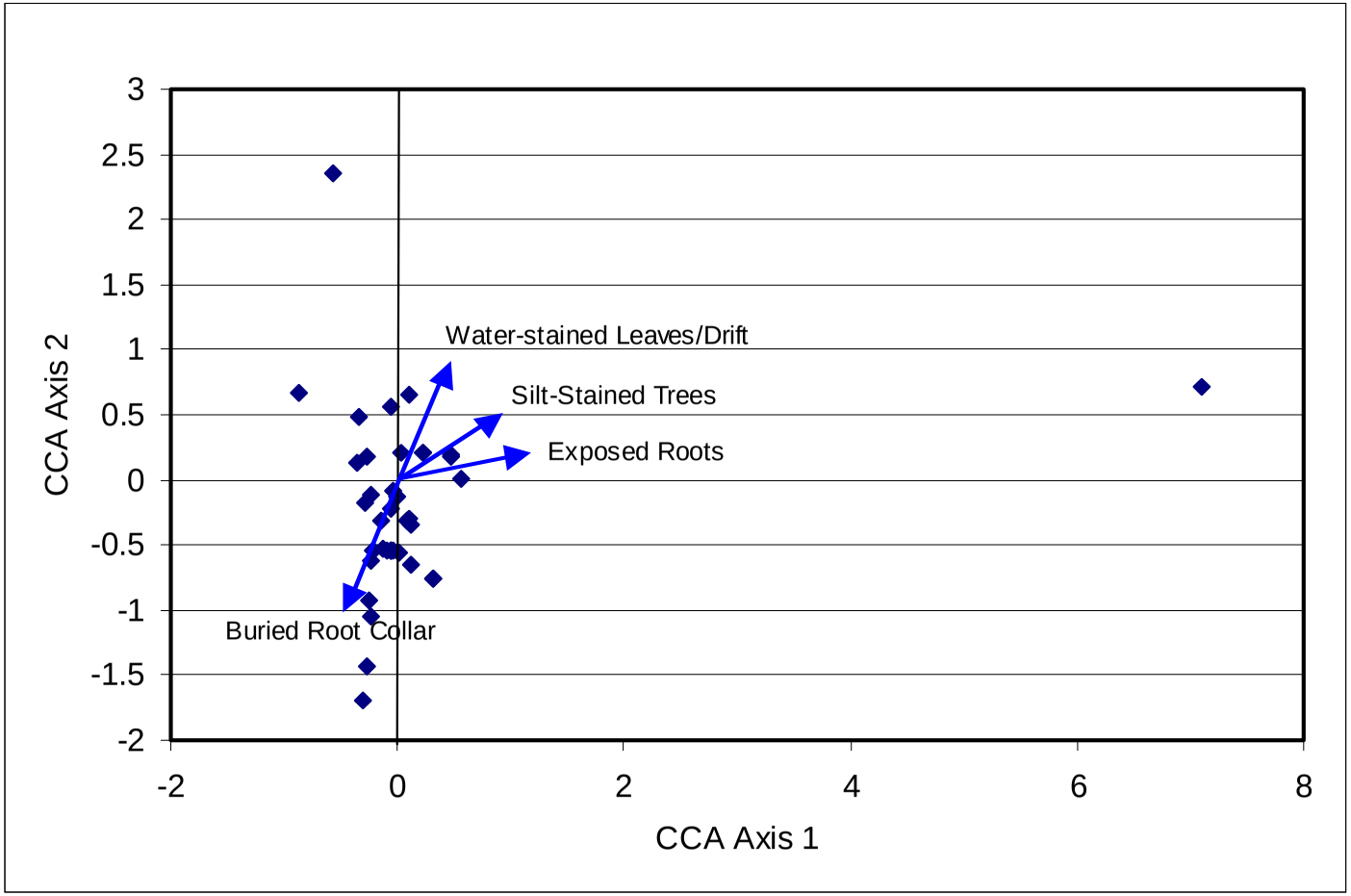

Figure 15. Hydrologic indicators overlaying shrub abundance using canonical correlation analysis (CCA), arrows represent direction of hydrologic indicators with corresponding shrub species.

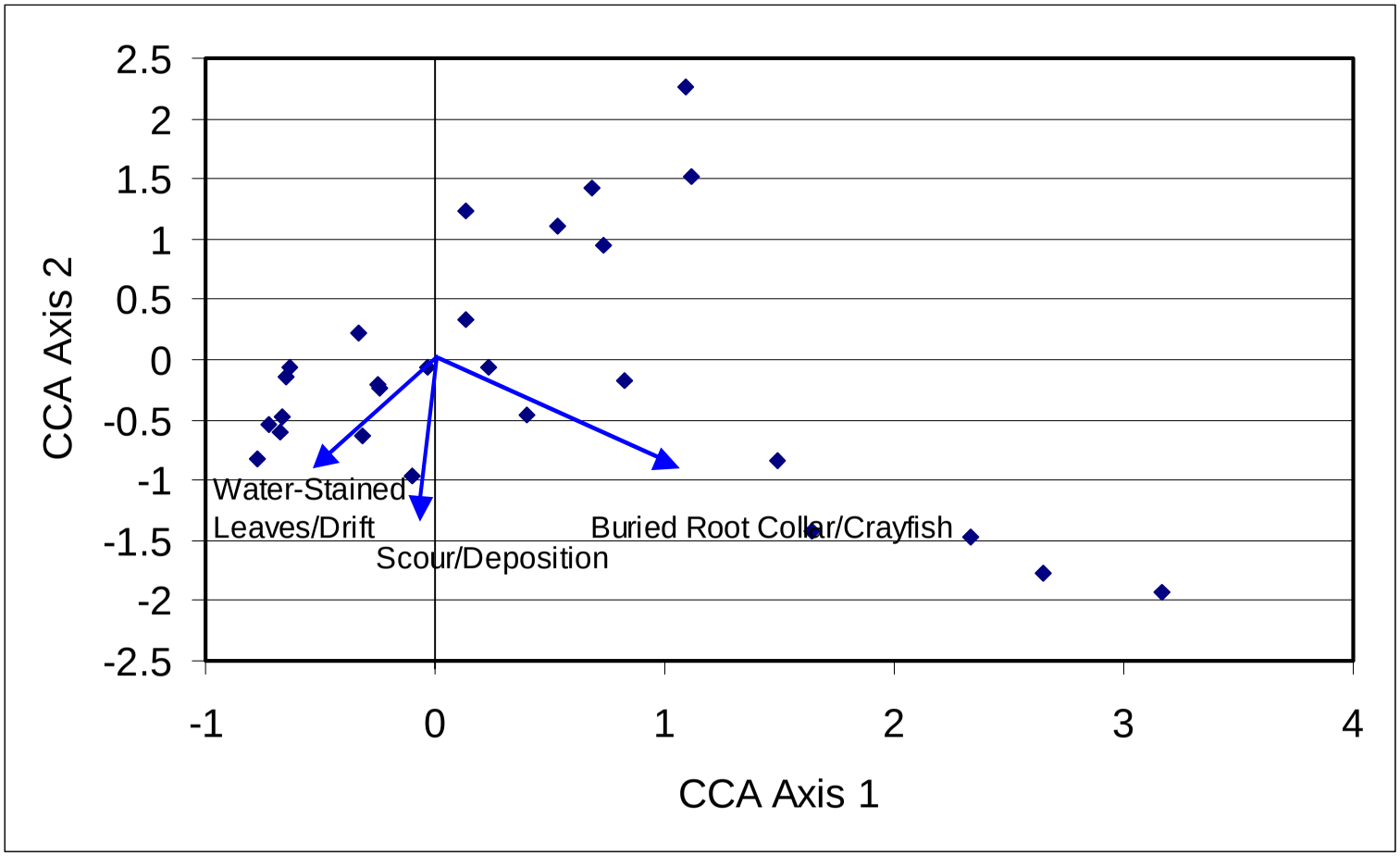

Figure 16. Hydrologic indicators overlaying herbaceous vegetation abundance by coverage using canonical correlation analysis (CCA), arrows represent direction of hydrologic indicators with corresponding herbaceous species.

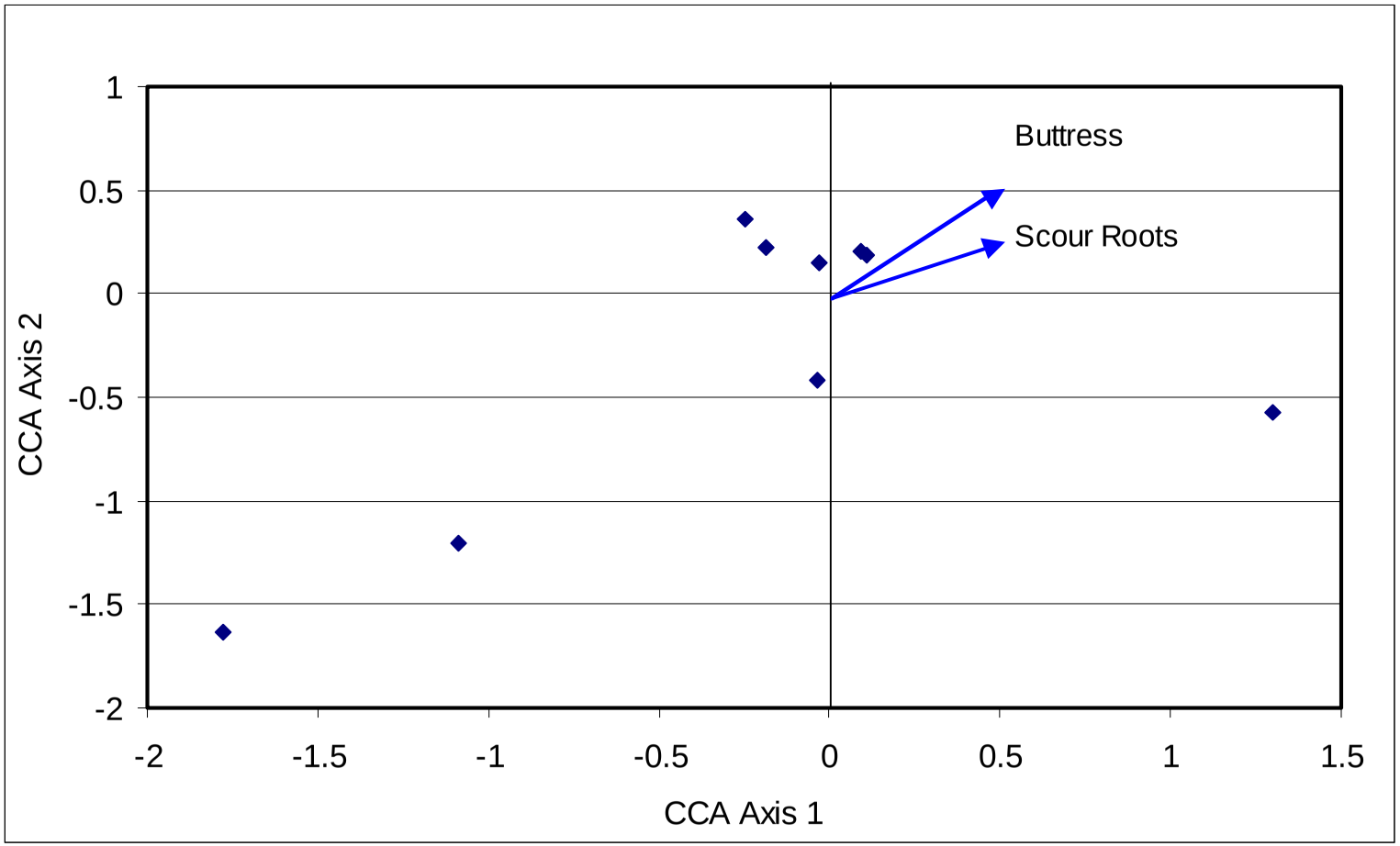

Figure 17. Hydrologic indicators overlaying woody vines by abundance using canonical correlation analysis (CCA), arrows represent direction of hydrologic indicators with corresponding woody vines species.

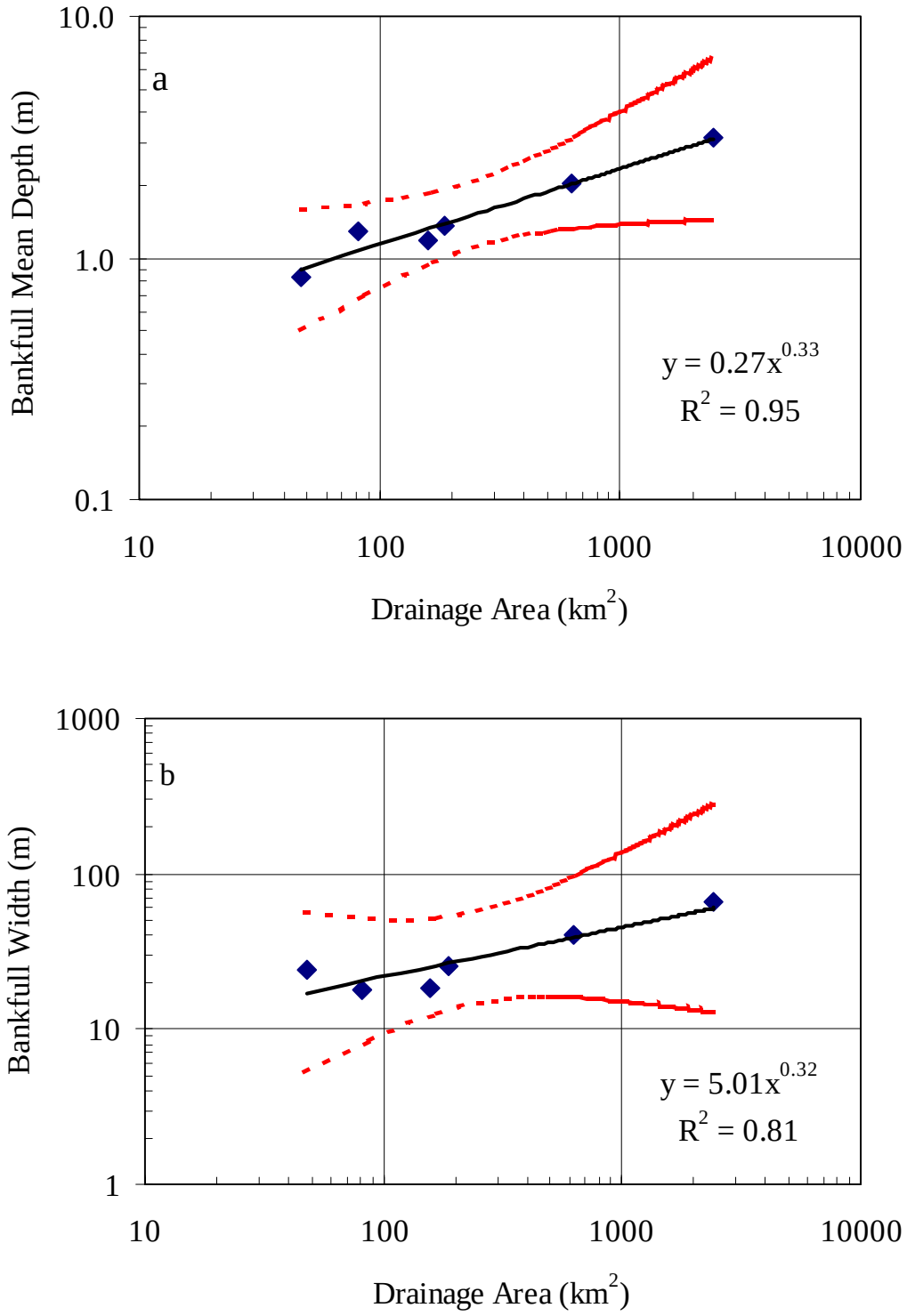

Figure 18. Piedmont regional hydraulic curves on log-log scales, a. mean bankfull depth and b. bankfull width plotted against drainage area.

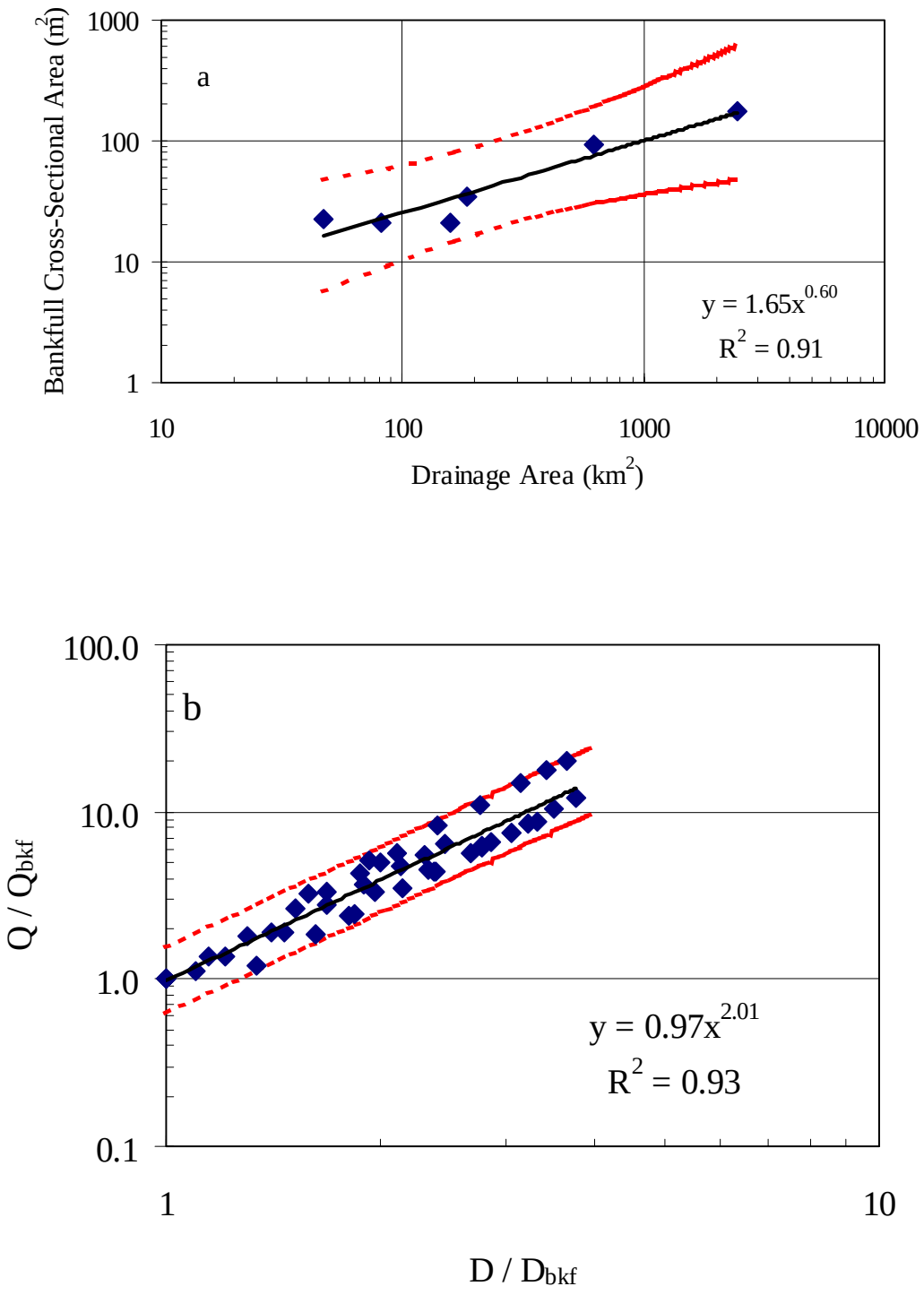

Figure 19. Piedmont regional hydraulic curves on log-log scales, a. bankfull cross-sectional area plotted against drainage area and b. Piedmont dimensionless rating curve. Dotted lines represent upper and lower 95% confidence intervals, Q = discharge at at given depth (D), Q_{bkf} = bankfull discharge, D_{bkf} = mean depth at bankfull.

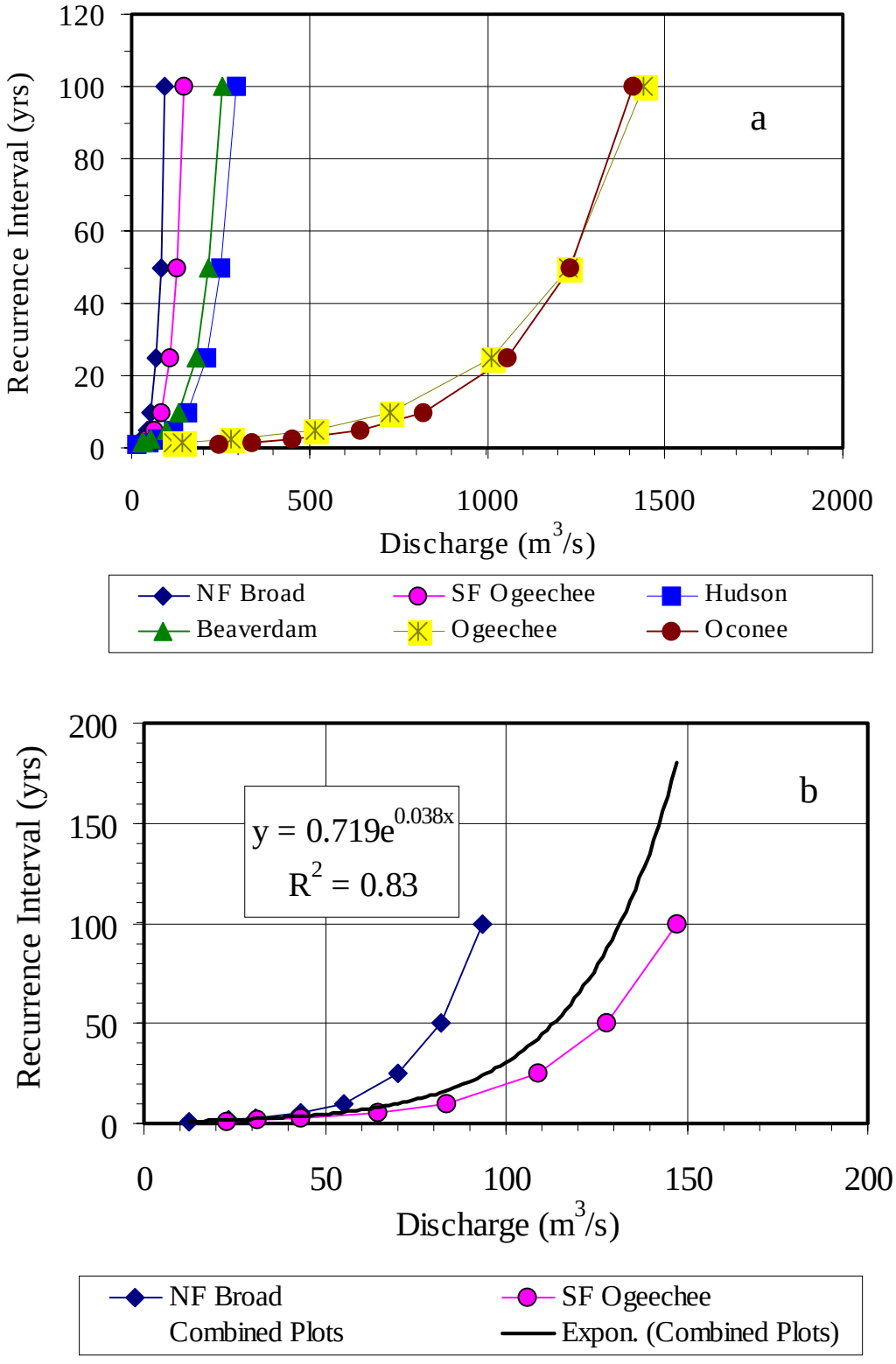

Figure 20. Recurrence interval plotted against discharge, a. all gaging stations and b. drainage area 0 to 130 km^2.

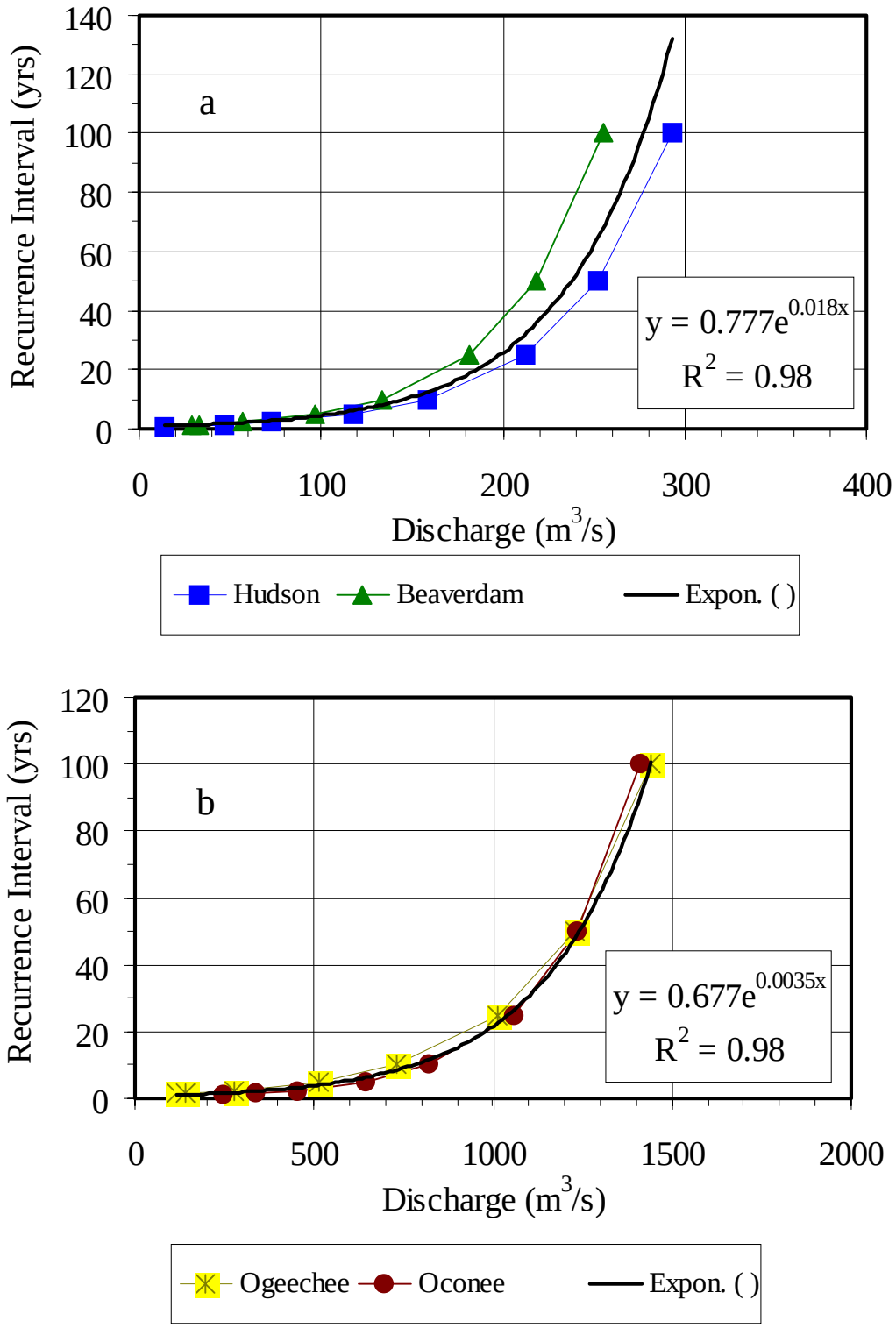

Figure 21. Recurrence interval plotted against discharge, a. drainage area 130 to 518 km^2 and b. drainage areas greater than 518 km^2.

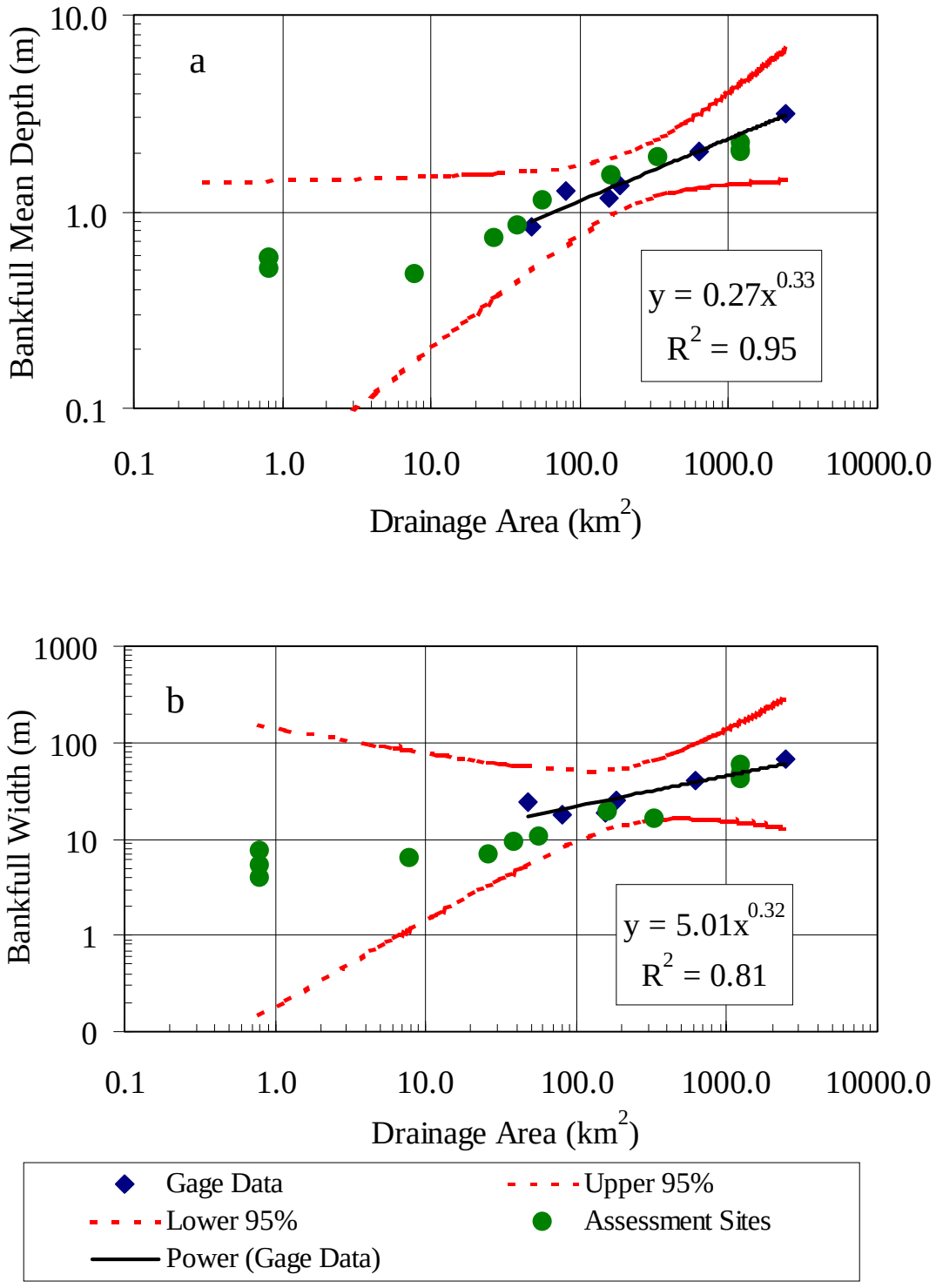

Figure 22. Regional assessment sites overlaying Piedmont regional hydraulic geometry curves on log-log scales, a. bankfull mean depth and b. bankfull width plotted against drainage area.

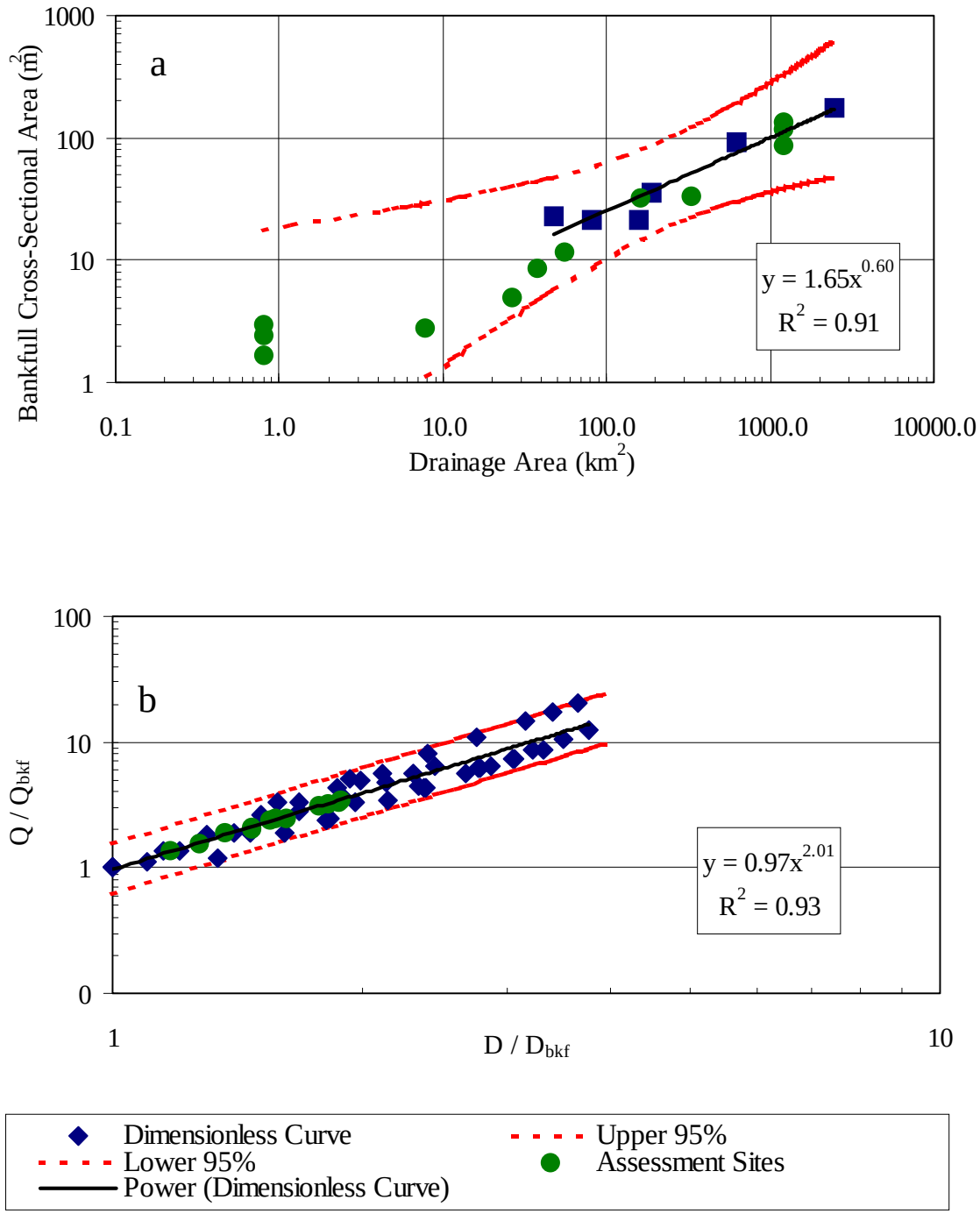

Figure 23. Regional assessment sites overlaying Piedmont regional hydraulic geometry curves on log-log scales, a. bankfull cross-sectional area plotted against drainage area and b. Piedmont dimensionless rating curve, Q = discharge at a given depth (D), Q_{bkf} = bankfull discharge, D_{bkf} = mean depth at bankfull.

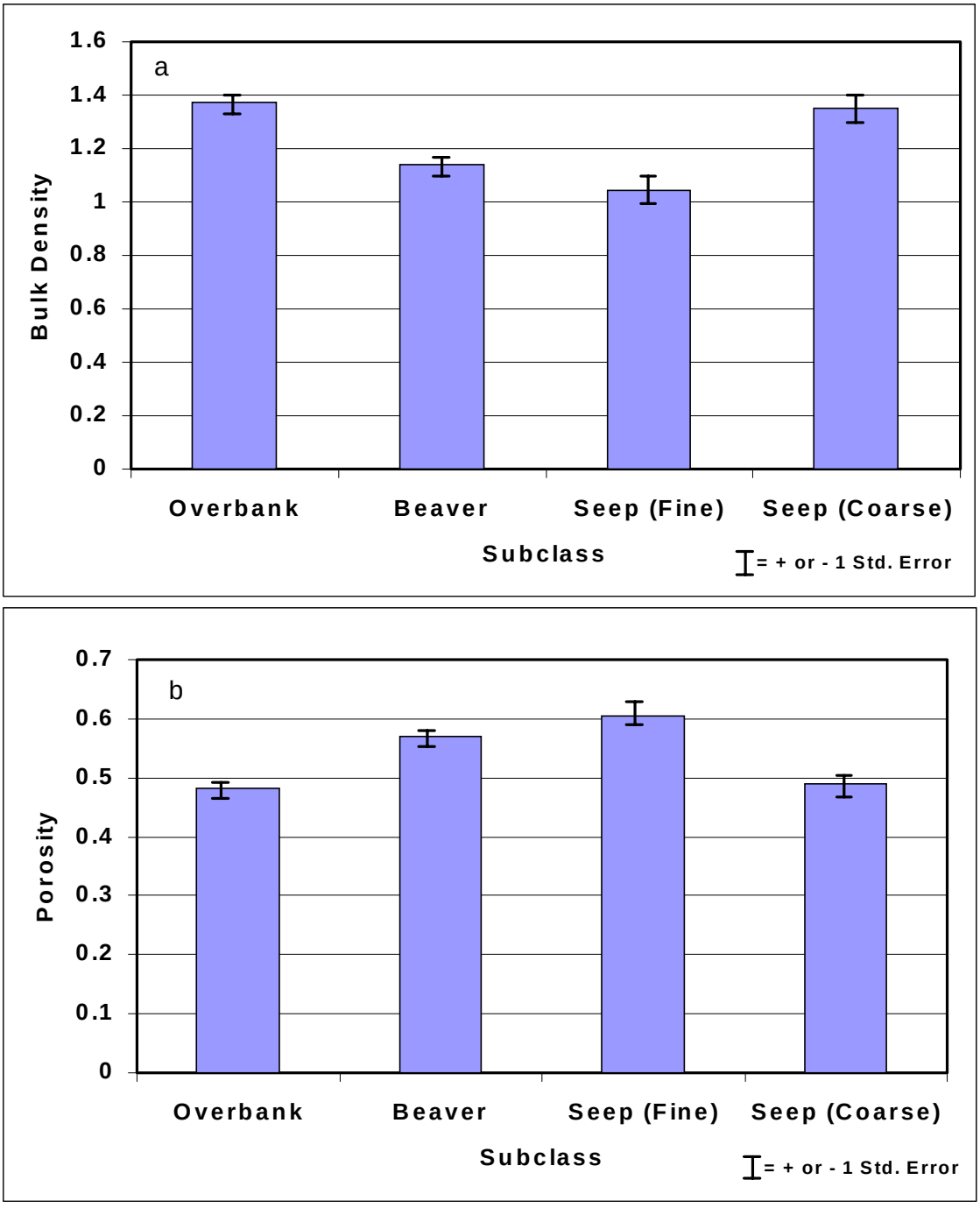

Figure 24. Comparison of a. bulk density and b. porosity across HGM subclasses.

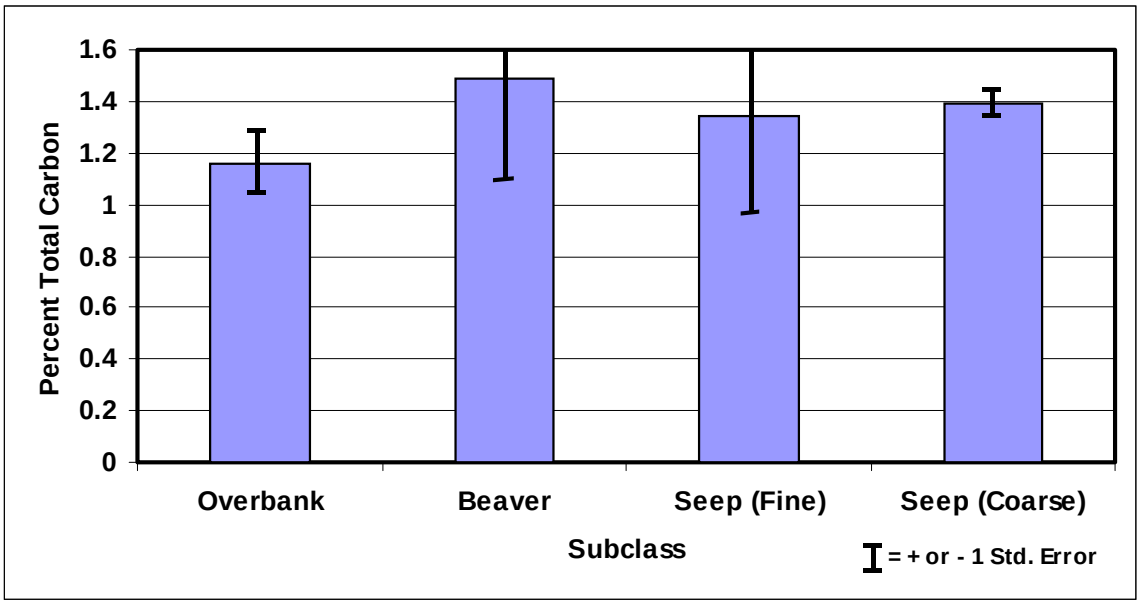

Figure 25. Comparison of percent total carbon across HGM subclasses.

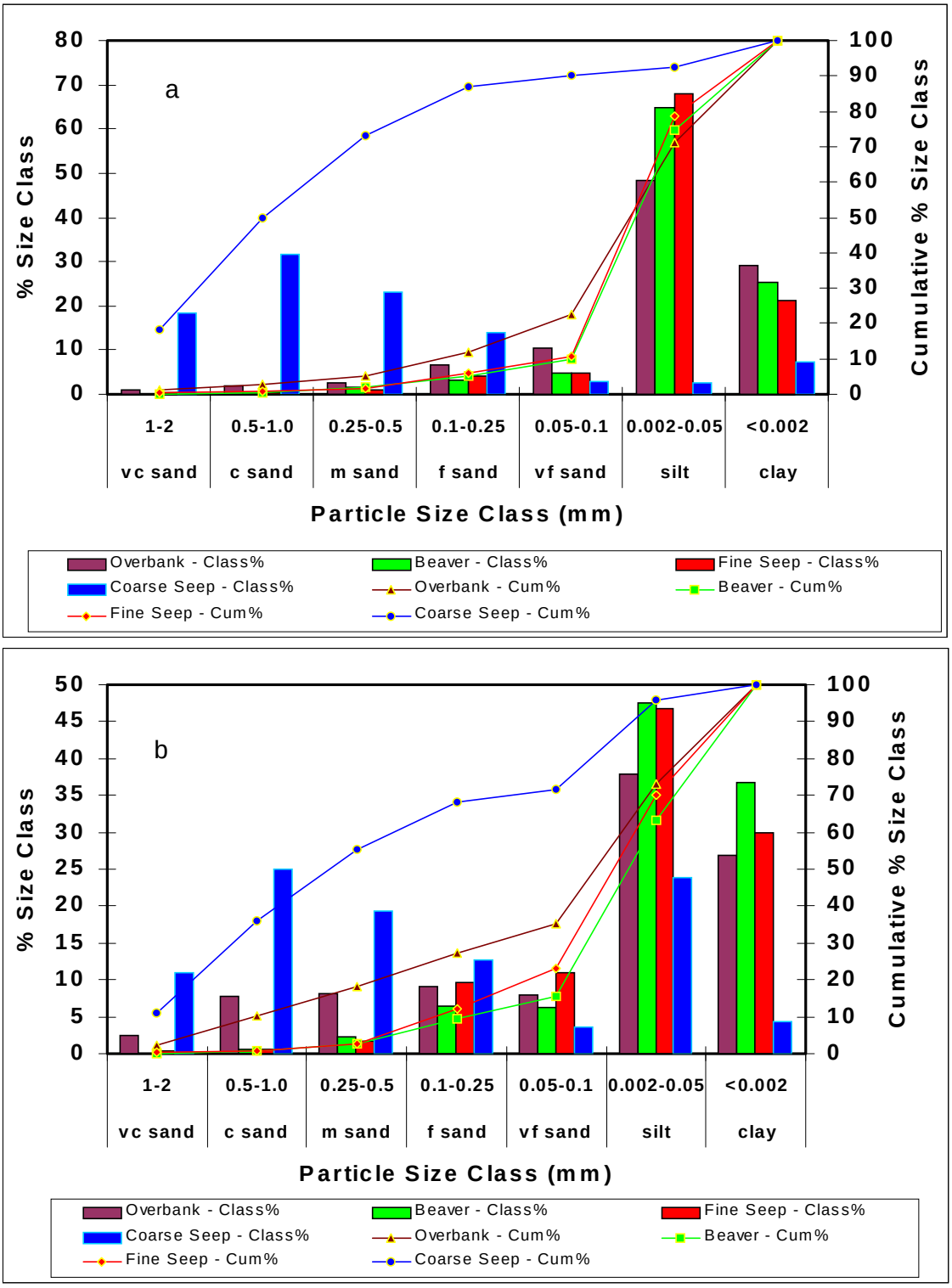

Figure 26. Comparison of particle size class distribution with HGM subclasses, a. surface horizon, and b. subsurface horizon.

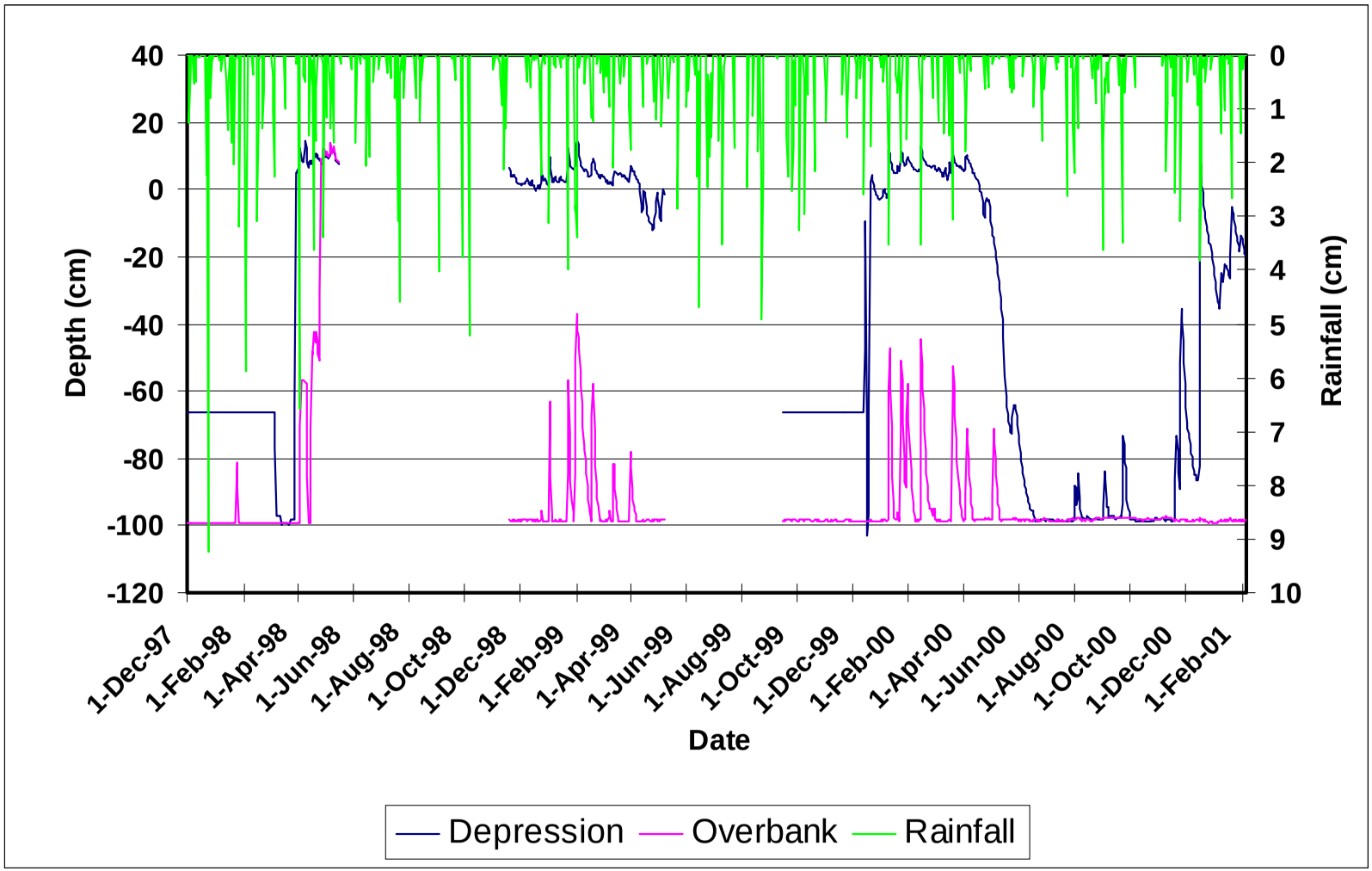

Figure 27. Water table and rainfall plotted over the research period, Deans Pond Research Site.

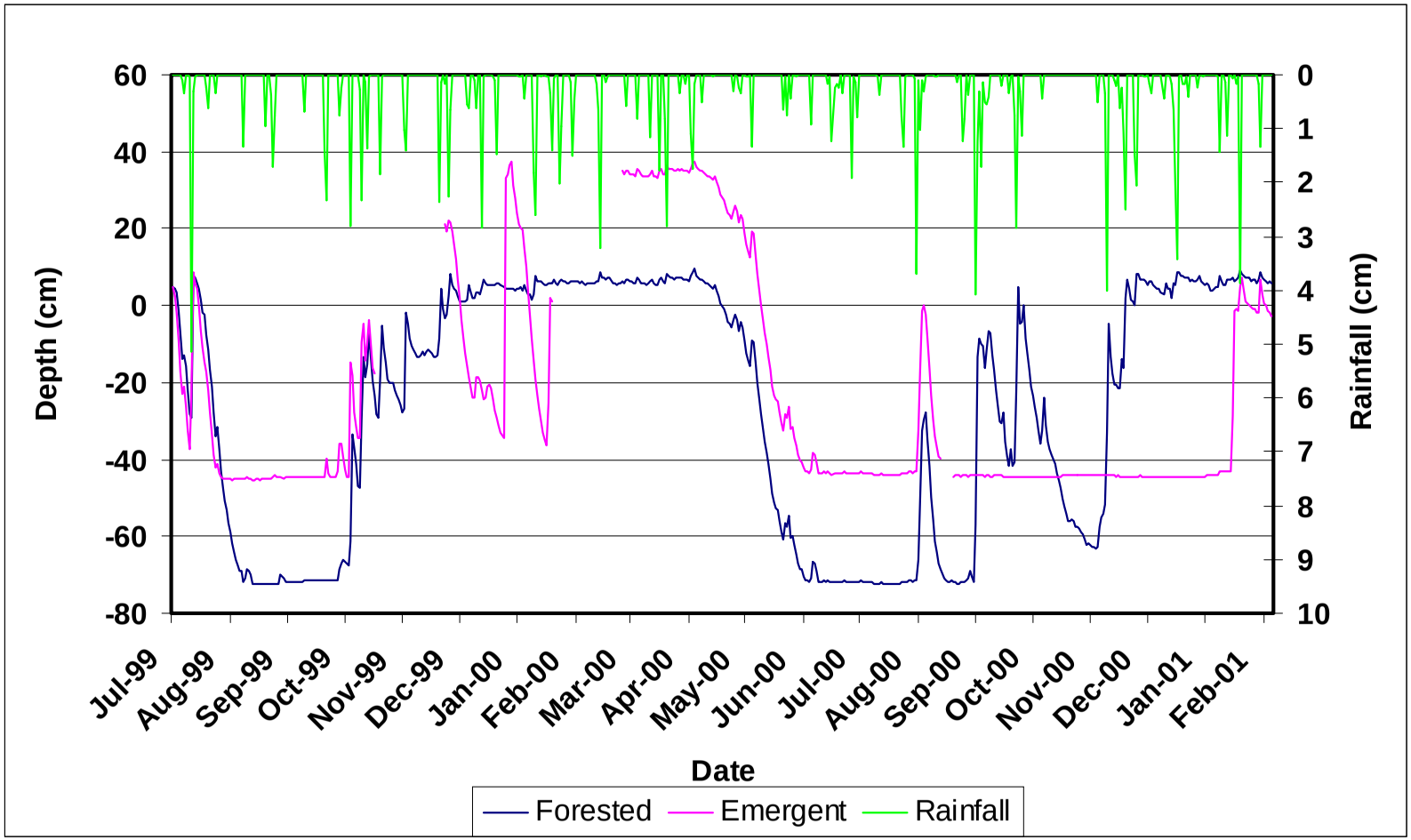

Figure 28. Water table and rainfall plotted over the research period, Plant Science Research Farm.

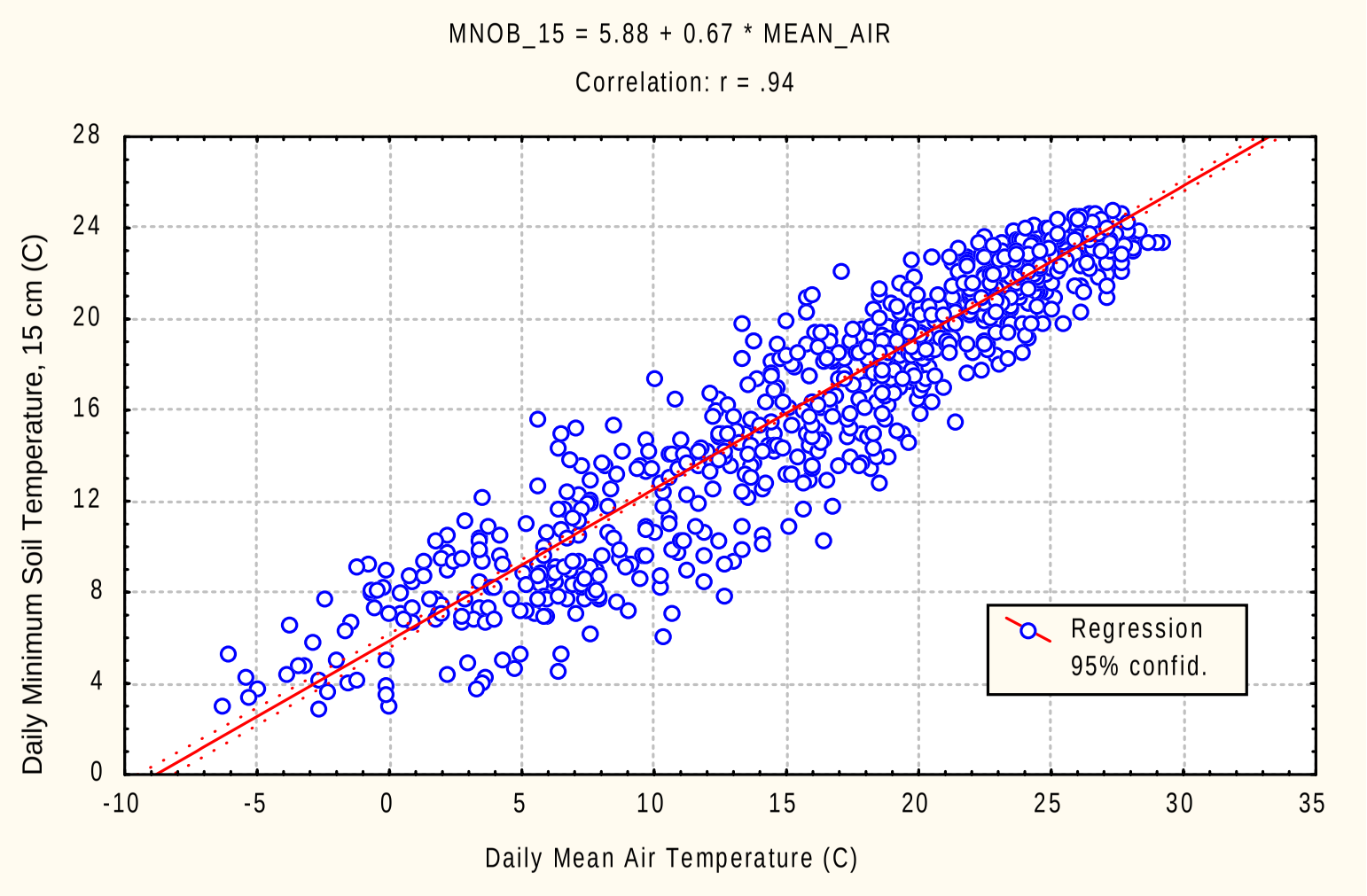

Figure 29. Relationship between daily minimum soil temperature and daily mean air temperature, DPRS overbank, 15 cm depth.

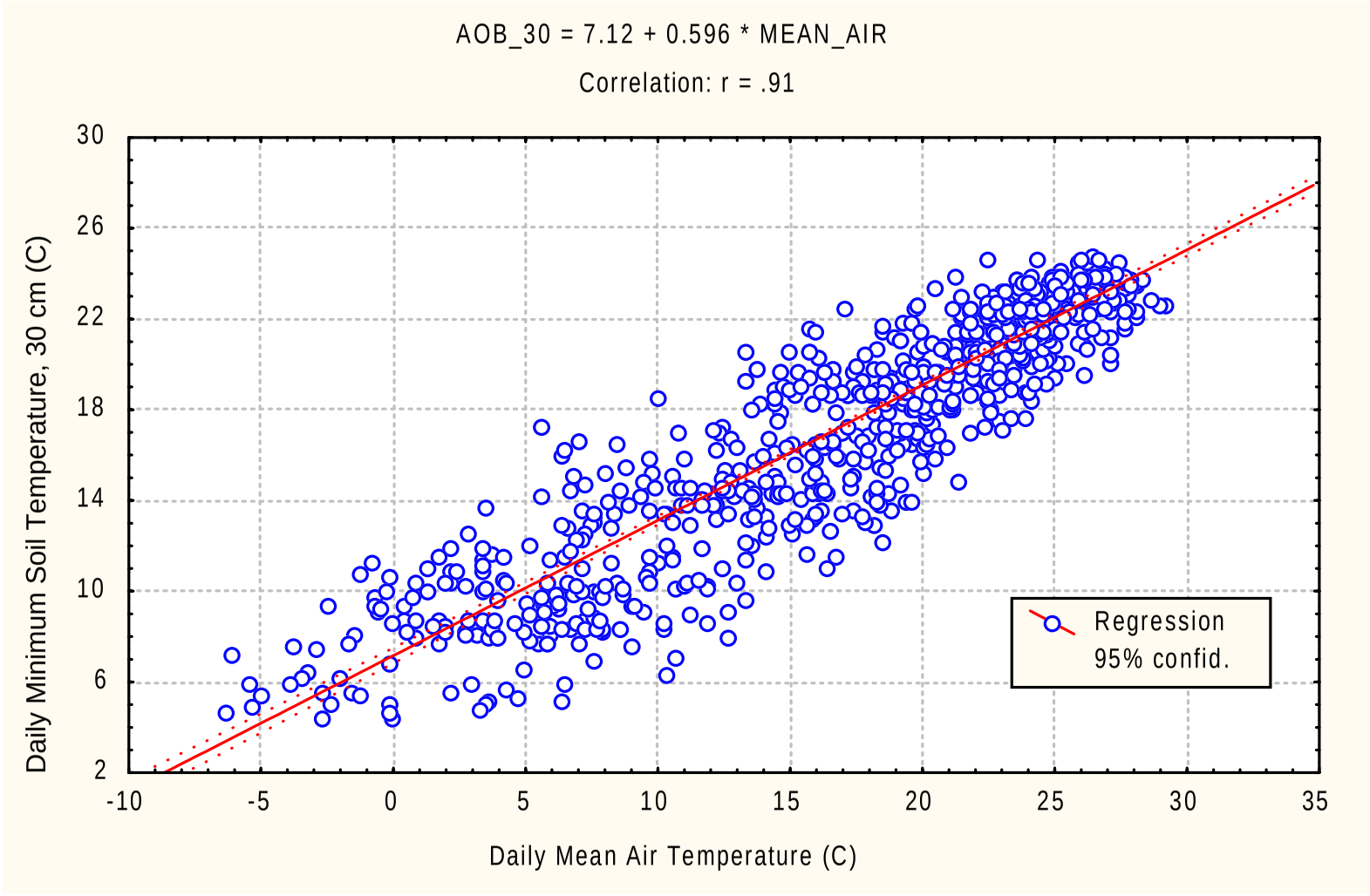

Figure 30. Relationship between daily minimum soil temperature and daily mean air temperature, DPRS overbank, 30 cm depth.

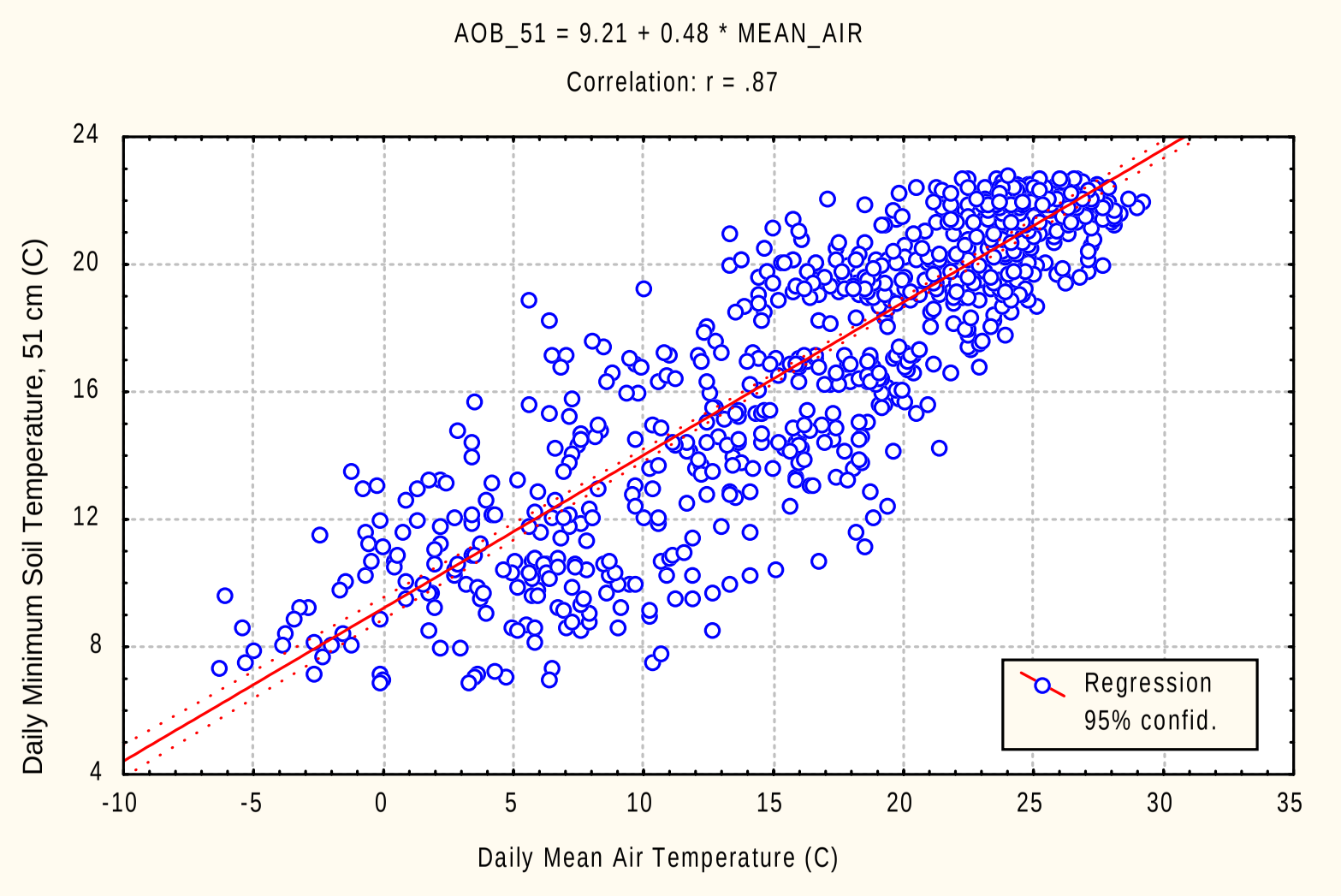

Figure 31. Relationship between daily minimum soil temperature and daily mean air temperature, DPRS overbank, 51 cm depth.

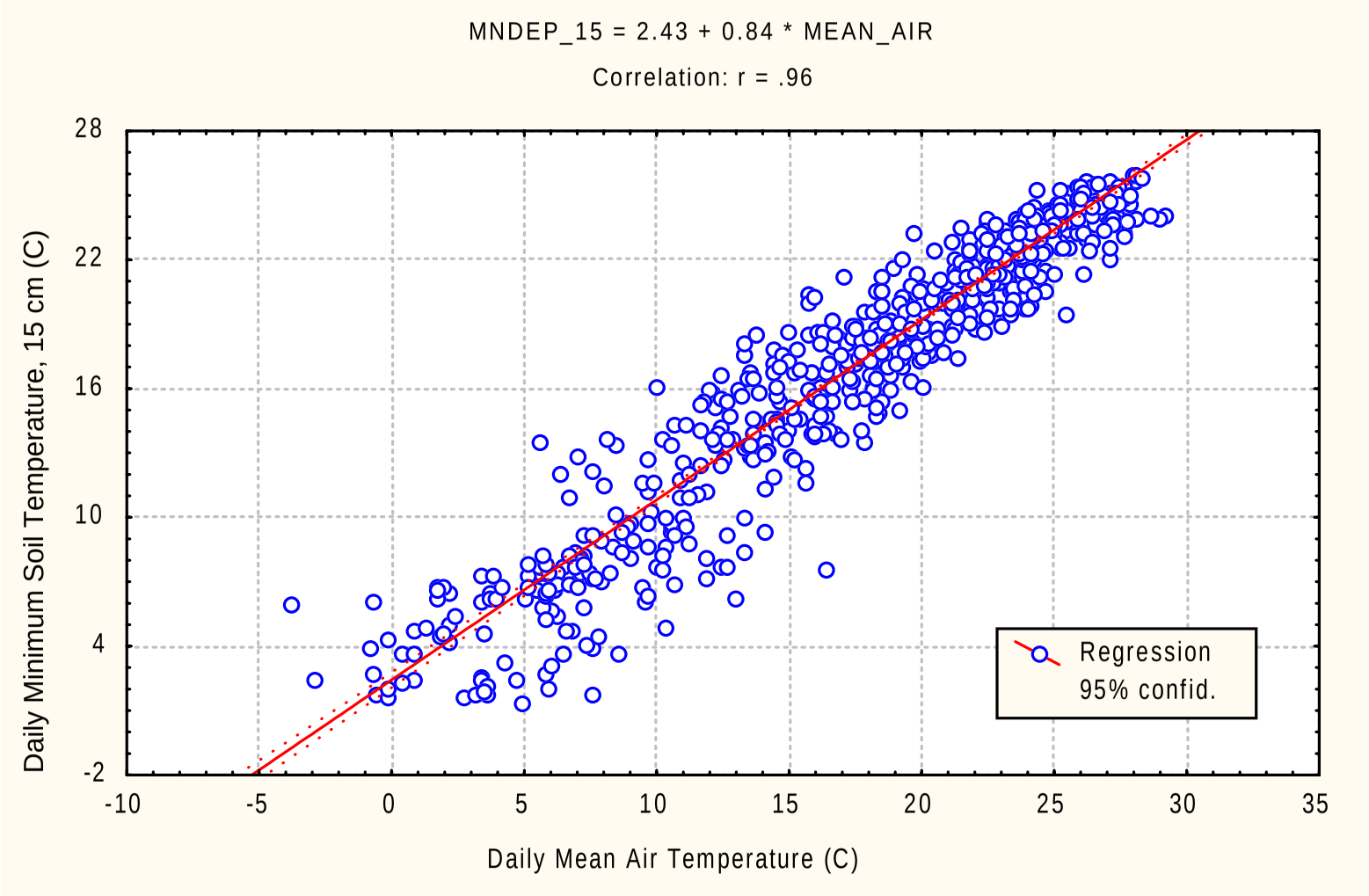

Figure 32. Relationship between daily minimum soil temperature and daily mean air temperature, DPRS depression, 15 cm depth.

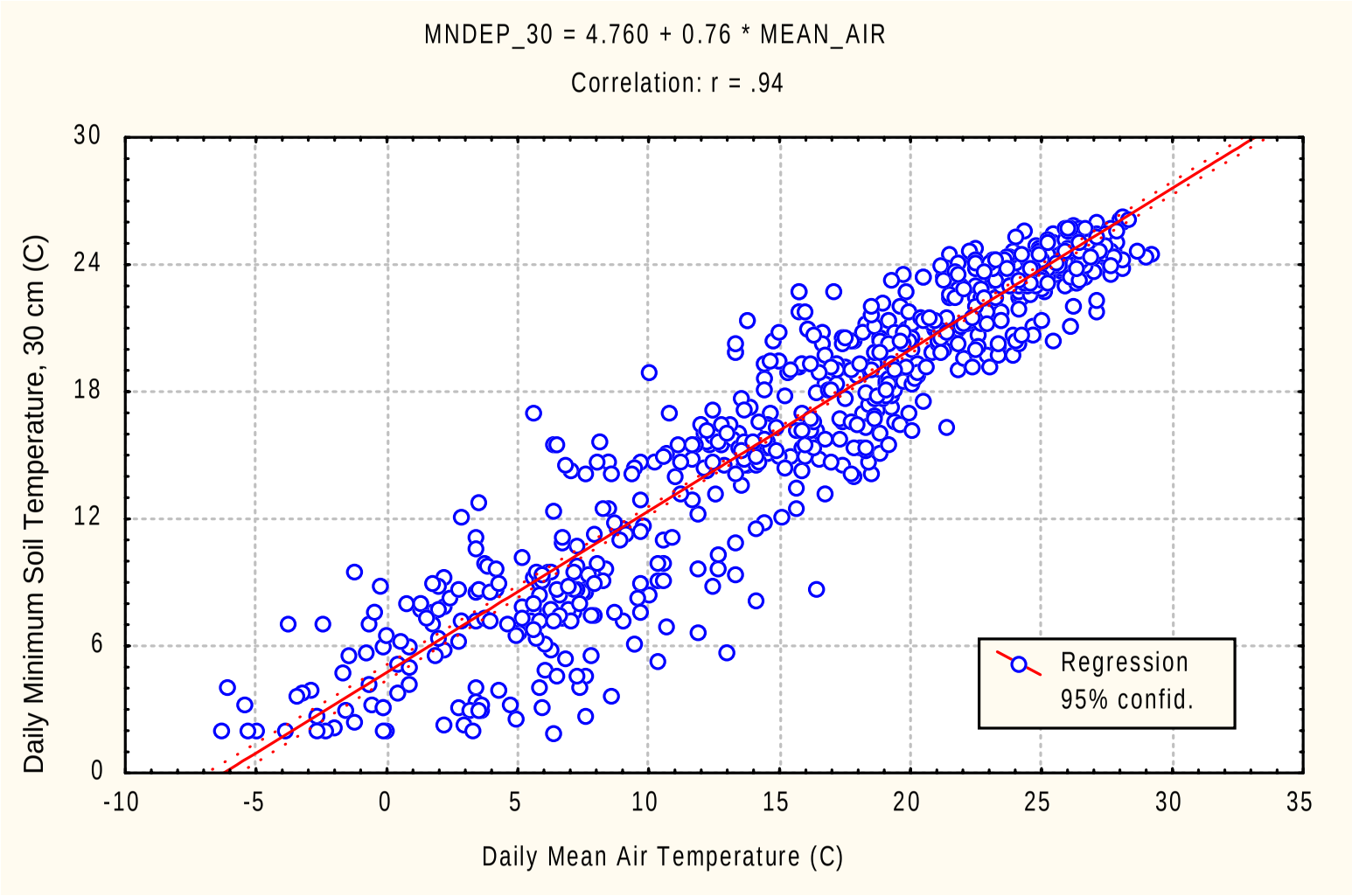

Figure 33. Relationship between daily minimum soil temperature and daily mean air temperature, DPRS depression, 30 cm depth.

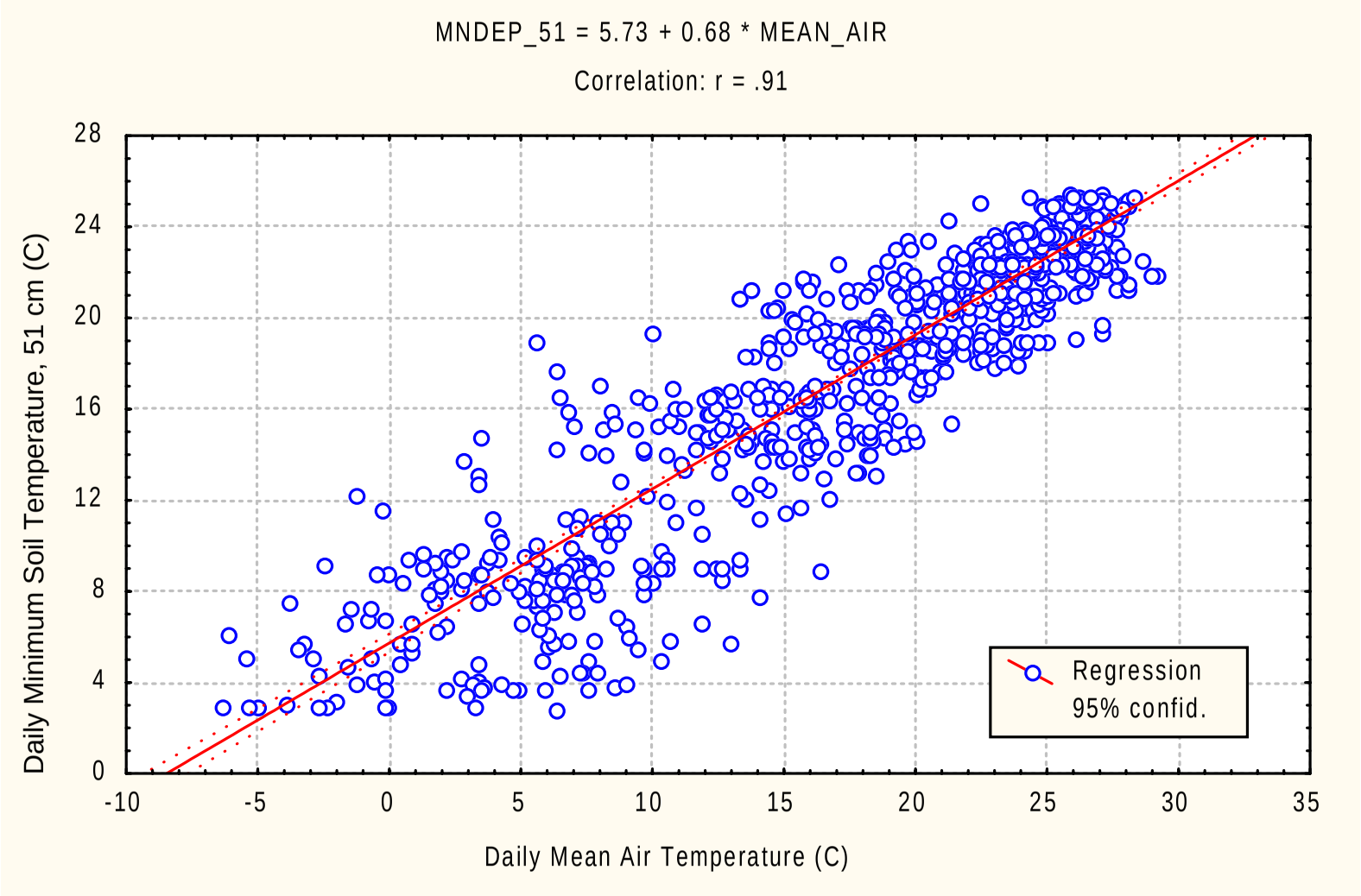

Figure 34. Relationship between daily minimum soil temperature and daily mean air temperature, DPRS depression, 51 cm depth.

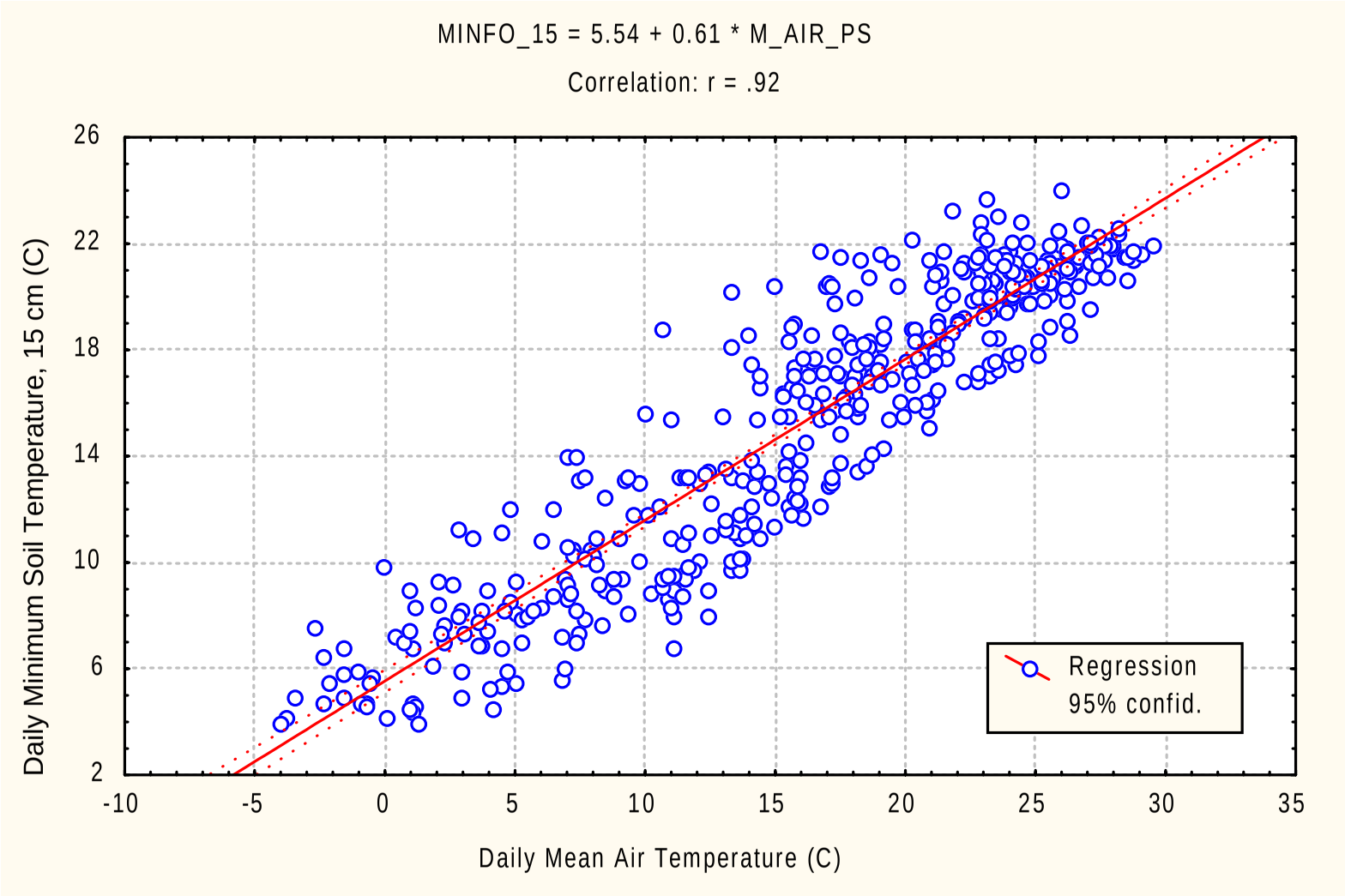

Figure 35. Relationship between daily minimum soil temperature and daily mean air temperature, PSRF forested, 15 cm depth.

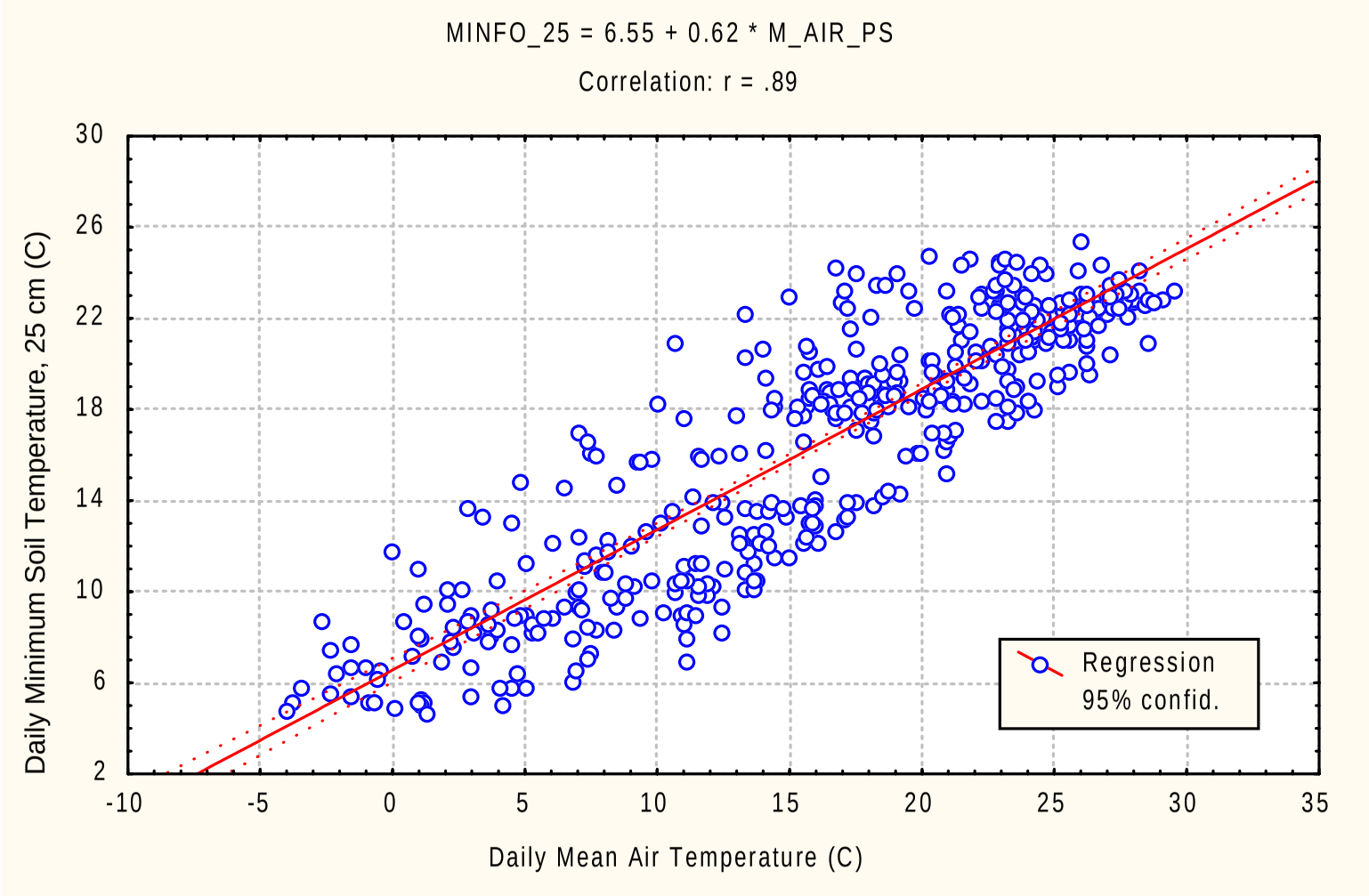

Figure 36. Relationship between daily minimum soil temperature and daily mean air temperature, PSRF forested, 25 cm depth.

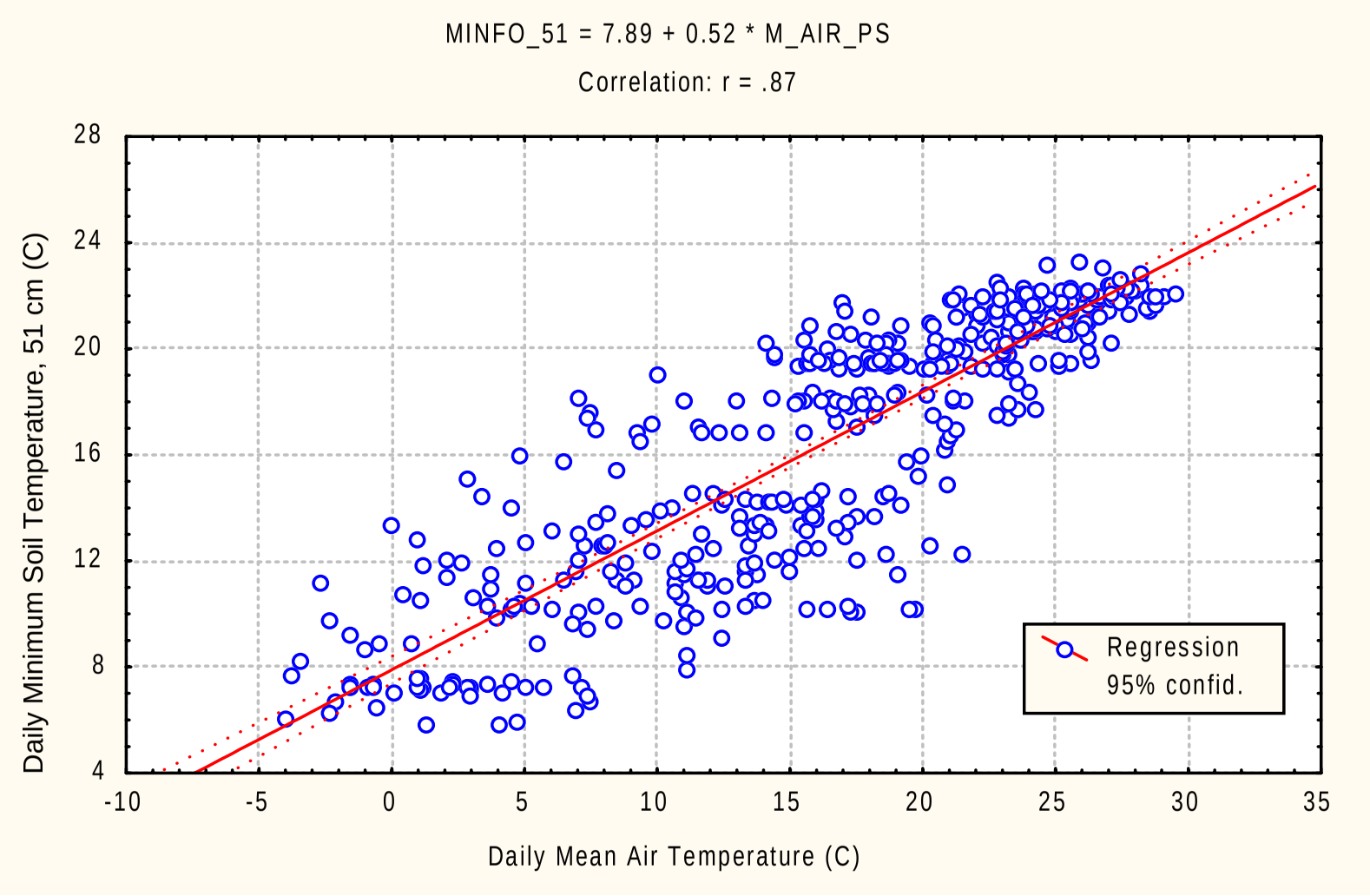

Figure 37. Relationship between daily minimum soil temperature and daily mean air temperature, PSRF forested, 51 cm depth.

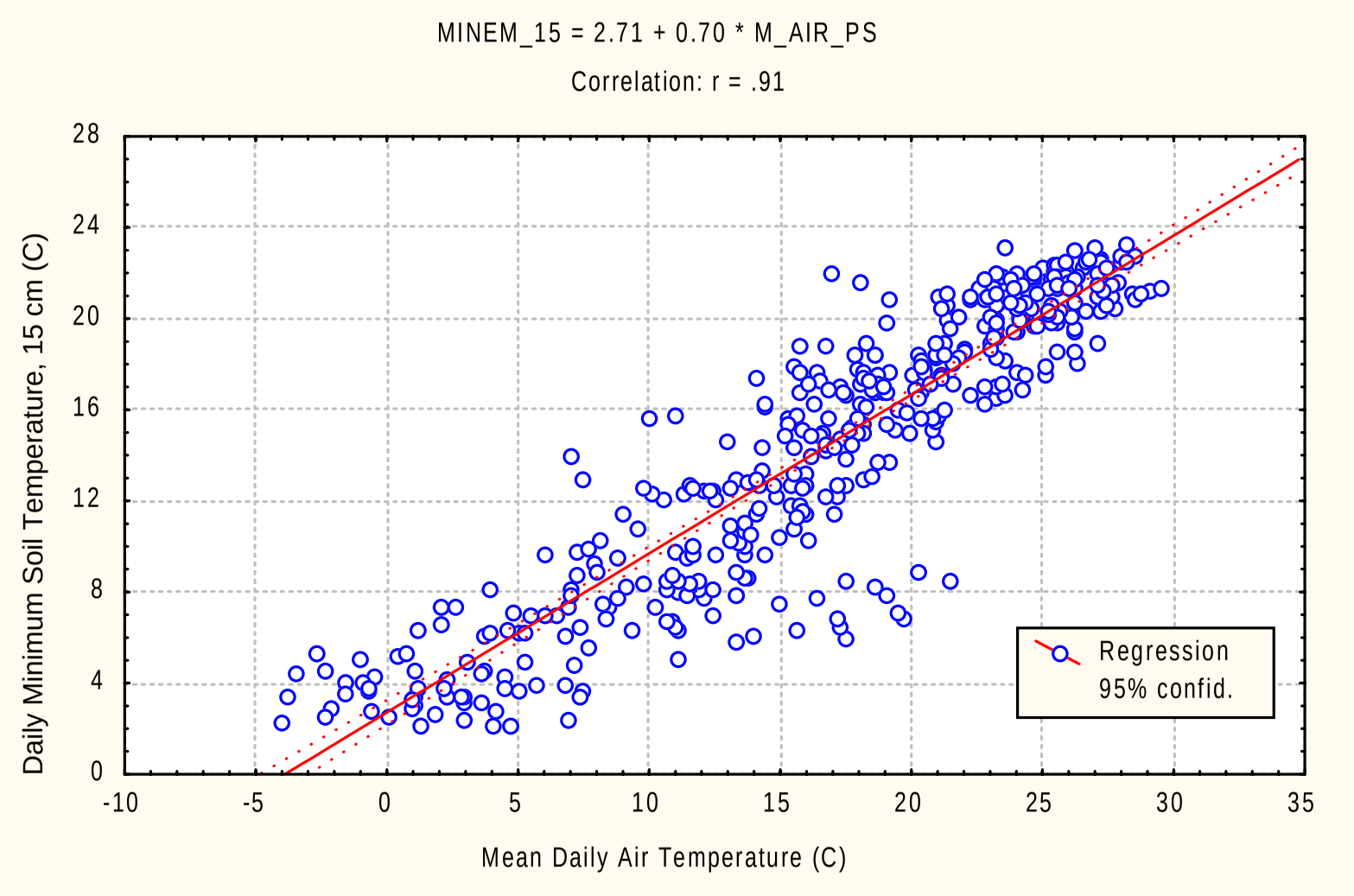

Figure 38. Relationship between daily minimum soil temperature and daily mean air temperature, PSRF emergent, 15 cm depth.

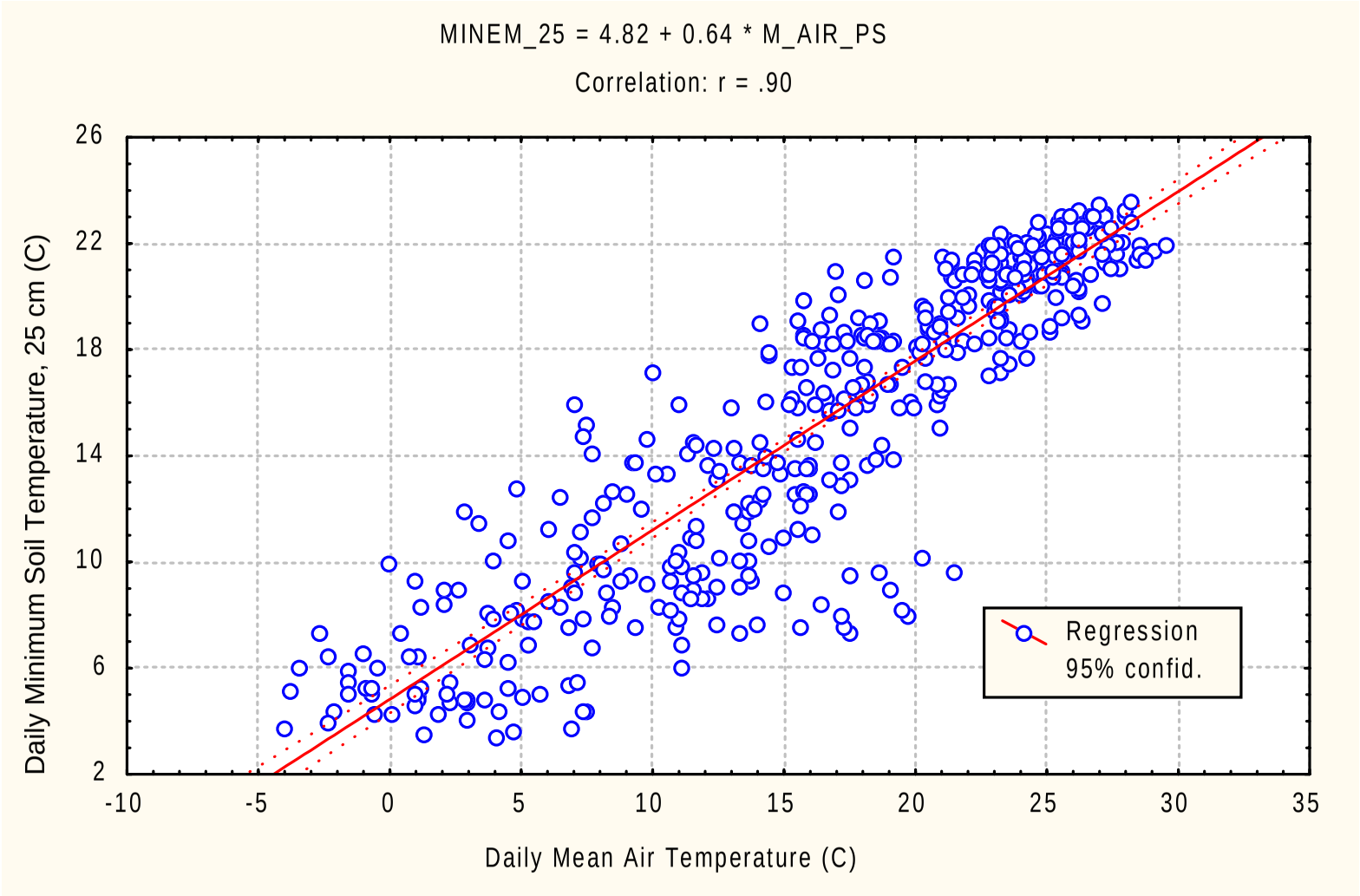

Figure 39. Relationship between daily minimum soil temperature and daily mean air temperature, PSRF emergent, 25 cm depth.

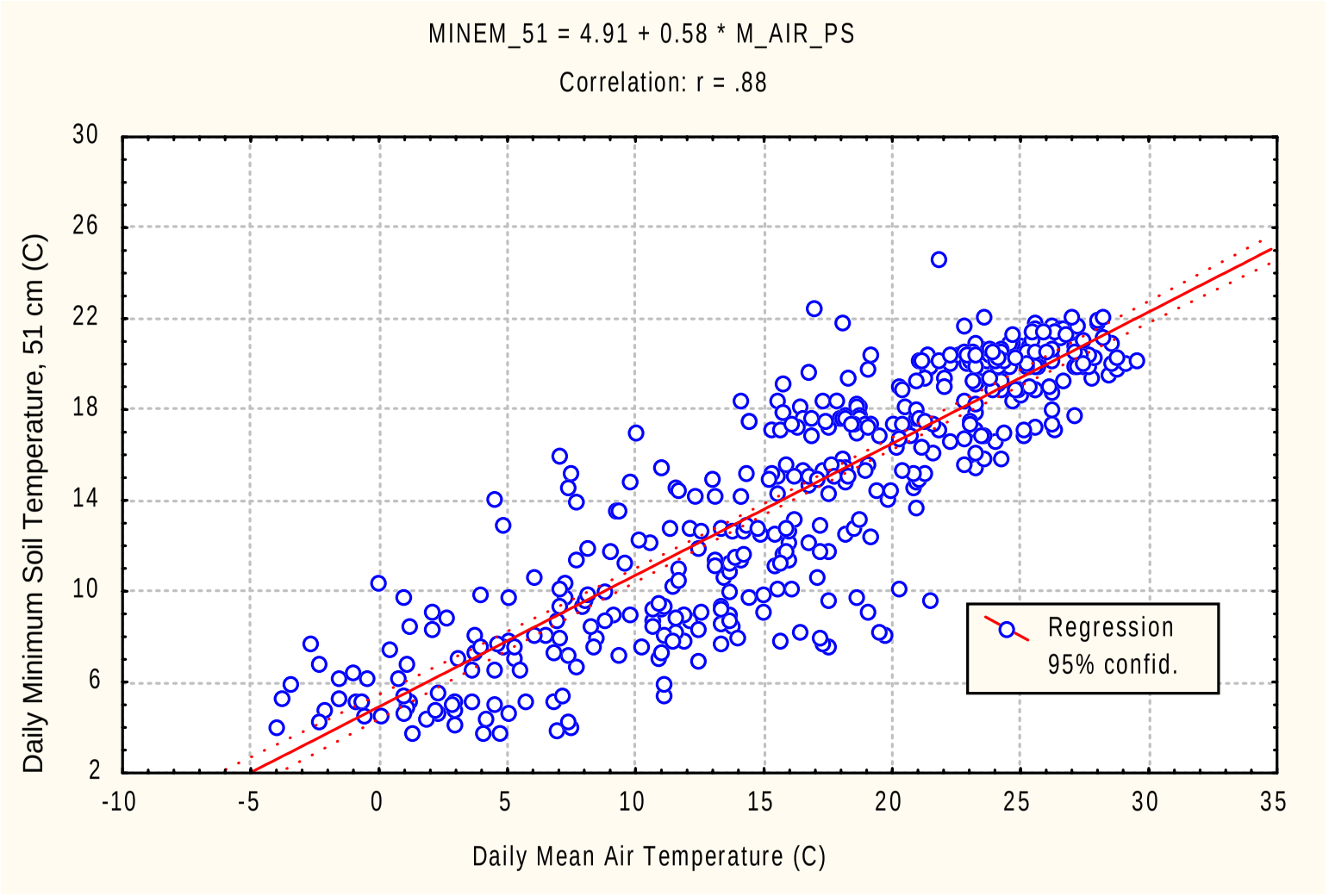

Figure 40. Relationship between daily minimum soil temperature and daily mean air temperature, PSRF emergent, 51 cm depth.

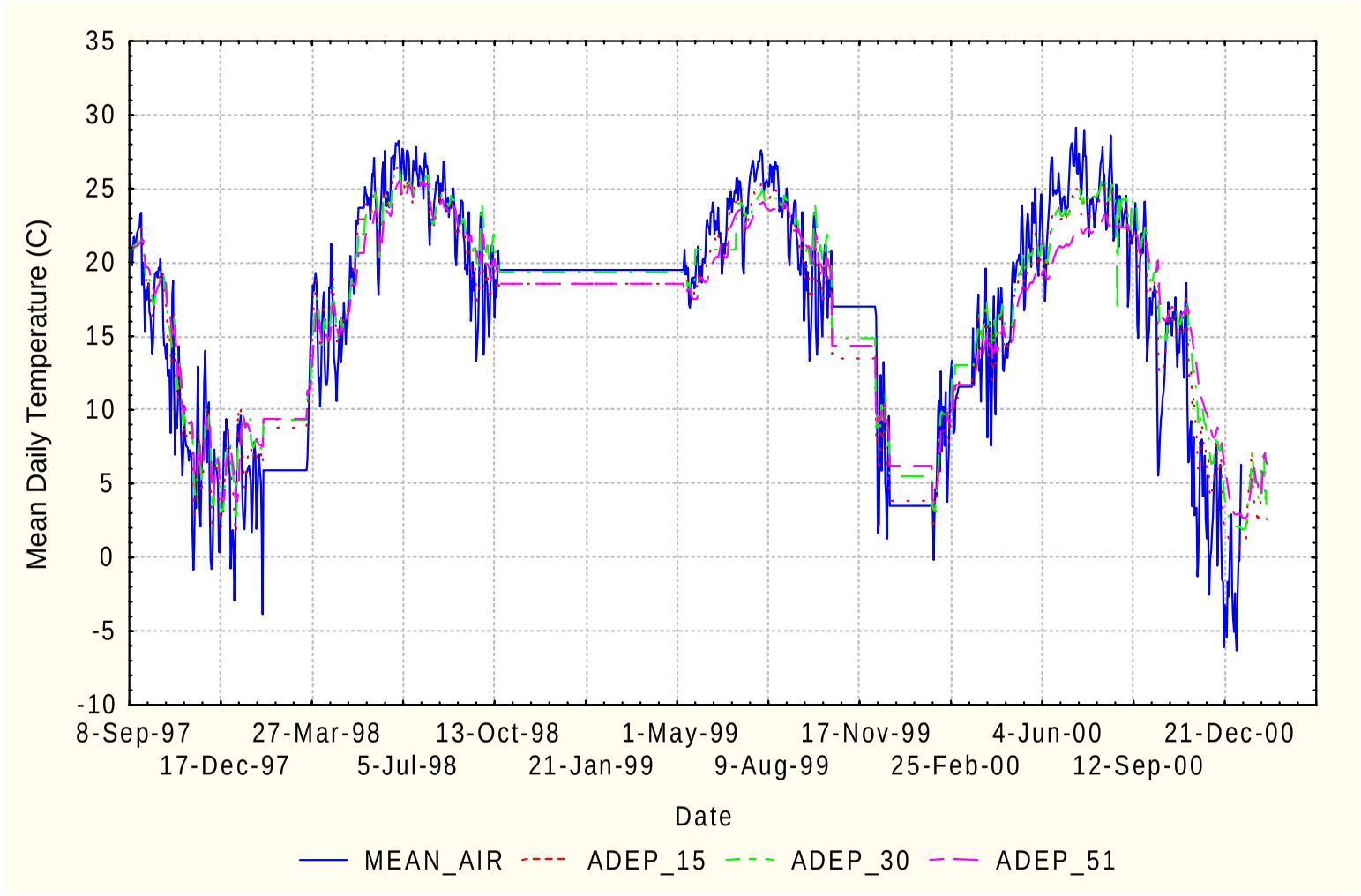

Figure 41. Time series, mean daily air and soil temperature, DPRS depression, untransformed data (ADEP 15 = mean daily temperature at 15 cm, ADEP 30 = mean daily temperature at 30 cm, and ADEP 51 = mean daily temperature at 51 cm).

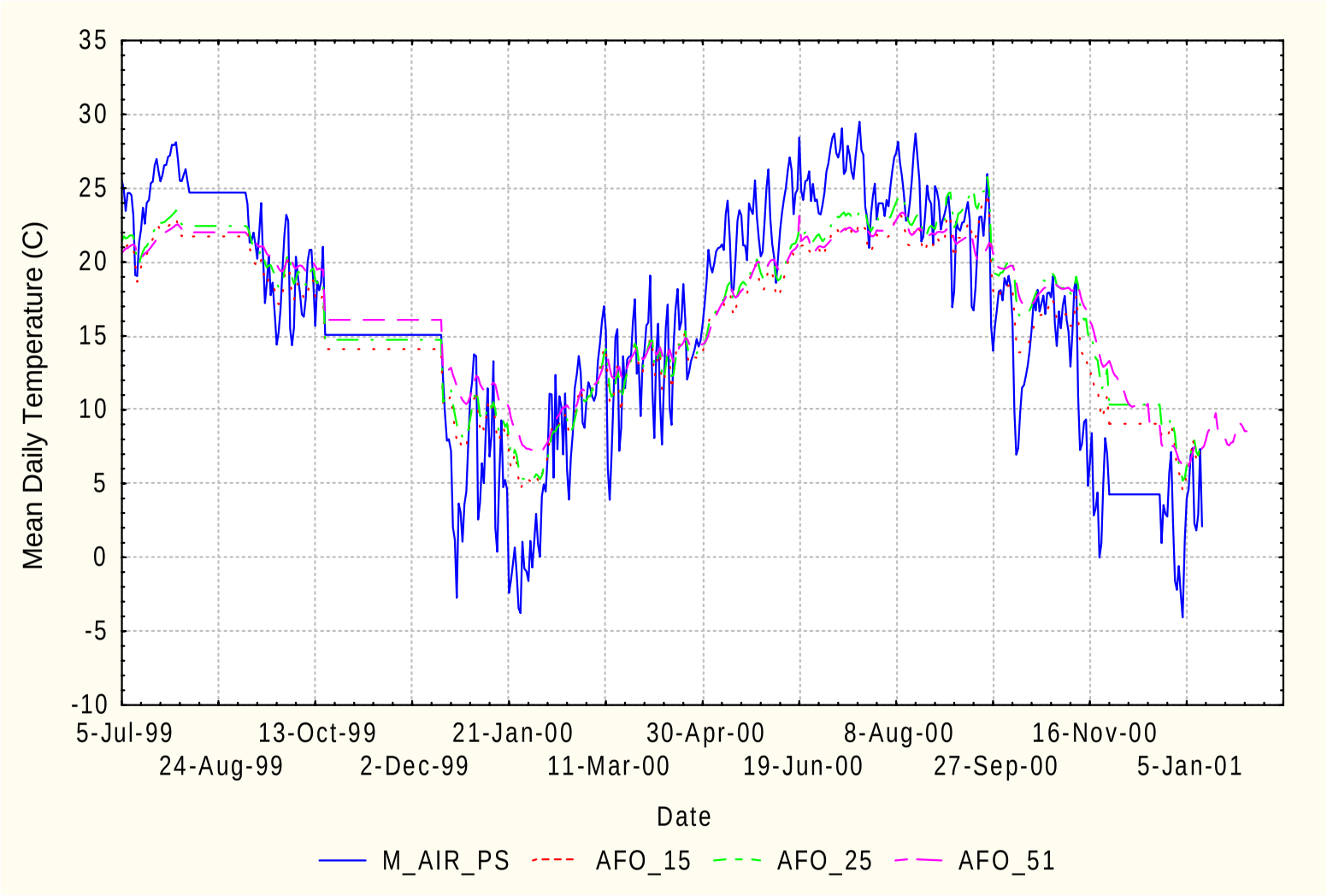

Figure 42. Time series, mean daily air and soil temperature, PSRF forested, untransformed data (AFO 15 = mean daily temperature at 15 cm, AFO 25 = mean daily temperature at 25 cm, and AFO 51 = mean daily temperature at 51 cm).

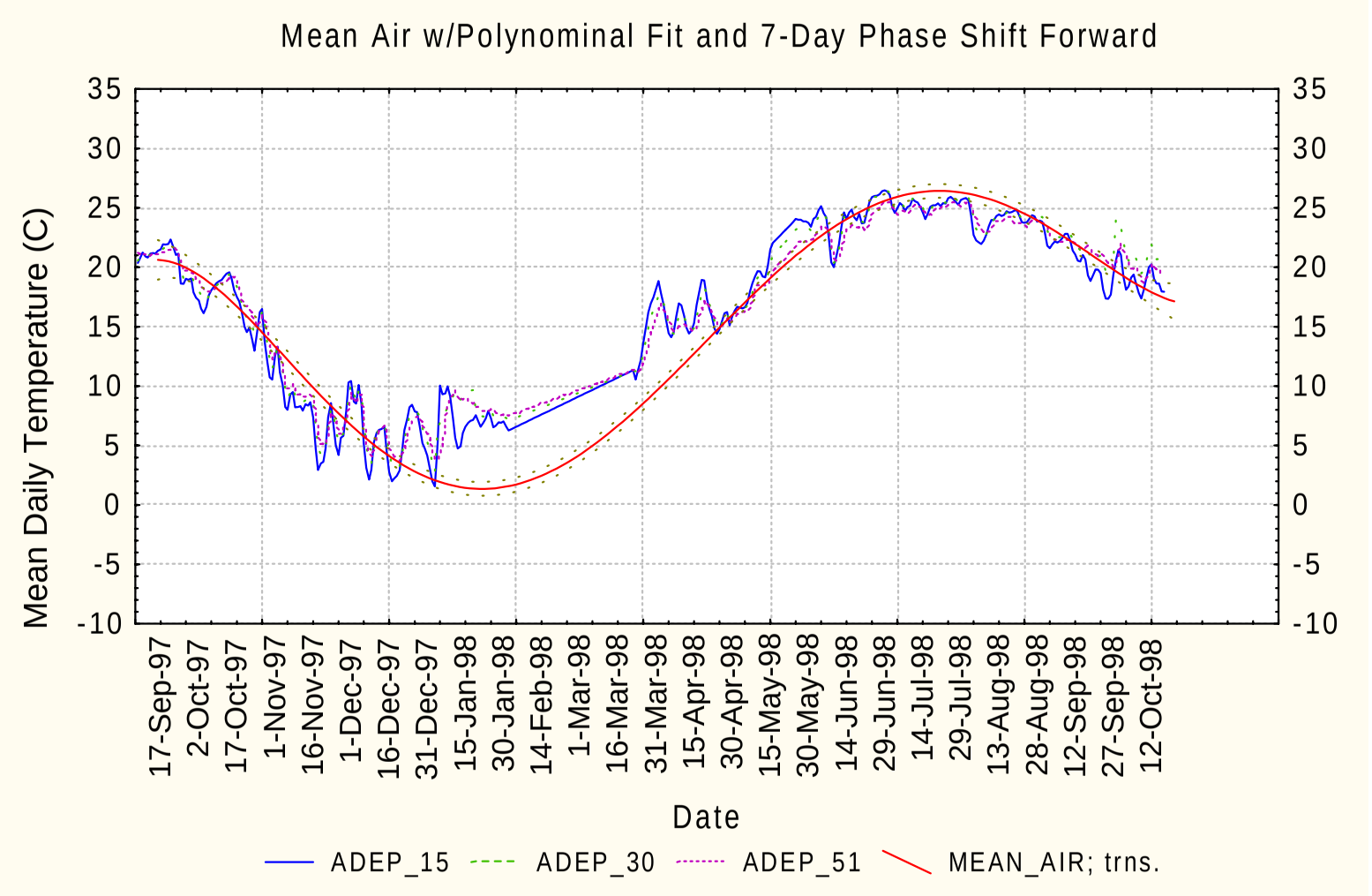

Figure 43. Time series, mean daily air and soil temperature, DPRS depression, transformed data for years 1997 and 1998 (ADEP 15 = mean daily temperature at 15 cm, ADEP 30 = mean daily temperature at 30 cm, and ADEP 51 = mean daily temperature at 51 cm).

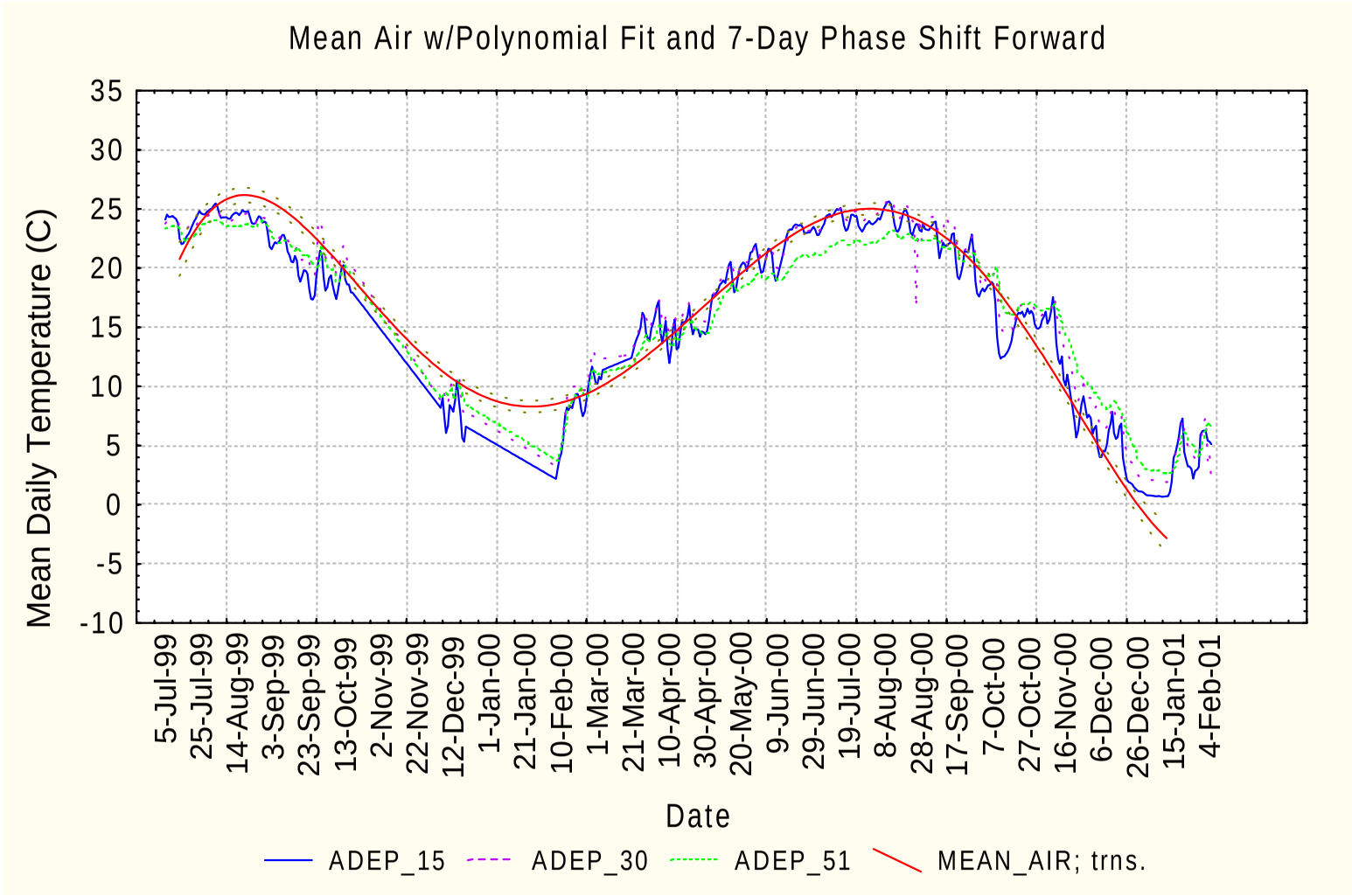

Figure 44. Time series, mean daily air and soil temperature, DPRS depression, transformed data for years 1999 and 2000 (ADEP 15 = mean daily temperature at 15 cm, ADEP 30 = mean daily temperature at 30 cm, and ADEP 51 = mean daily temperature at 51 cm).

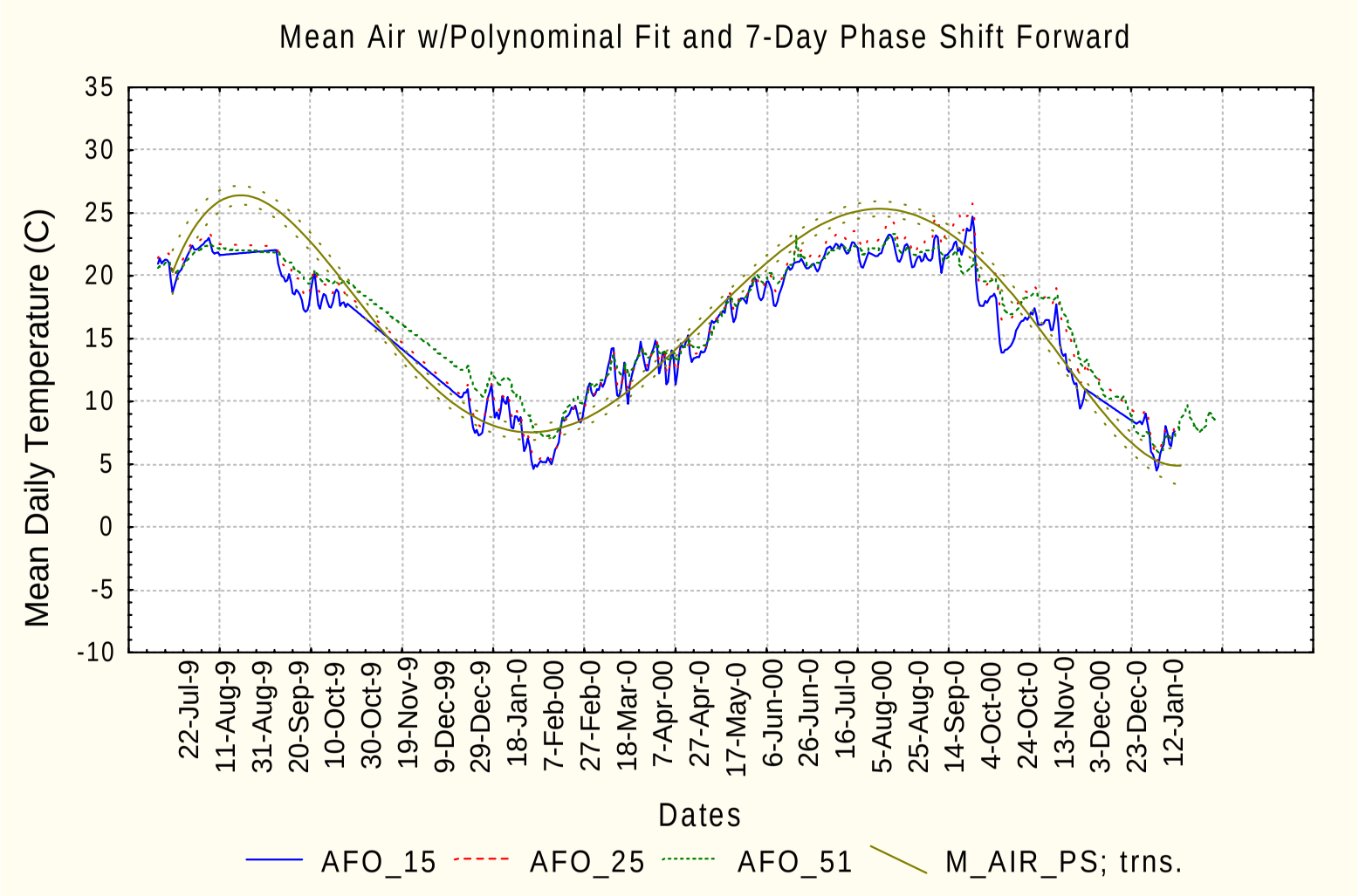

Figure 45. Time series, mean daily air and soil temperature, PSRF forested, transformed data for years 1999 and 2000 (AFO 15 = mean daily temperature at 15 cm, AFO 25 = mean daily temperature at 25 cm, and AFO 51 = mean daily temperature at 51 cm).

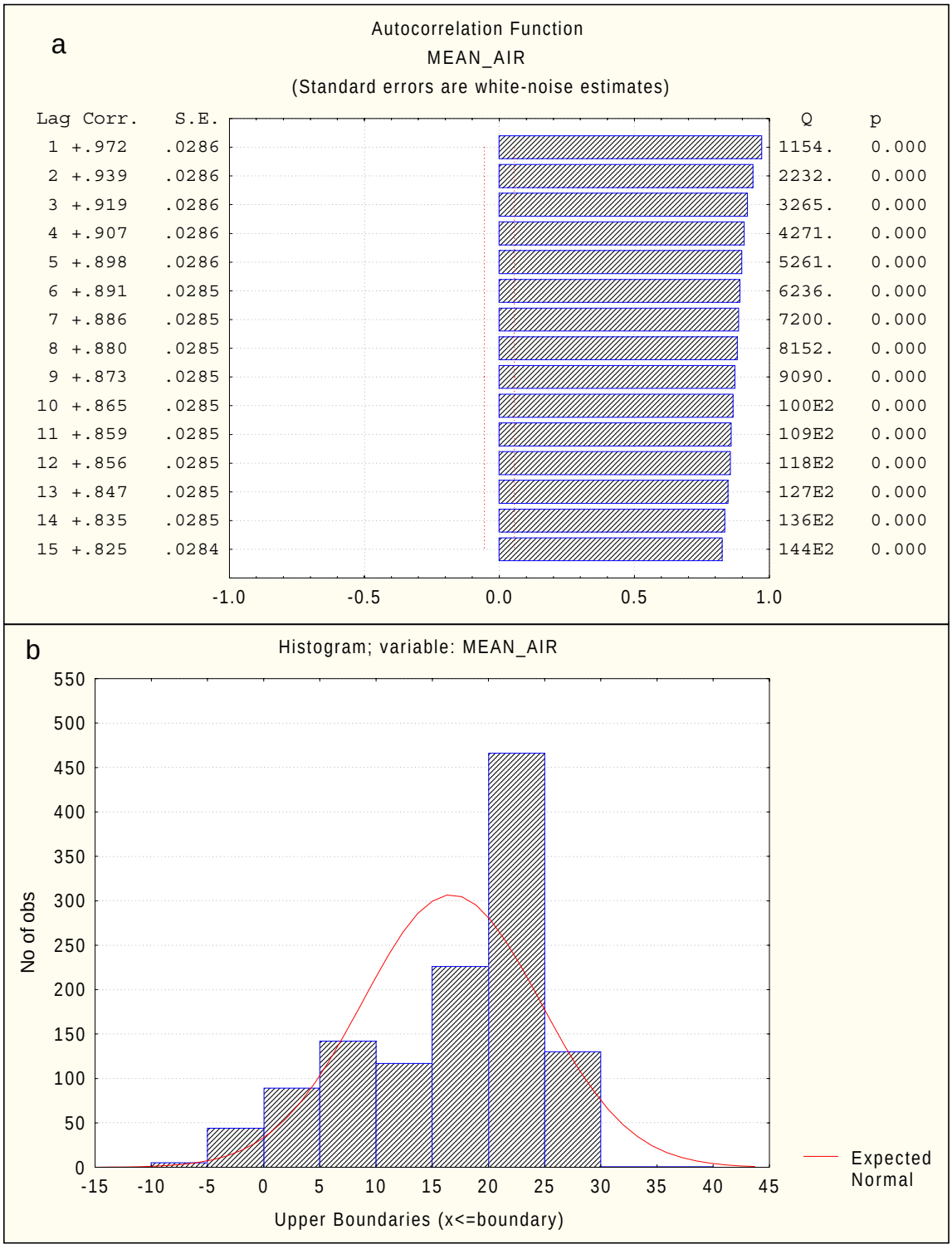

Figure 46. Example of a. autocorrelation and b. distribution of residuals prior to ARIMA transformation (mean daily air temperature).

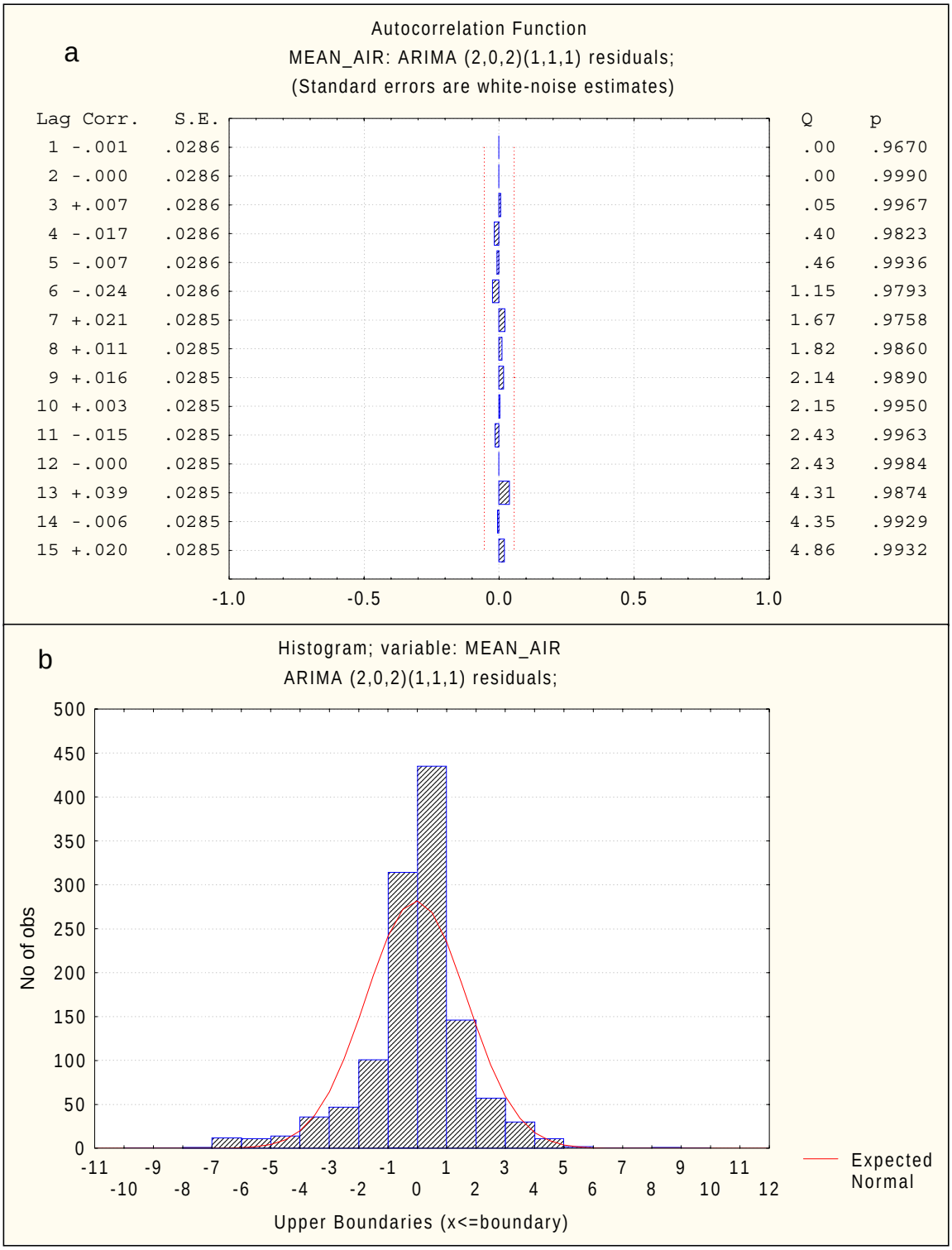

Figure 47. Example of a. autocorrelation (top graph) and b. distribution of residuals (bottom graph) following ARIMA transformation (mean daily air temperature).

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APPENDIX A

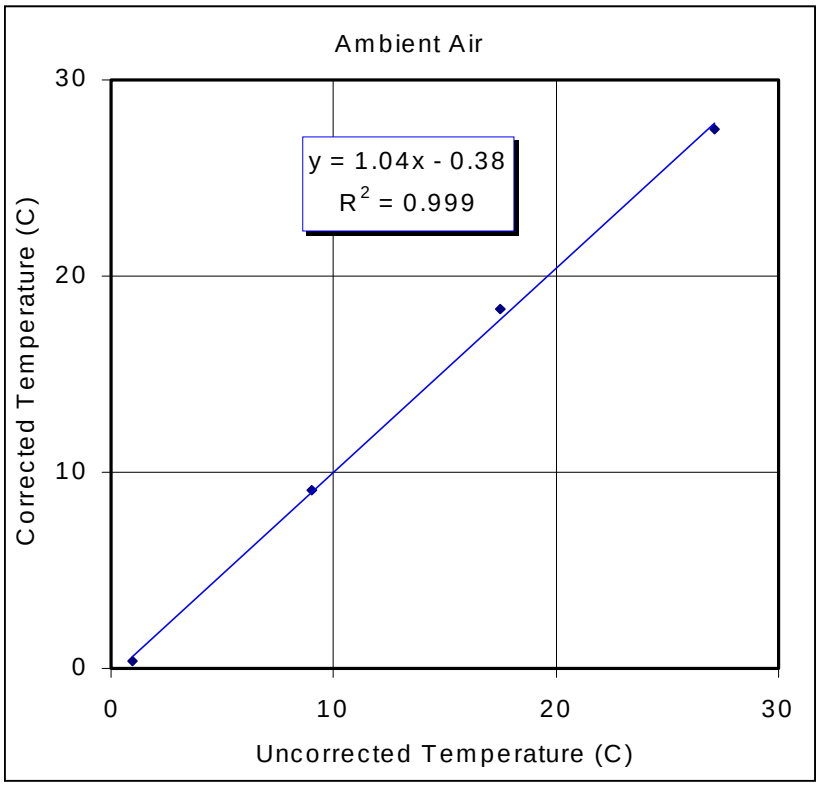
THERMOCOUPLE CALIBRATION AND INSTALLATION

Calibration

Thermocouples were calibrated at several temperature, which included anticipated field conditions, against a certified mercury thermometer (Fisher Scientific, #15-041A, Range = -1/51^{o}C in 0.1^{o}C divisions total immersion). Four-point and 5-point calibration curves were developed for each of seven thermocouples for DPRS and PSRF, respectively (calibration curves below).

Installation

A small pit was excavated to approximately 60 cm, and the thermocouples were inserted (at 15, 30, and 51 cm at DPRS and at 15, 25, and 51 cm at PSRF) into the undisturbed wall of the pit at the same depths of the redox potential probes (see Redox Potential Methods). The pit was refilled with soil and tamped gently. The thermocouples were connected to a Campbell™ CR-10X datalogger equipped with a Campbell™ AM-416 multiplexer.



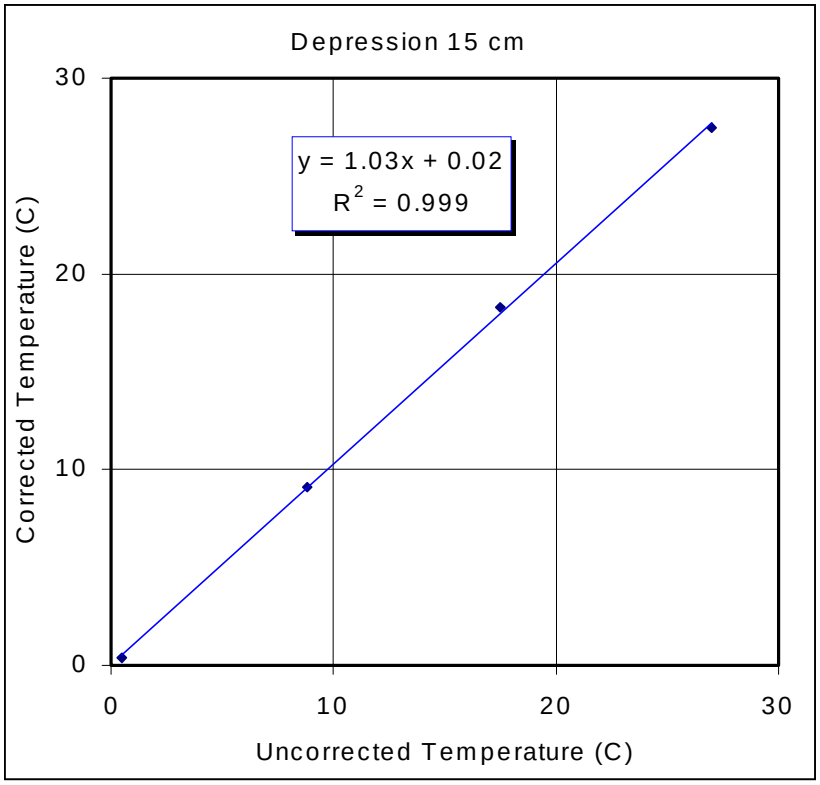


Figure 48. Thermocouple calibration curve, DPRS depression, air and soil 15 cm.

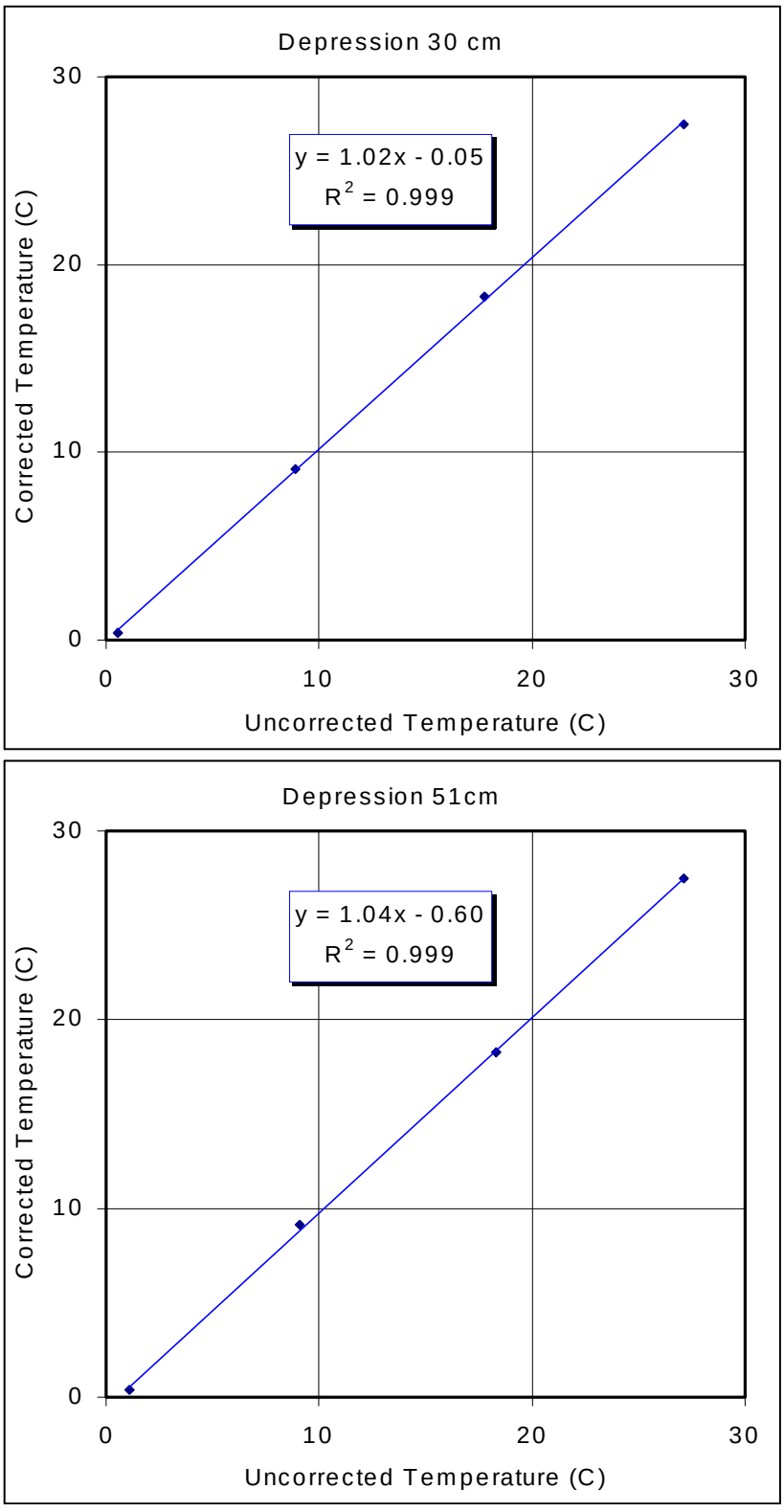
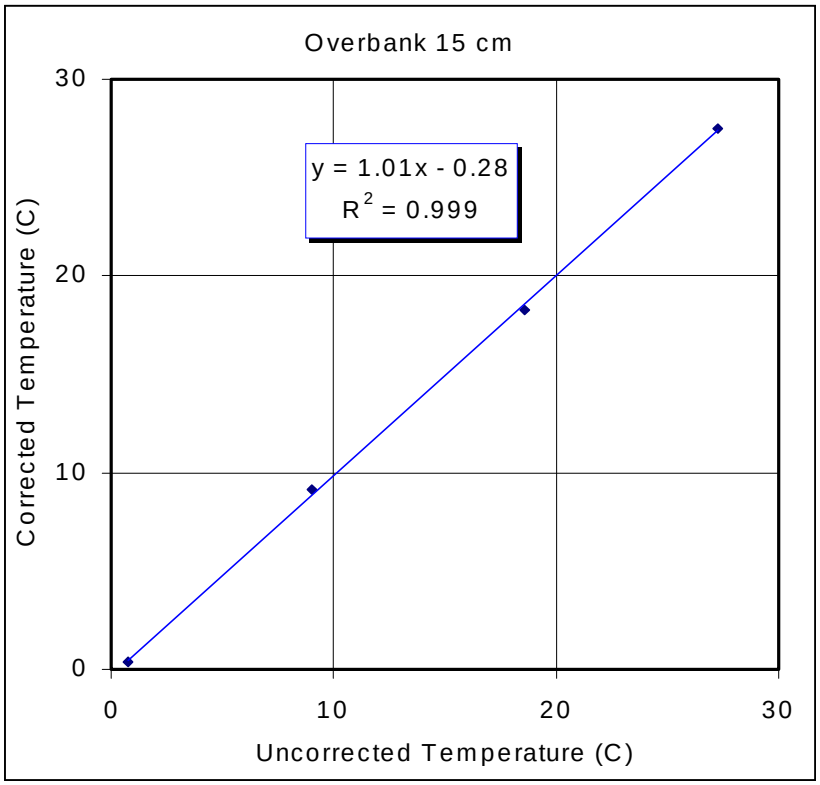


Figure 49. Thermocouple calibration curve, DPRS depression , soil 30 and 51 cm.



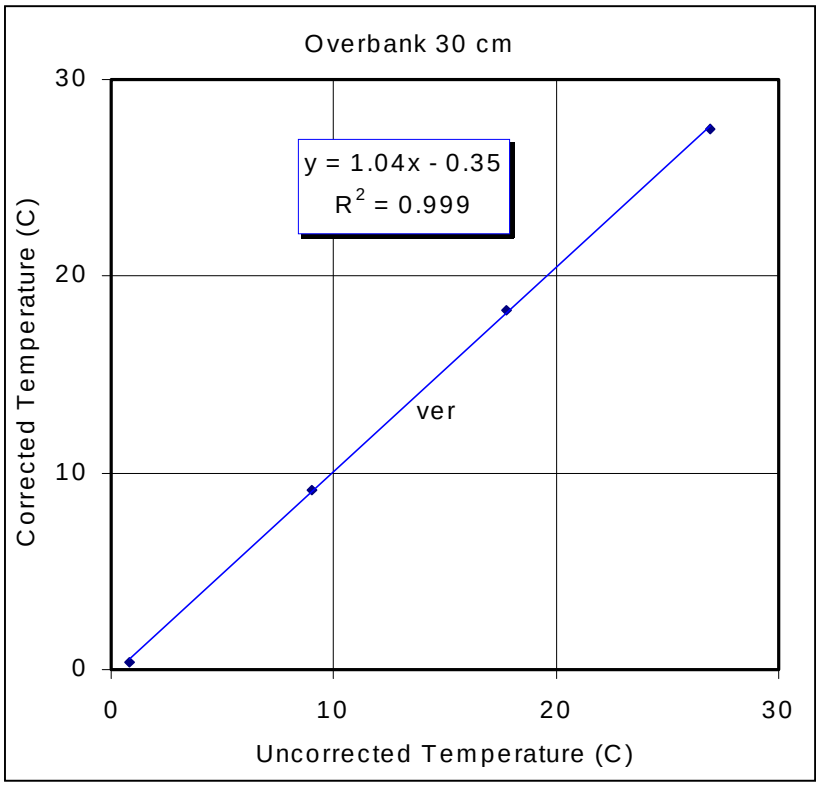


Figure 50. Thermocouple calibration curve, DPRS overbank , soil 15 and 30 cm.

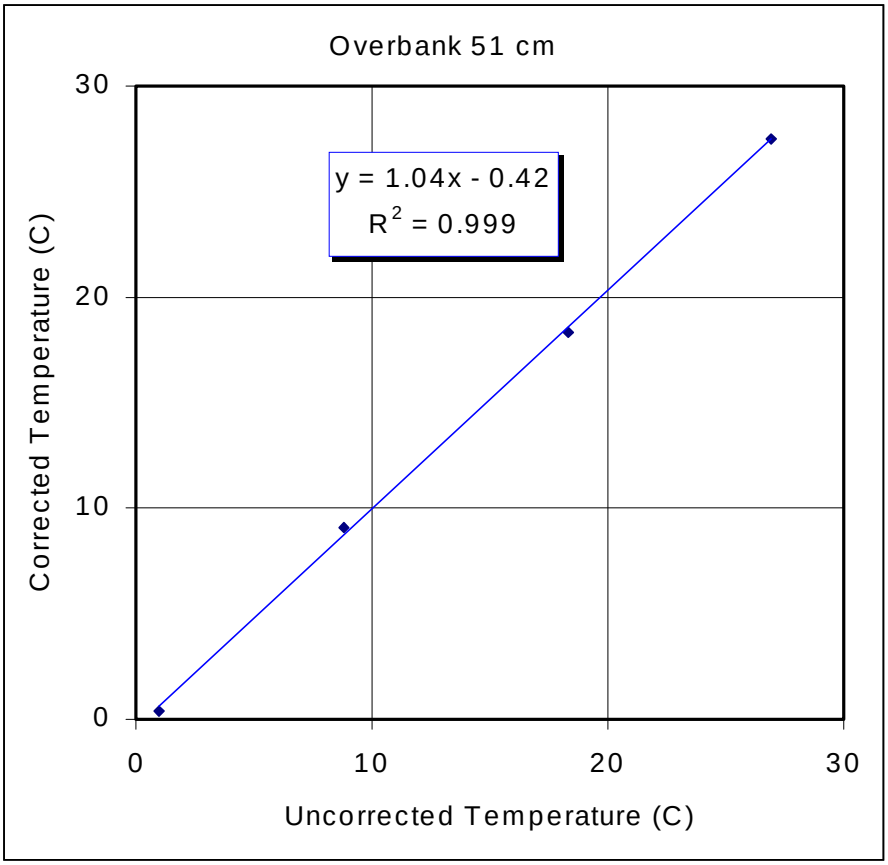


Figure 51. Thermocouple calibration curve, DPRS overbank , soil 51 cm.

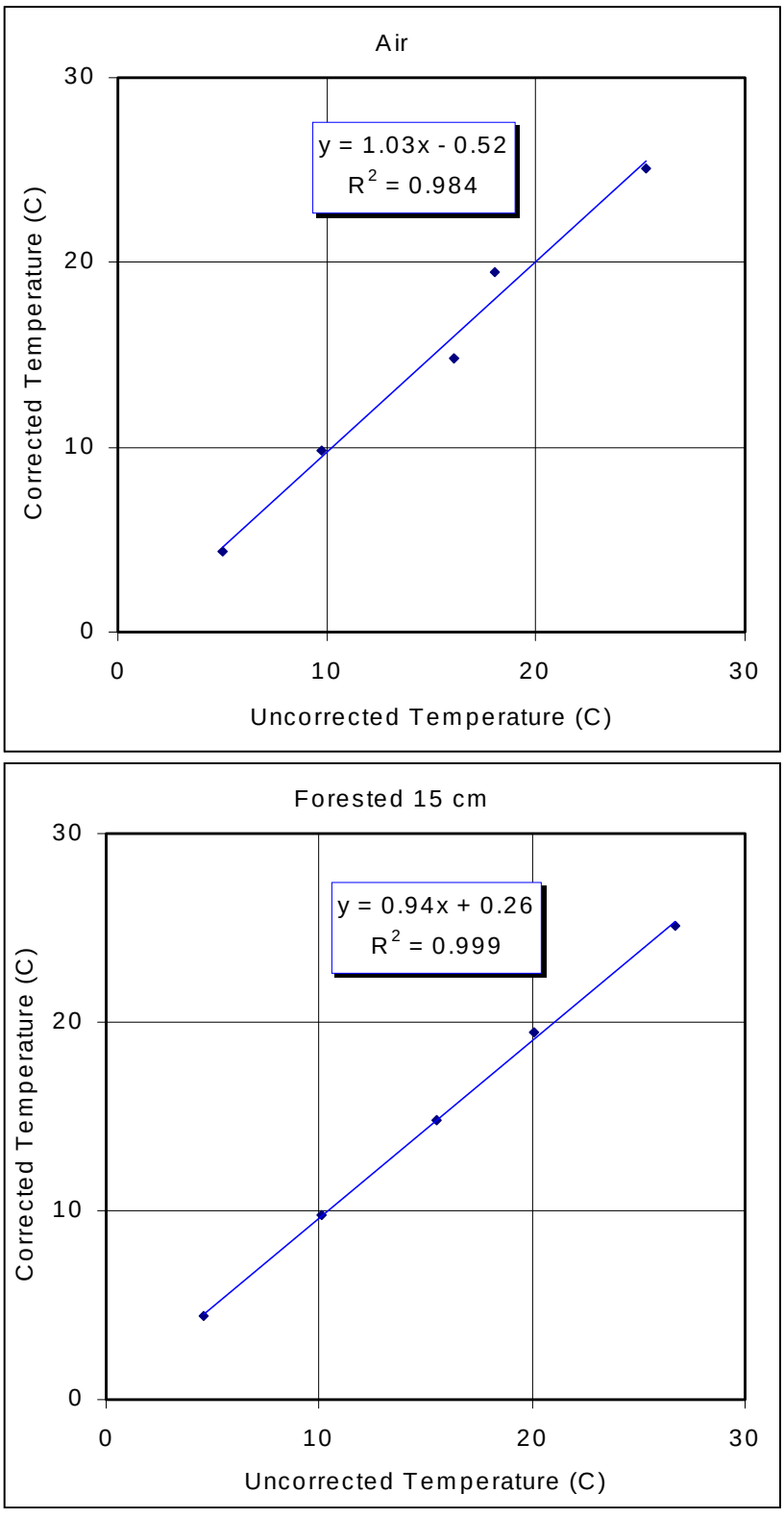


Figure 52. Thermocouple calibration curve, PSRF forested, air and soil 15 cm.

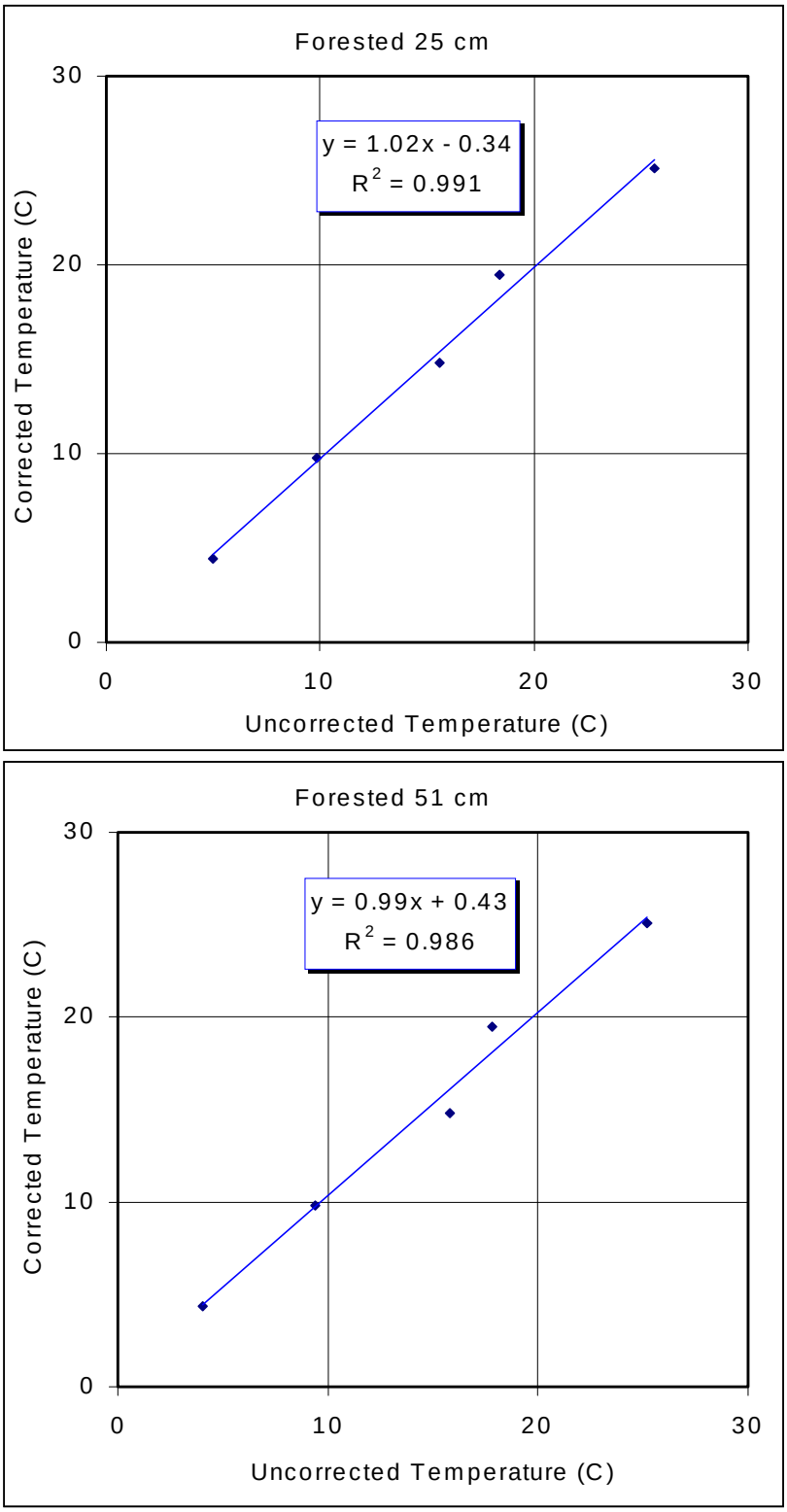


Figure 53. Thermocouple calibration curve, PSRF forested, soil 25 and 51 cm.

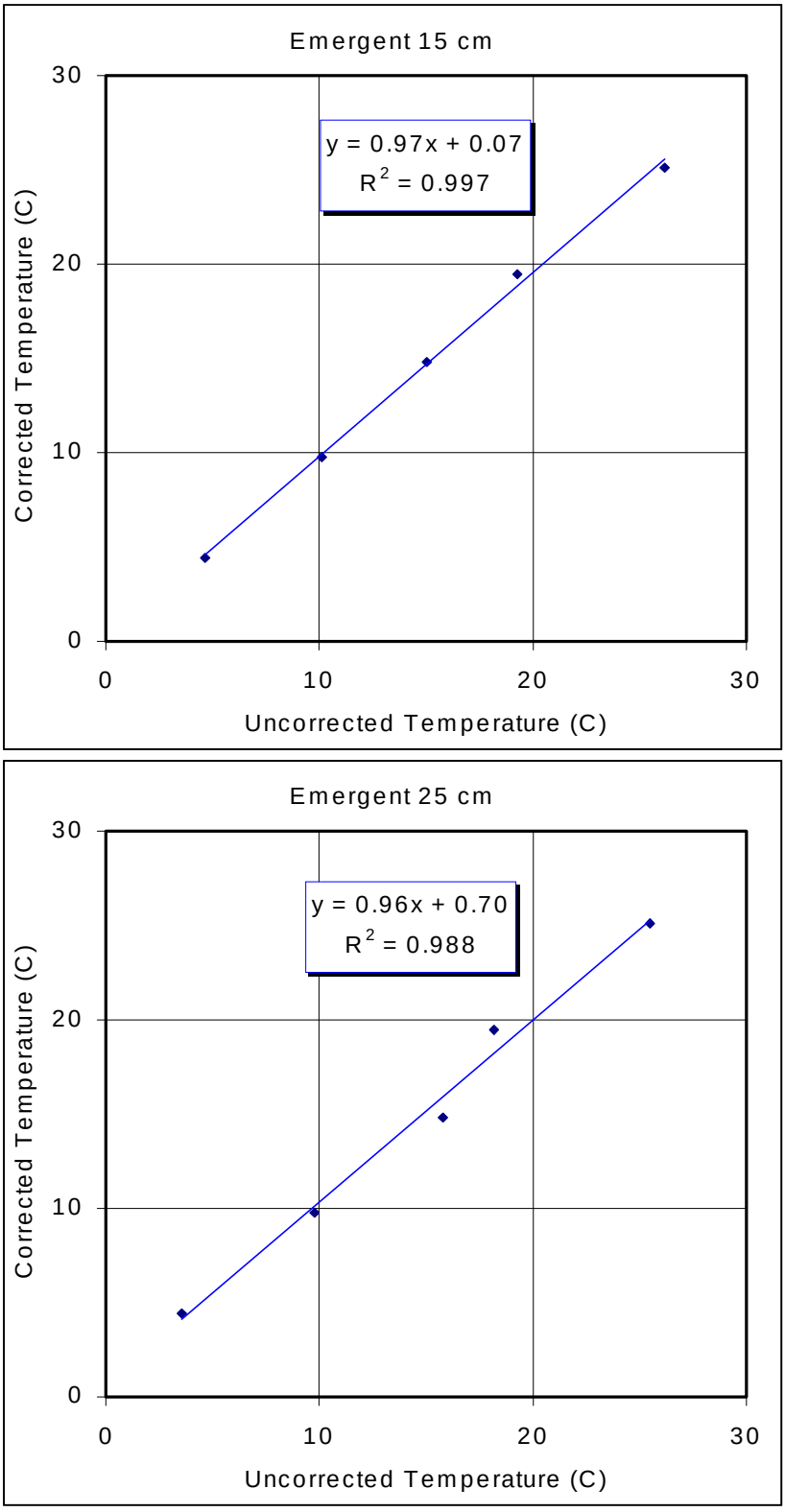


Figure 54. Thermocouple calibration curve, PSRF emergent, soil 15 and 25 cm.

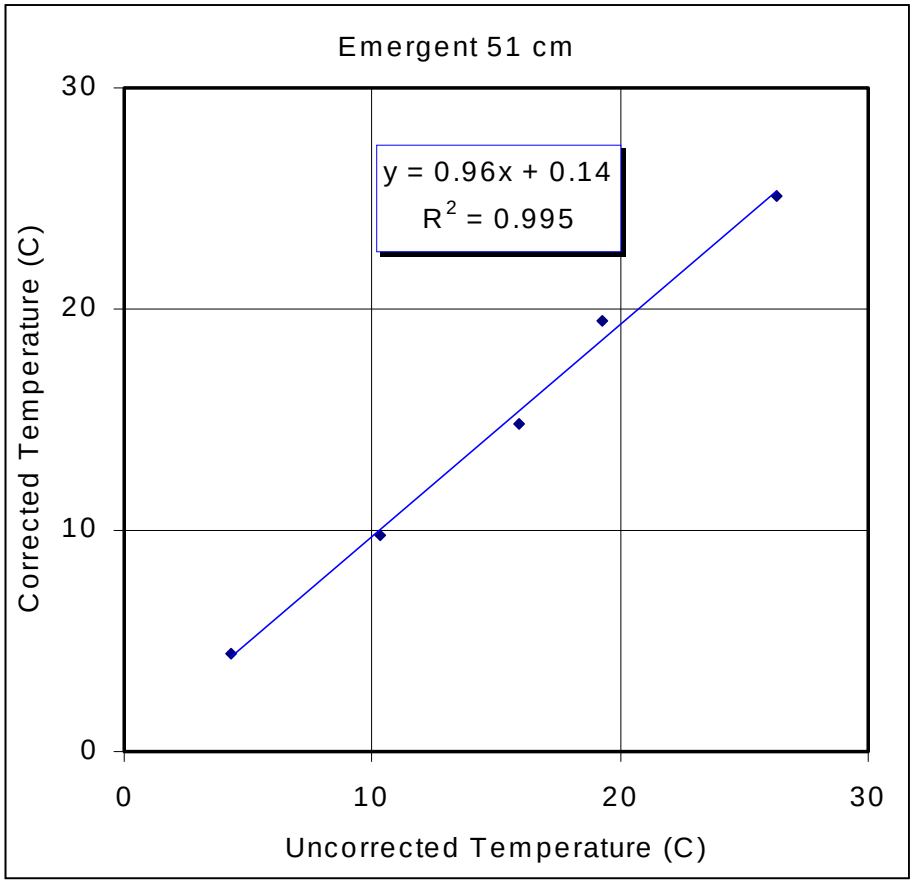


Figure 55. Thermocouple calibration curve, PSRF emergent, soil 51 cm.

APPENDIX B

REDOX POTENTIAL PROBES CONSTRUCTION, CALIBRATION, AND INSTALLATION

Construction

Construction of redox potential probes followed methods developed by Dirasian (1968), Bricker (1980), Mueller et al. (1985), and Faulkner et al. (1989). Soil redox potential probes were constructed using a 7 to 8 mm long, 18-gage platinum tip soldered (silver solder) to 10-gage, solid copper wire. The platinum was cut using a new, stainless steel wire cutter, bathed in a 1:1 solution of concentrated HCl and HNO_3, rinsed with deionized water, and air dried before construction. The connection between the platinum and the copper was sealed with epoxy and heat shrink wrap. The completed probe was wired to a Campbell™ CR-10 and multiplexer AM-16 with 16-gage, shielded wire. The connection between the probe and the shielded wire was water-proofed by using epoxy, shrink wrap, tygon tubing, and silicon caulking.

Calibration

Redox potential probes were calibrated to quinhydrone ($C_6H_{10}OH_2$) (Dirasian 1968). Quinhydrone is poisonous if ingested, but does not affect pH buffers and is easily prepared fresh prior to meter calibration. Thus, it must be prepared "fresh" prior to calibration. However, field preparation is as simple as adding pH buffered standards to a pre-weighed aliquot of quinhydrone and mixing thoroughly as follows:

1. Three standards were made by mixing 250 mg of quinhydrone with 250 ml each of pH buffered standards of 4, 7, and 10 resulting in redox standards +218.4, +41, and -36.5 mV, respectively;
2. The standard was thoroughly mixed to reach saturation;
3. The resulting saturated solution was decanted into a suitable container and the redox potential probe, and the reference probe was placed in the solution;
4. A pre-calibration of each redox probe was conducted to ensure proper probe construction;
5. A final calibration, on the probes that passed the pre-calibration step, was conducted following complete wiring through the Campbell™ CR-10X to account for resistance and equipment effects;

6. Once the reading was stable, the values of each of the three standards were recorded; and
7. A three-point, calibration curve for each probe was developed.

Calibration curves for each redox probe are included below.

Installation

Each probe was assigned a number and pre-marked with the number and probe depth before installation. A 10-gage, welding rod was used to excavate a pilot hole to insert the probe. The pilot hole was extended 7 to10 mm less than the specified installation depth. Consequently, when the redox probe was installed, the platinum tip extended beyond the soil matrix disturbed by the pilot.

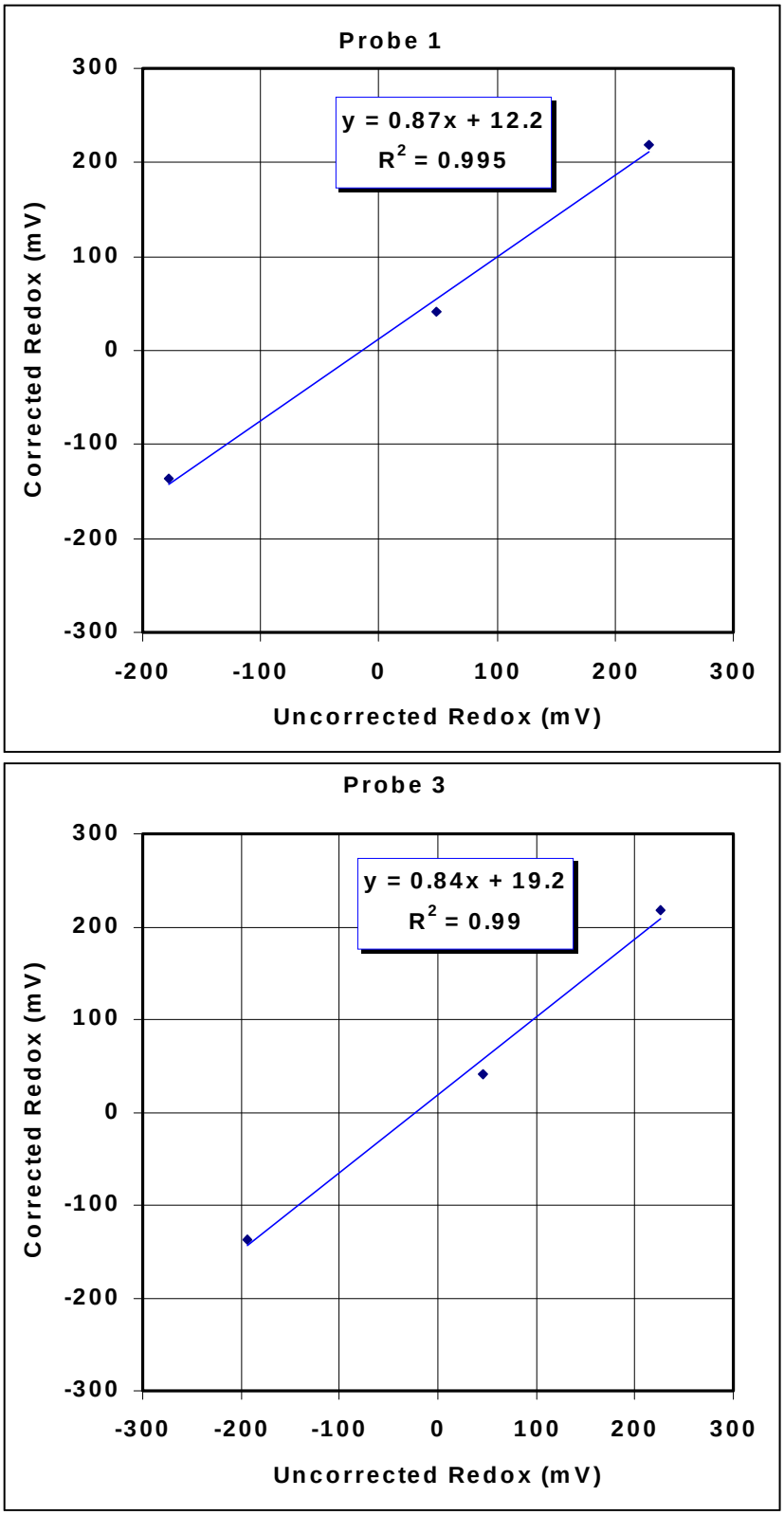


Figure 56. Redox potential calibration curves, DPRS, probes 1 and 3.

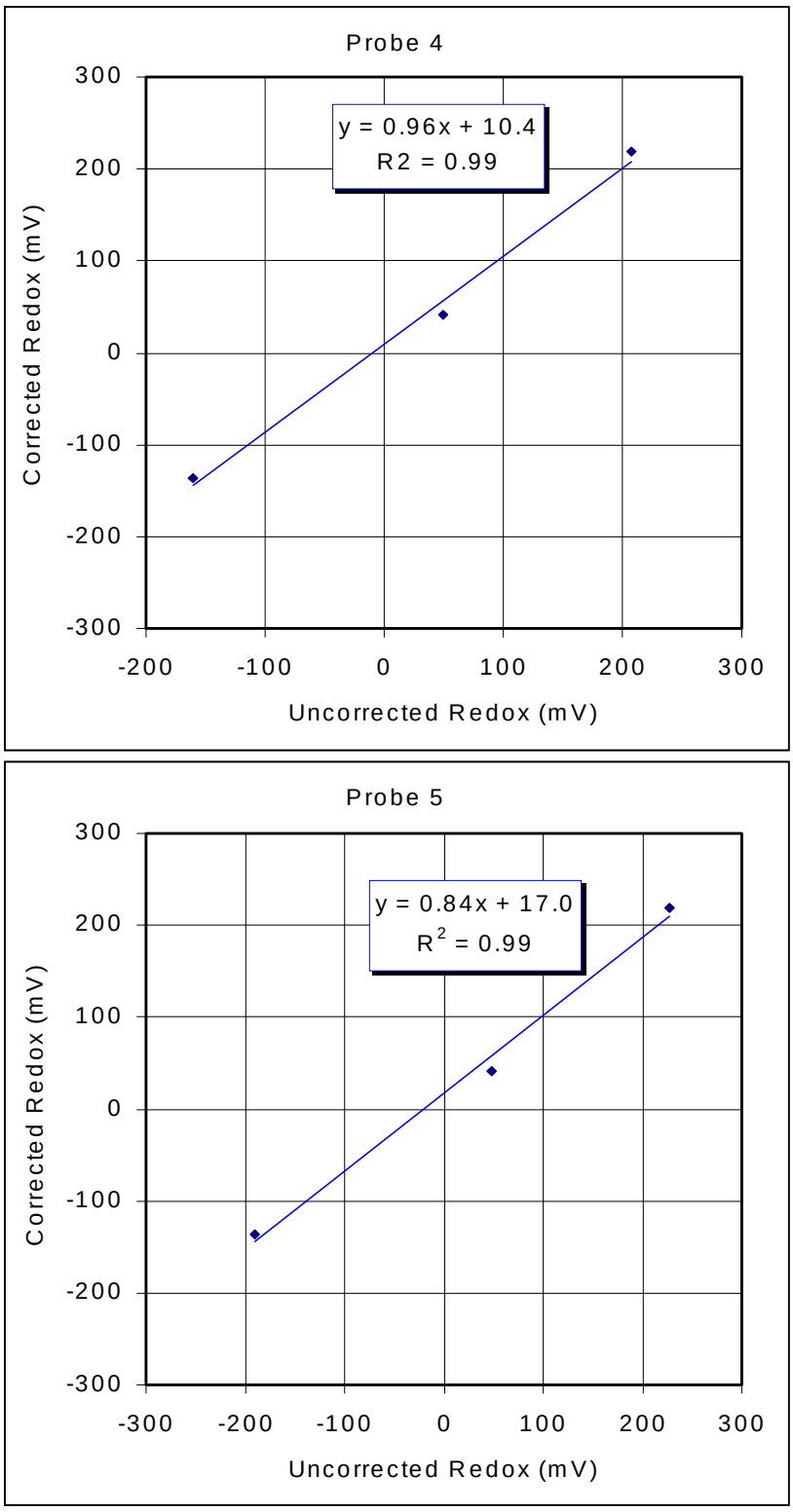


Figure 57. Redox potential calibration curves, DPRS, probes 4 and 5.

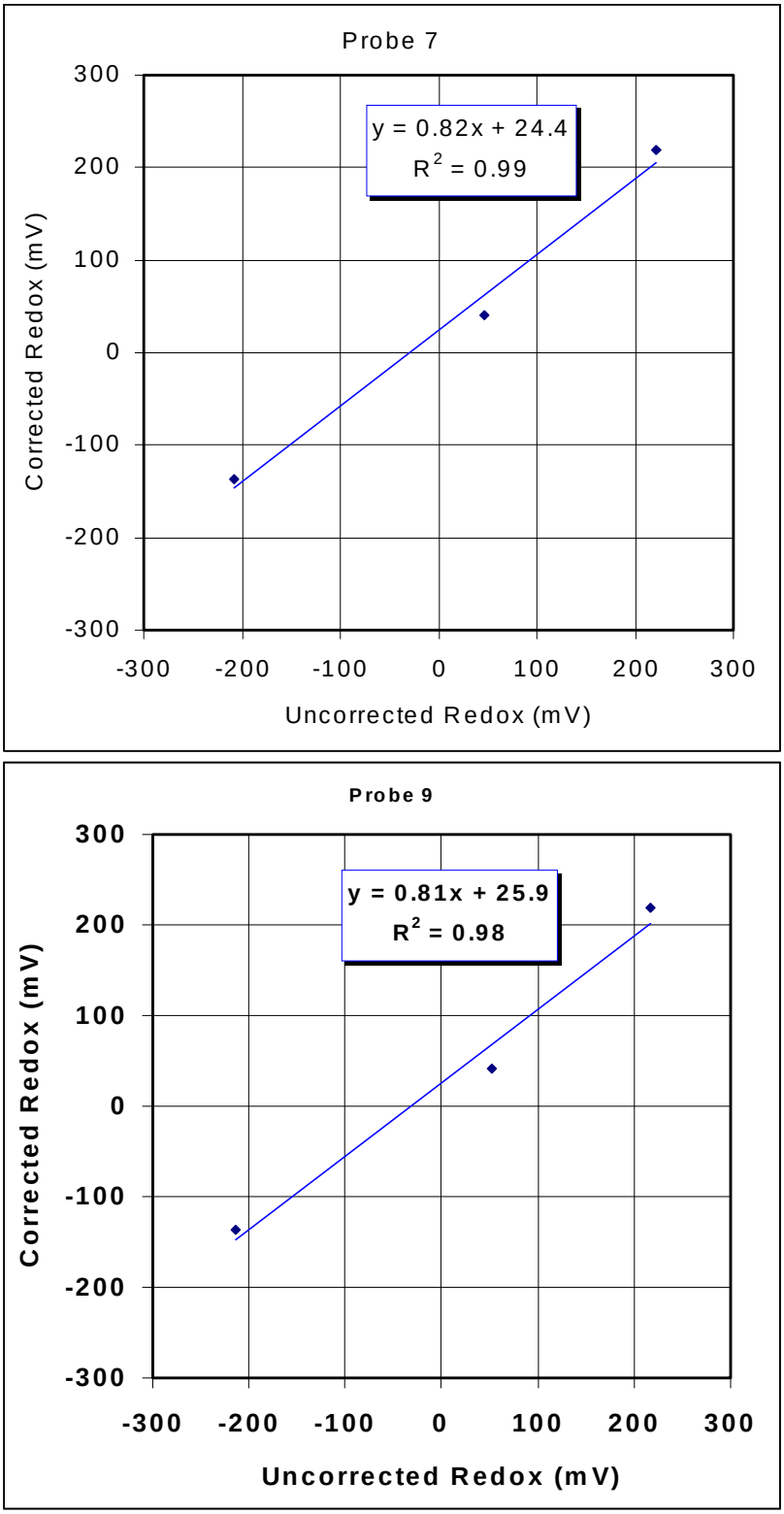


Figure 58. Redox potential calibration curves, DPRS, probes 7 and 9.

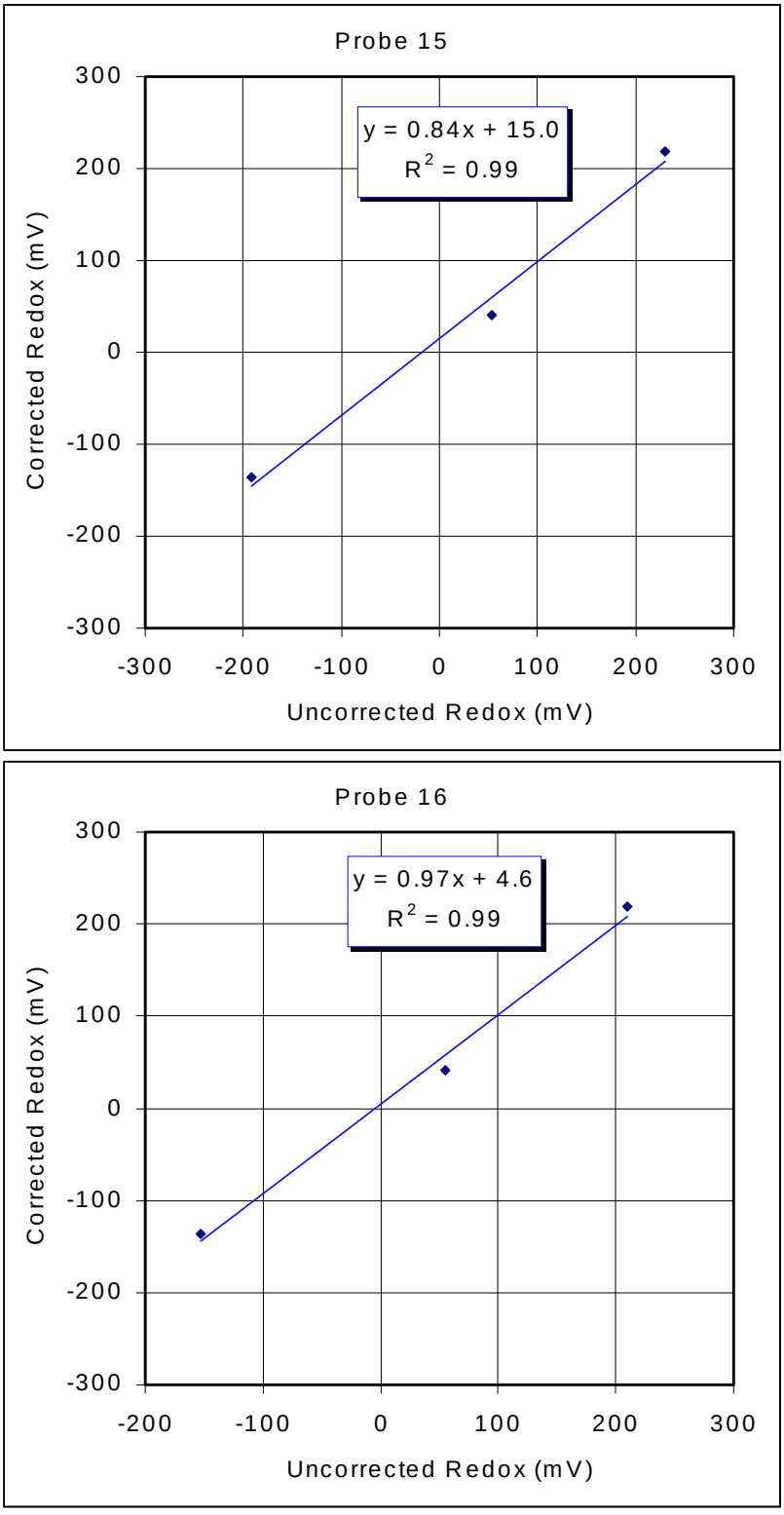


Figure 59. Redox potential calibration curves, DPRS, probes 15 and 16.

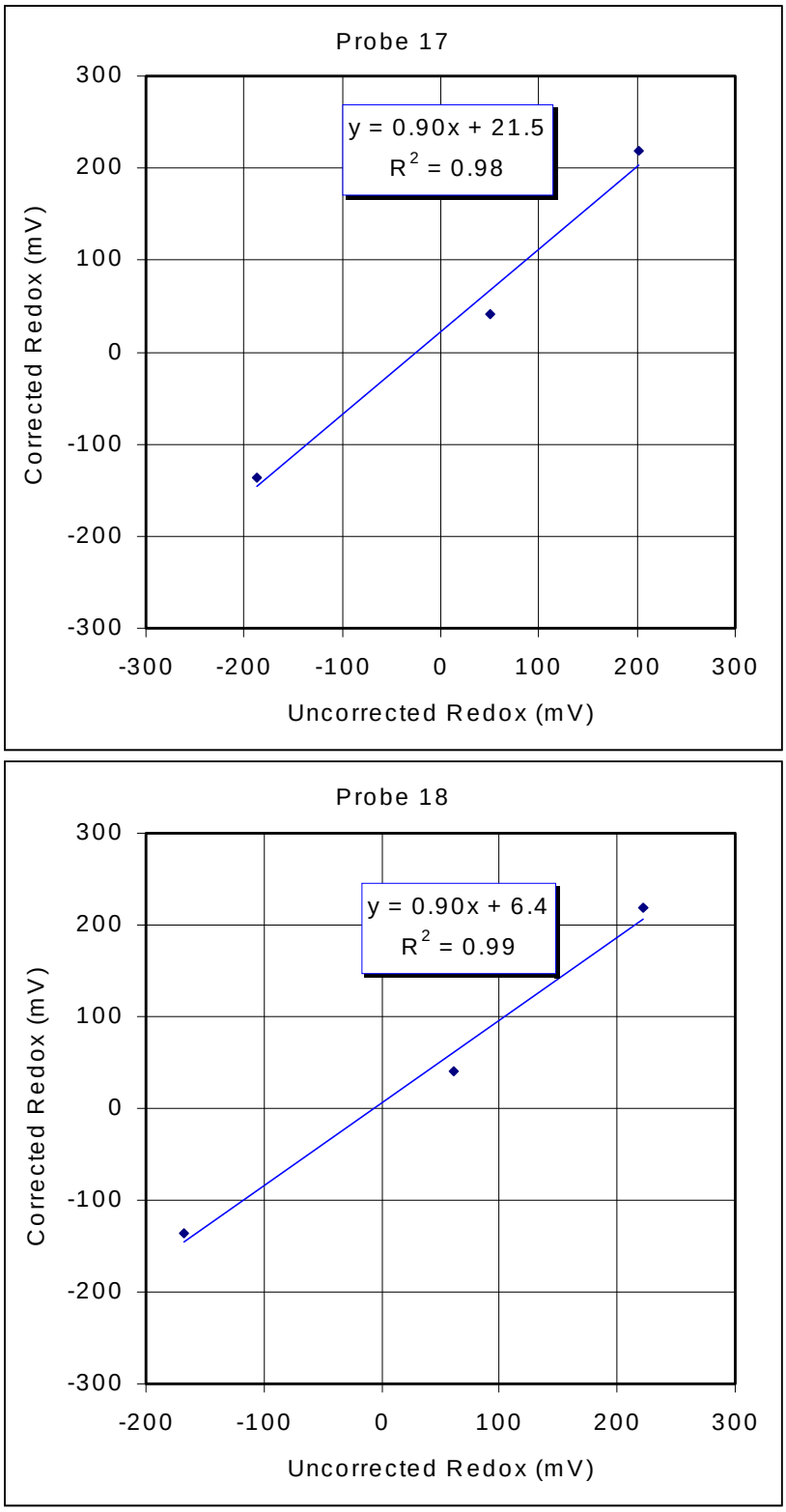


Figure 60. Redox potential calibration curves, DPRS, probes 17 and 18.

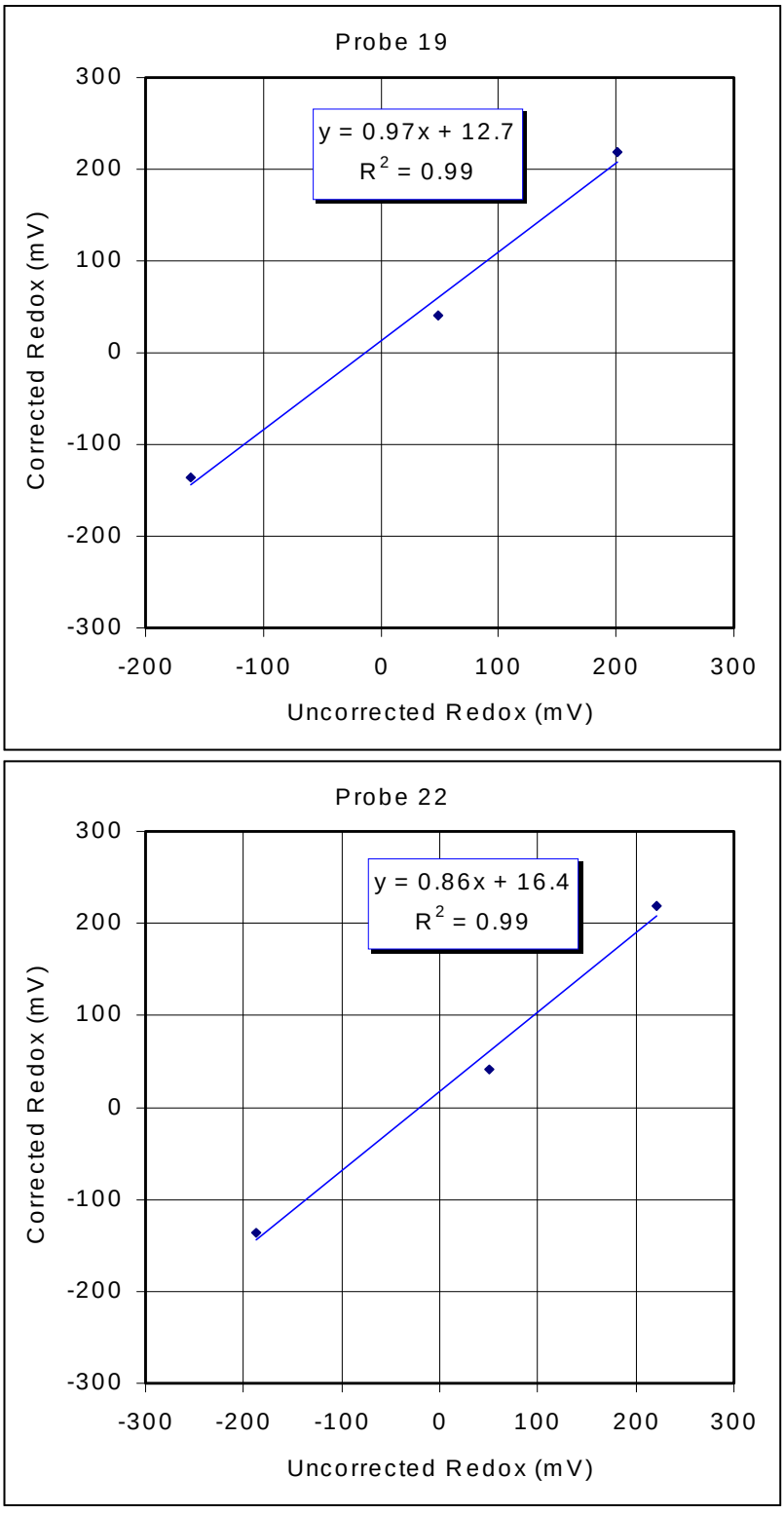


Figure 61. Redox potential calibration curves, DPRS, probes 19 and 22.

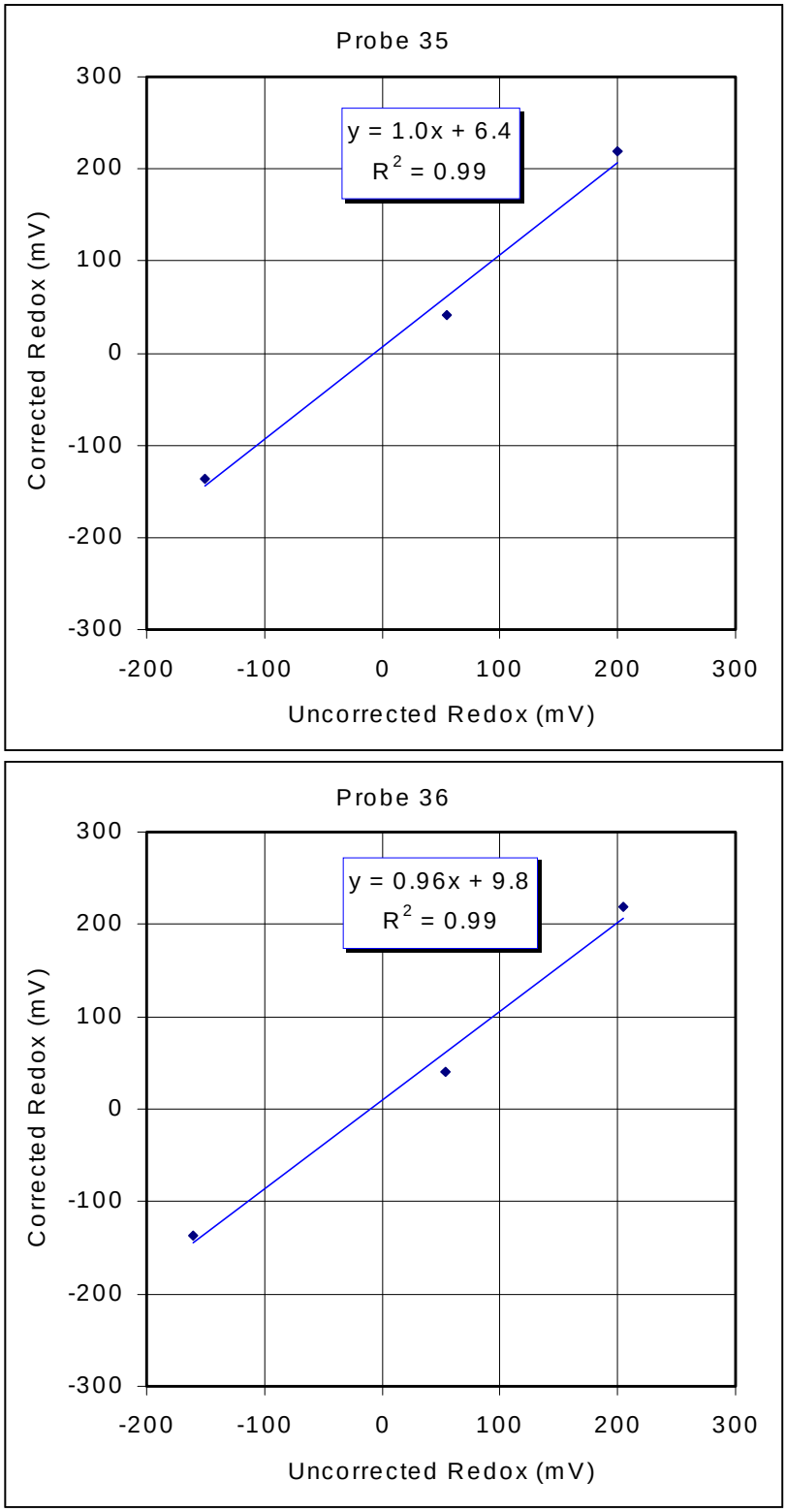


Figure 62. Redox potential calibration curves, DPRS, probes 35 and 36.

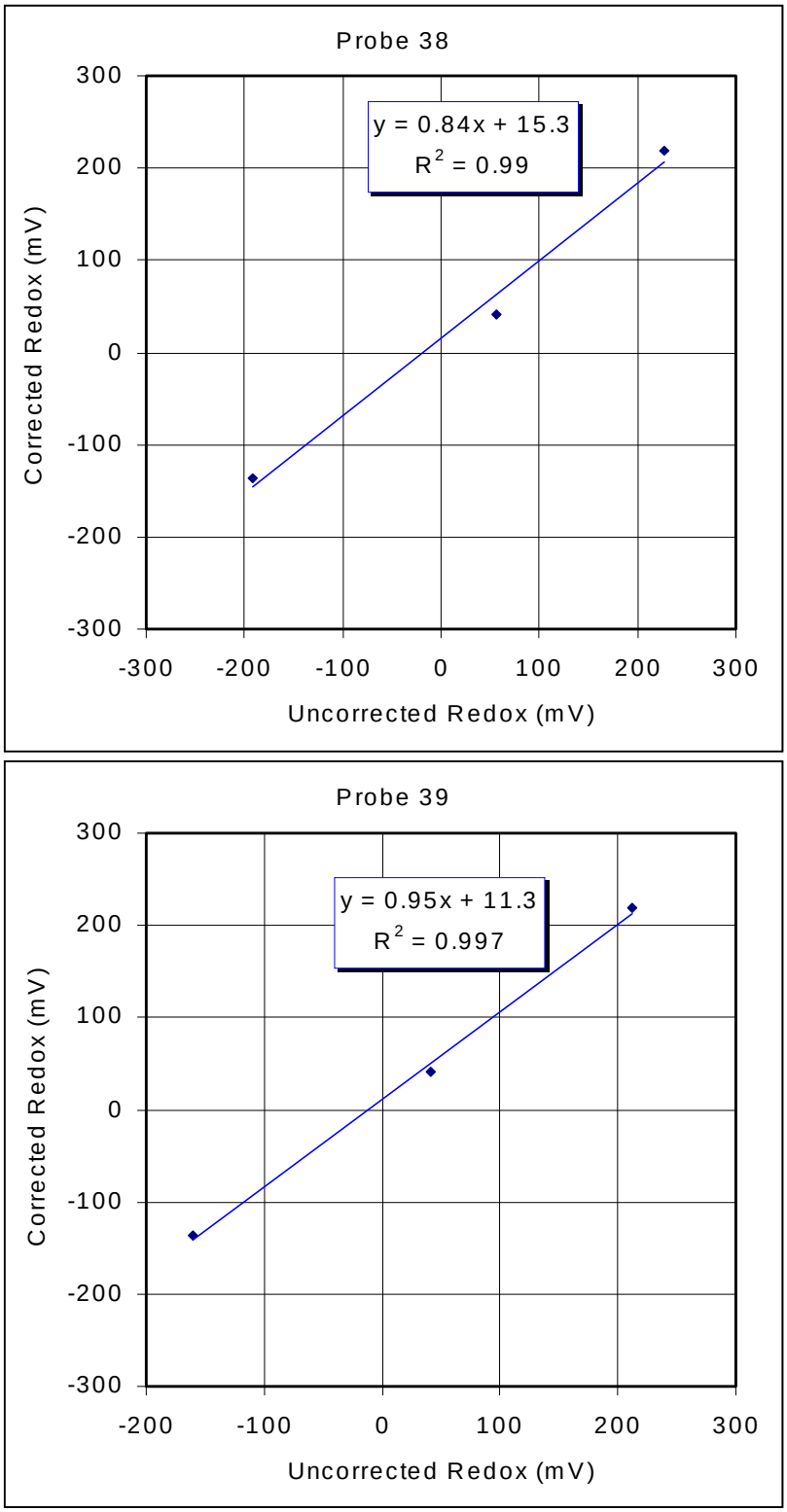


Figure 63. Redox potential calibration curves, DPRS, probes 38 and 39.

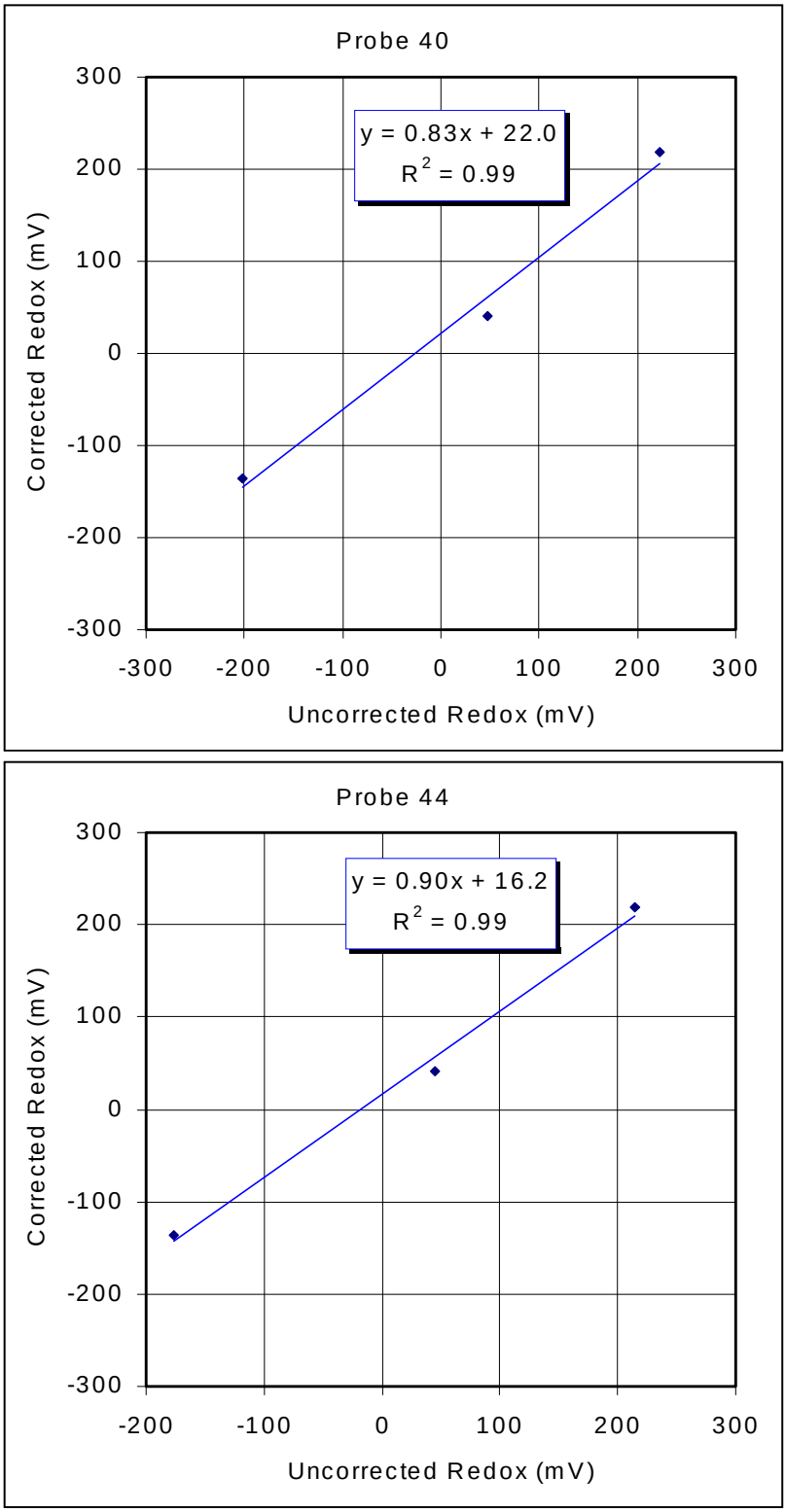


Figure 64. Redox potential calibration curves, DPRS, Probes 40 and 44.

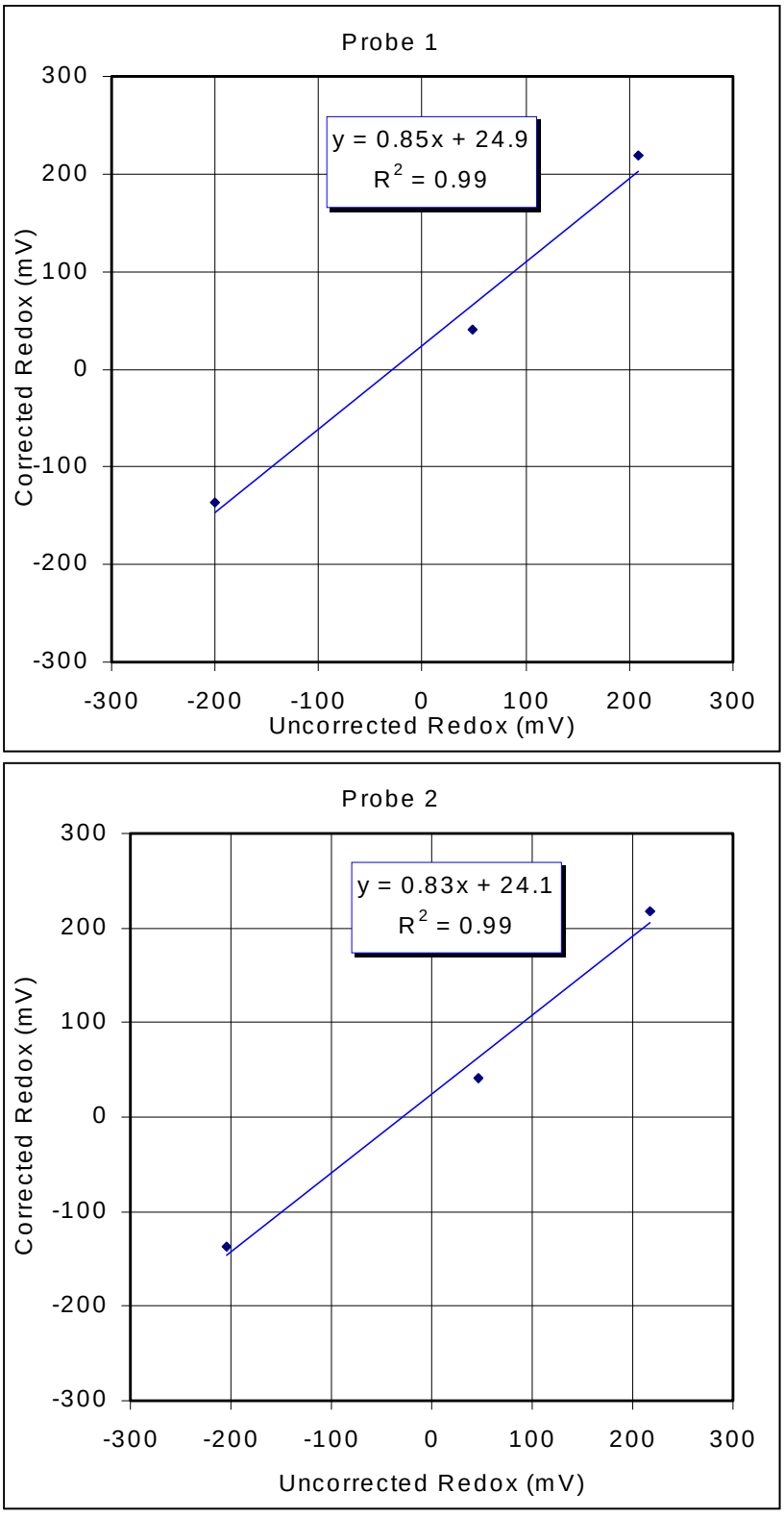
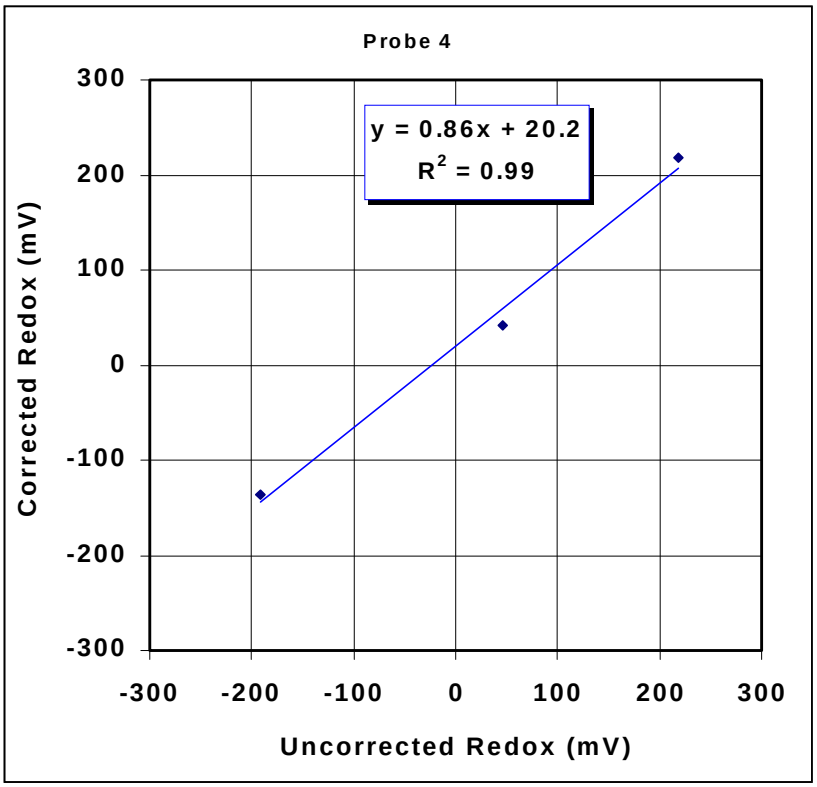


Figure 65. Redox potential calibration curves, PSRF, probes 1 and 2.



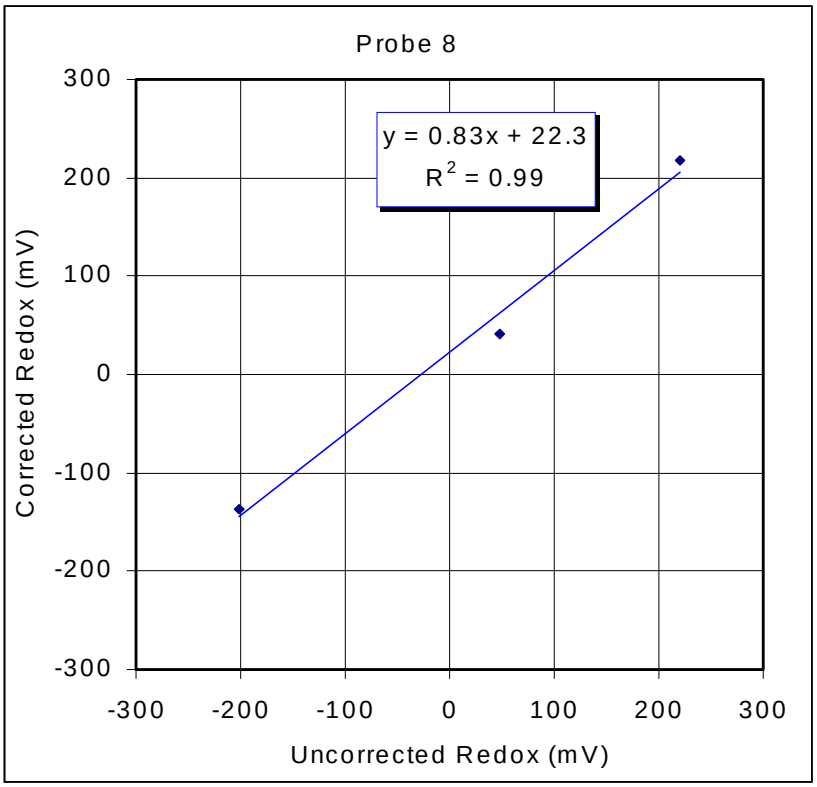


Figure 66. Redox potential calibration curves, PSRF, probes 4 and 8.

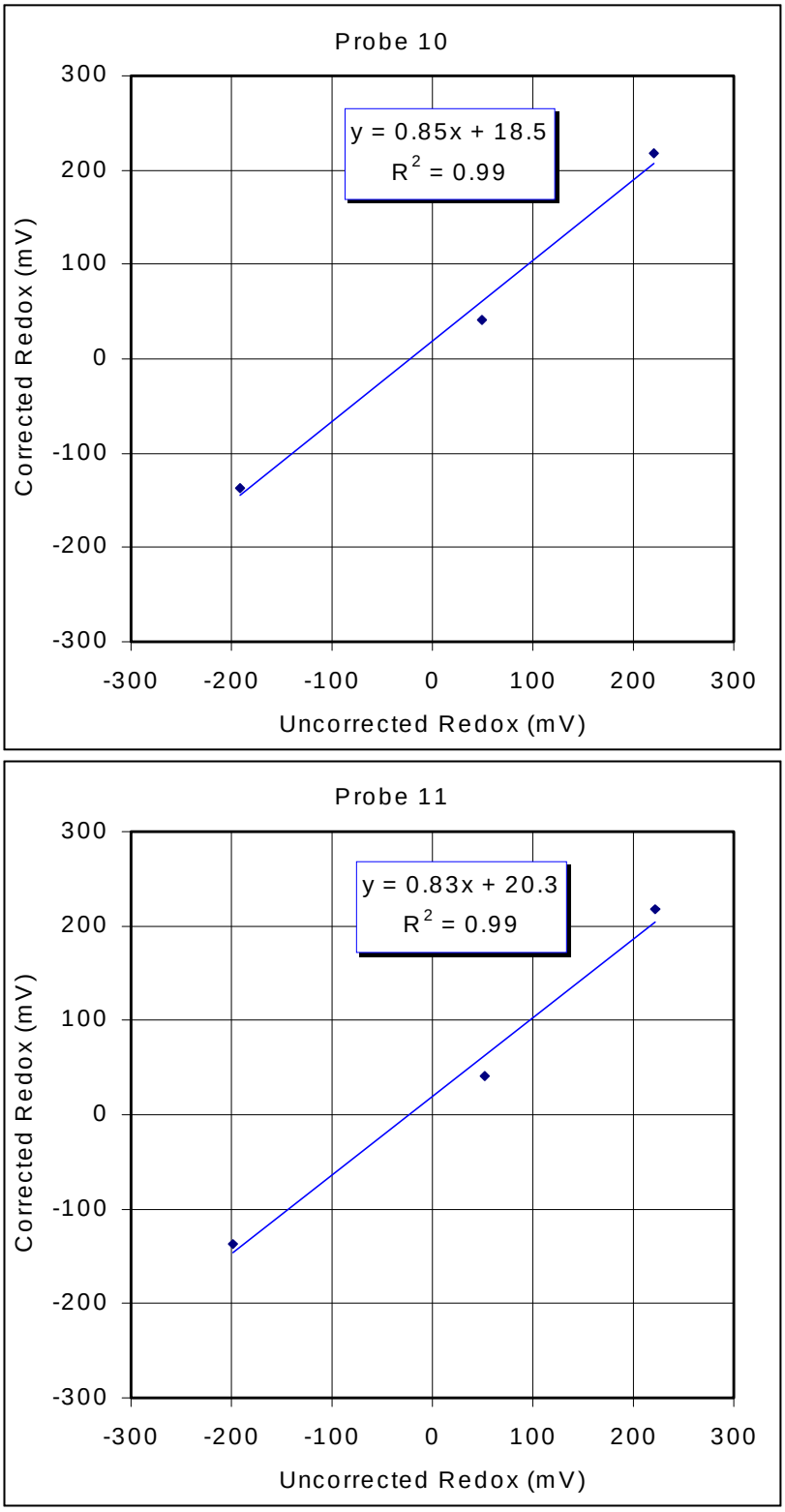


Figure 67. Redox potential calibration curves, PSRF, probes 10 and 11.

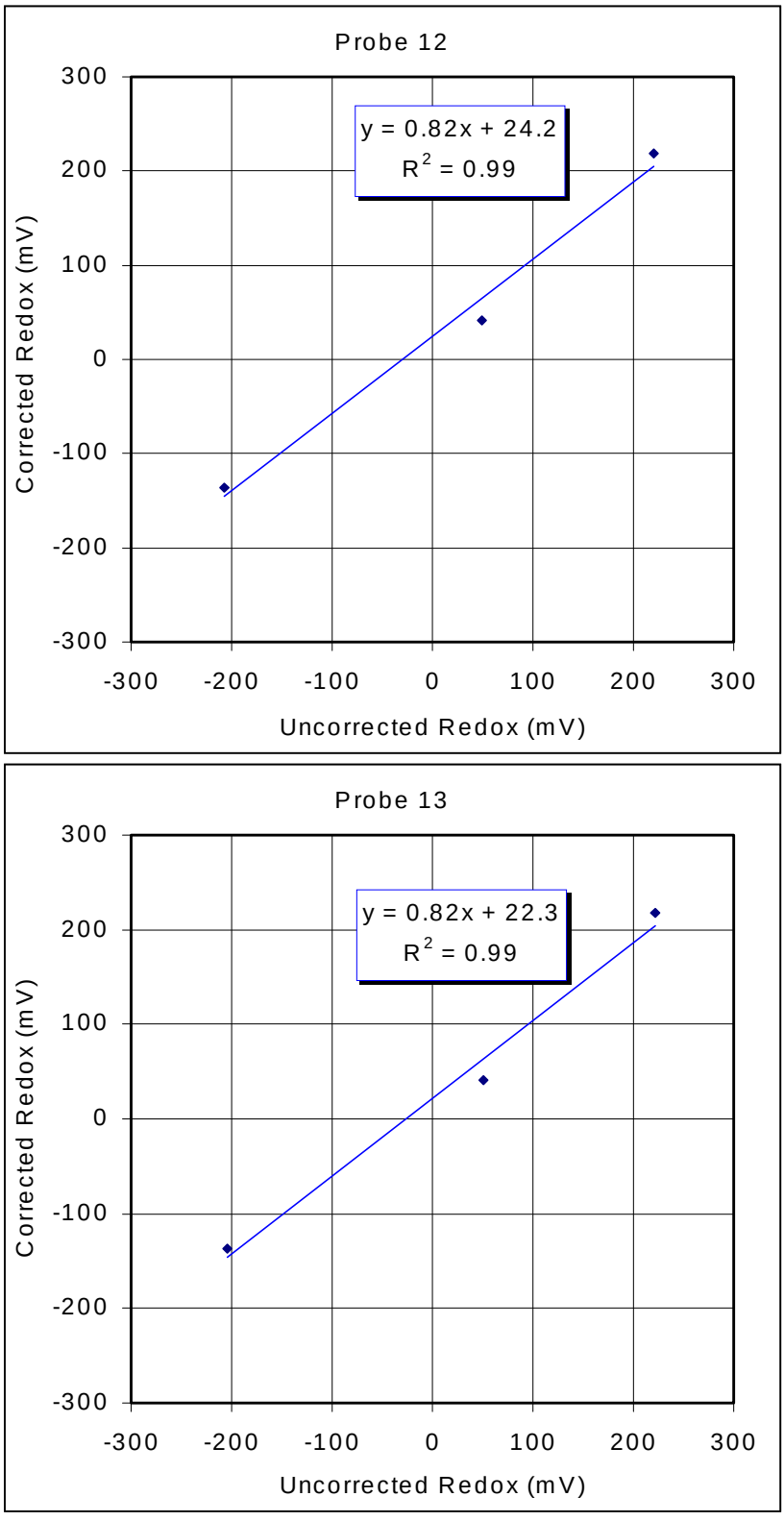
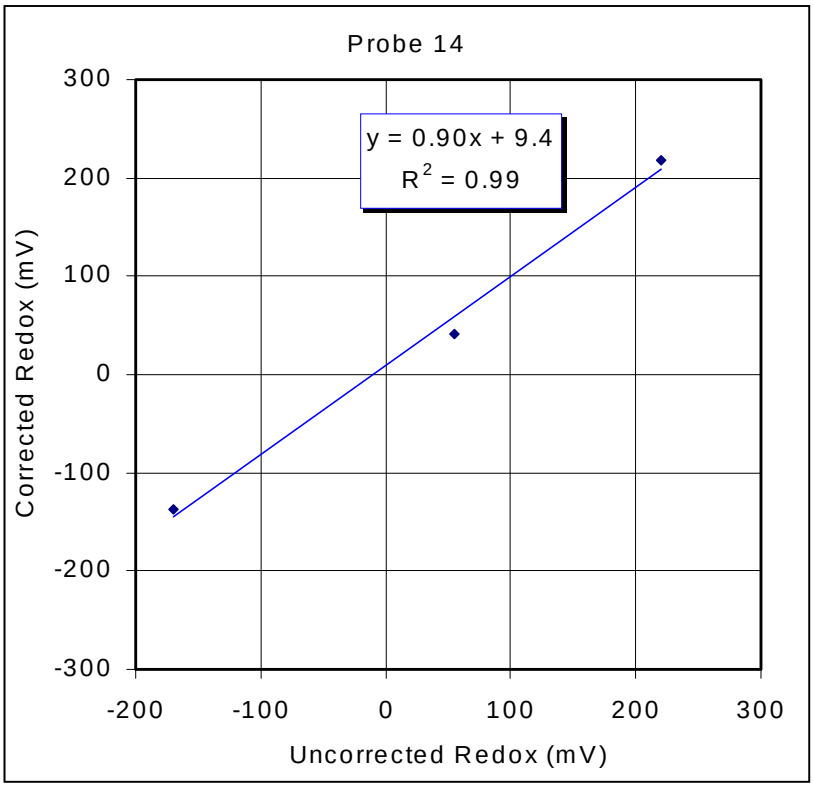


Figure 68. Redox potential calibration curves, PSRF, probes 12 and 13.



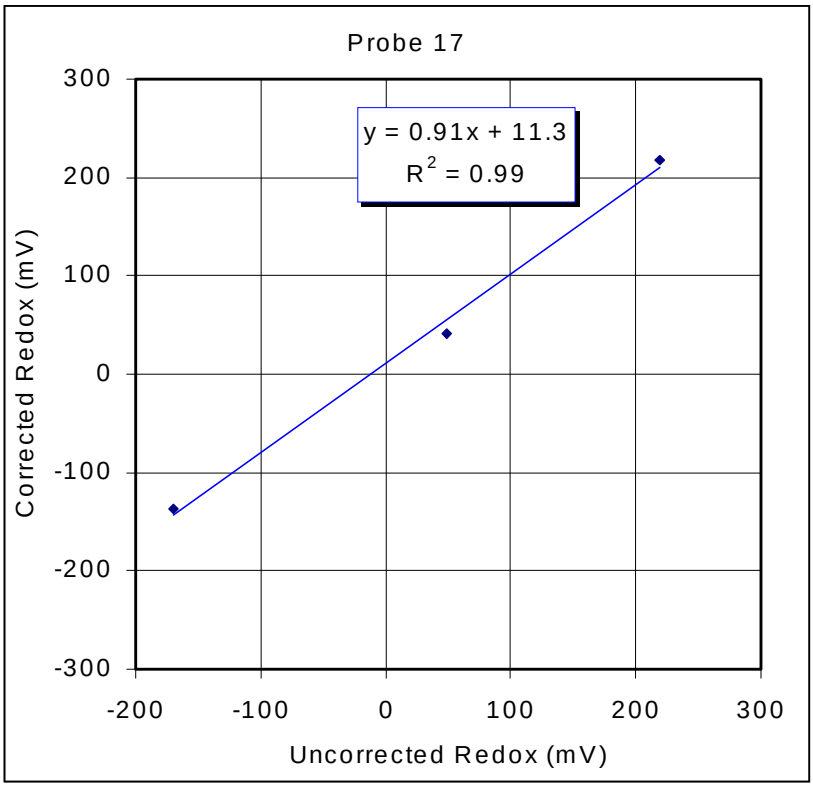
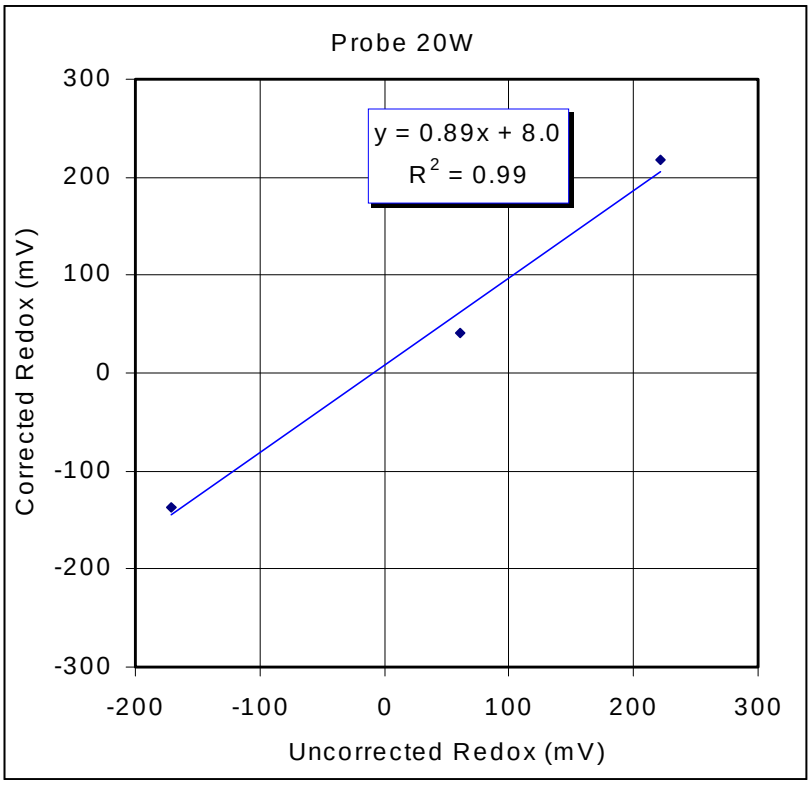


Figure 69. Redox potential calibration curves, PSRF, probes 14 and 17.



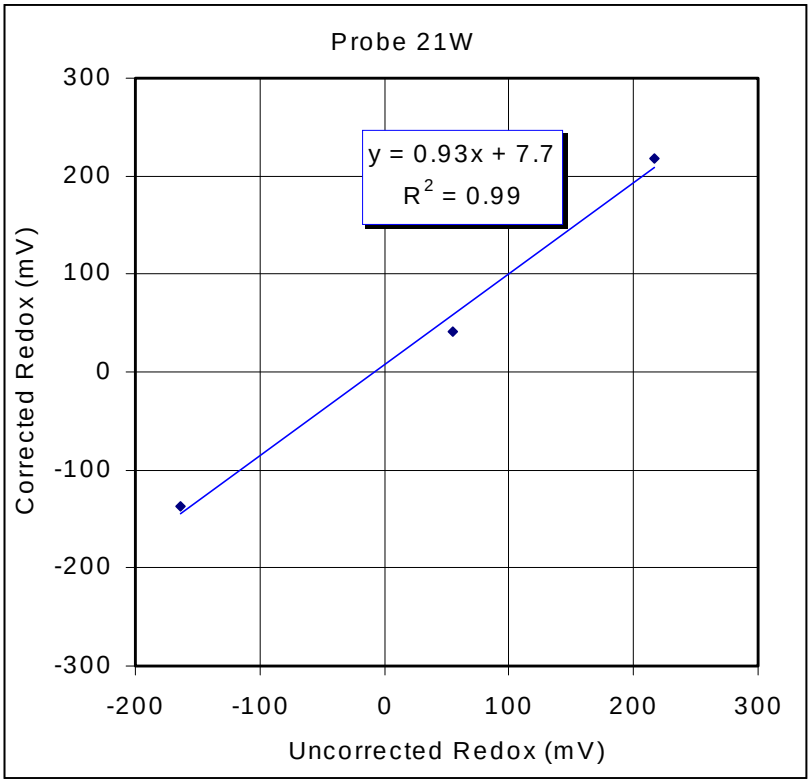


Figure 70. Redox potential calibration curves, PSRF, probes 20W and 21W.

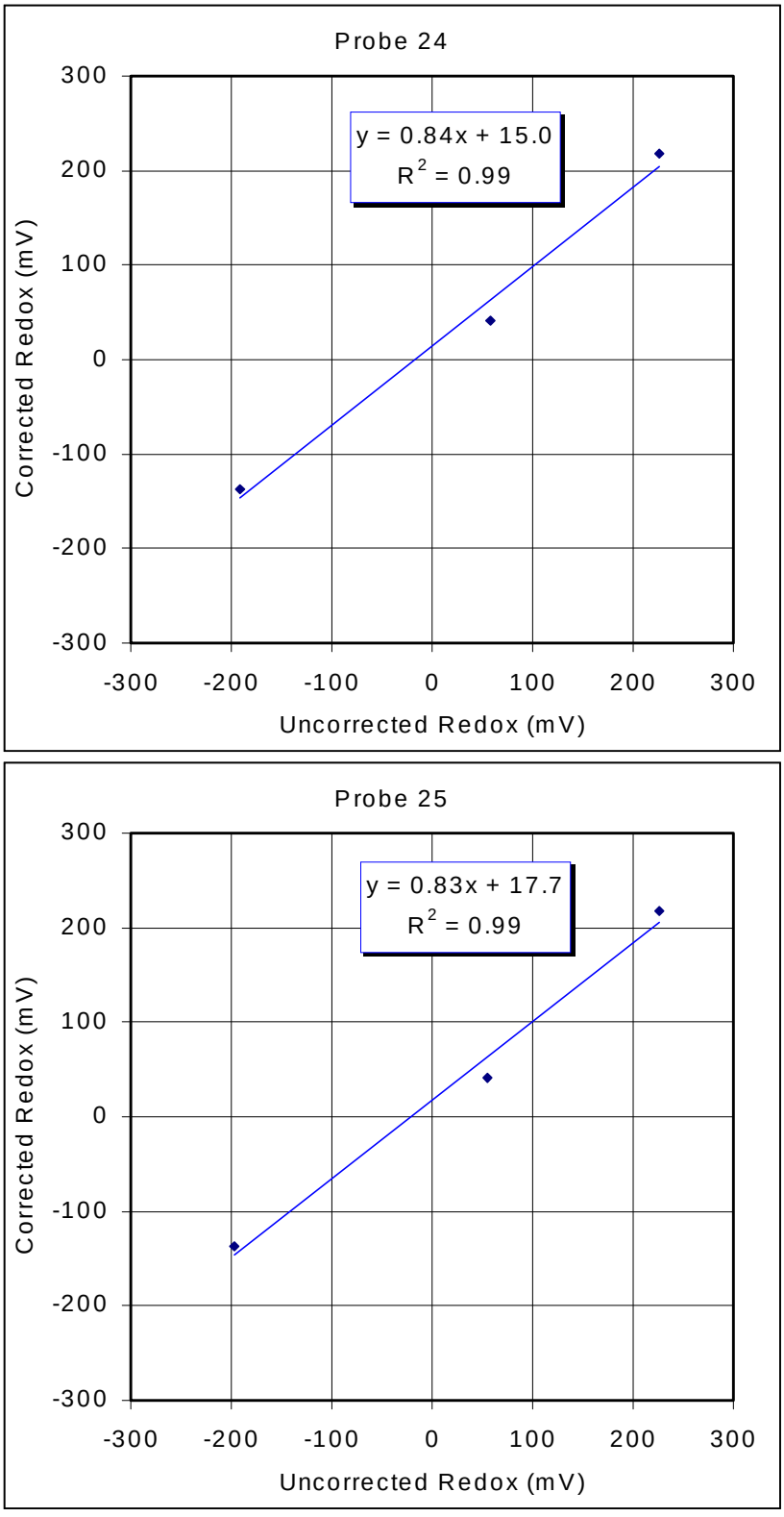
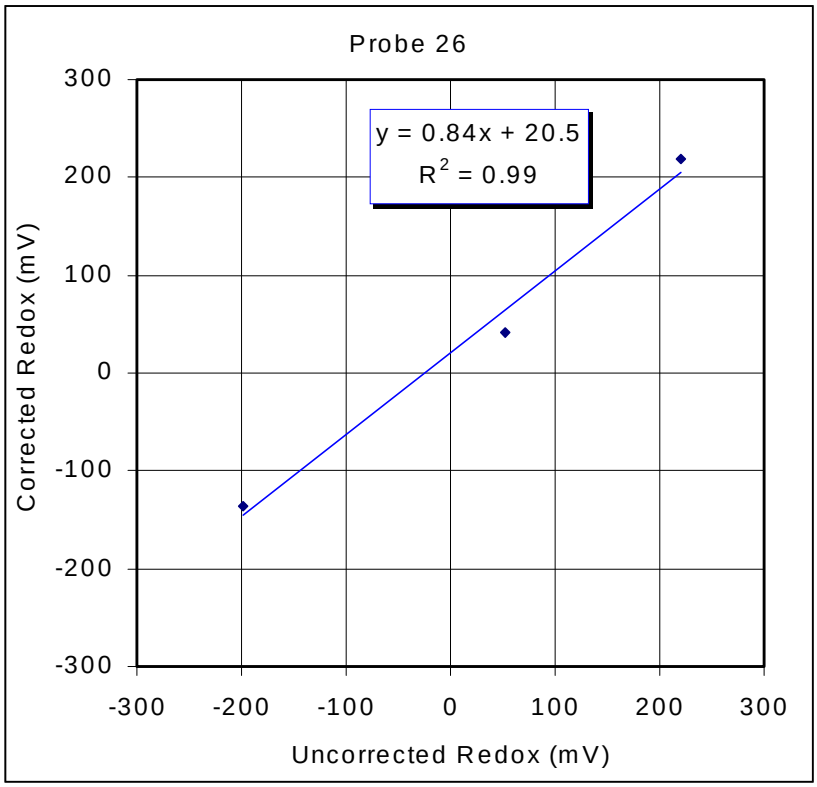


Figure 71. Redox potential calibration curves, PSRF, probes 24 and 25.



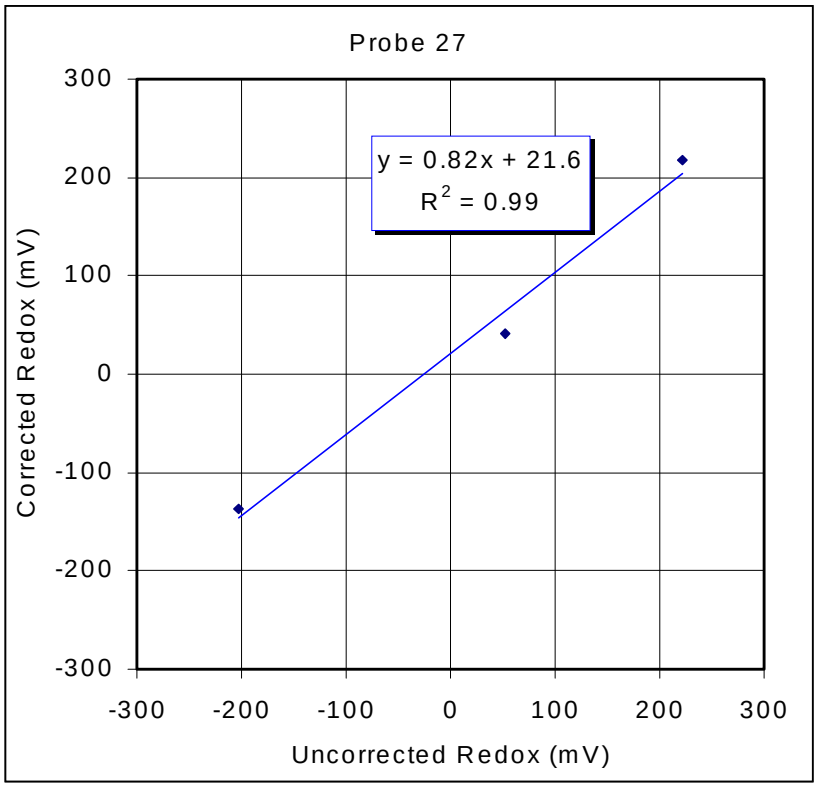
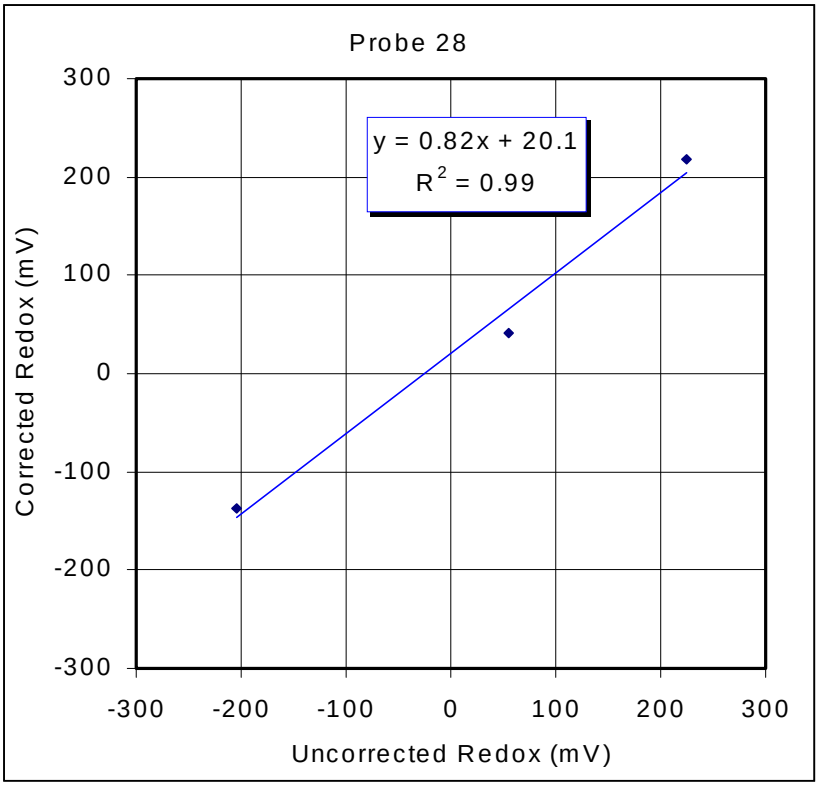


Figure 72. Redox potential calibration curves, PSRF, probes 26 and 27.



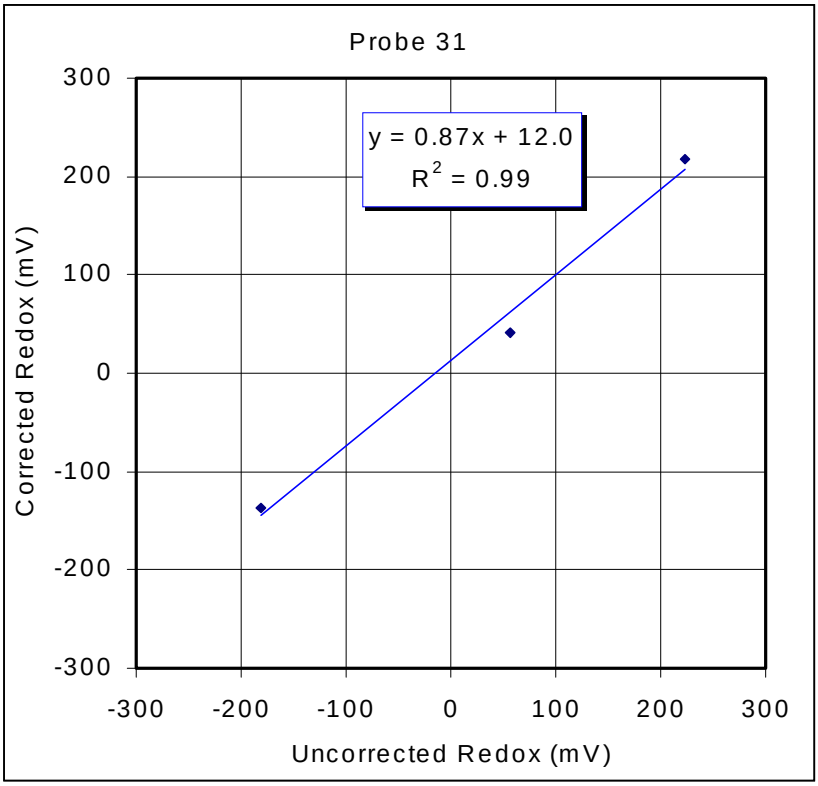


Figure 73. Redox potential calibration curves, PSRF, probes 28 and 31.

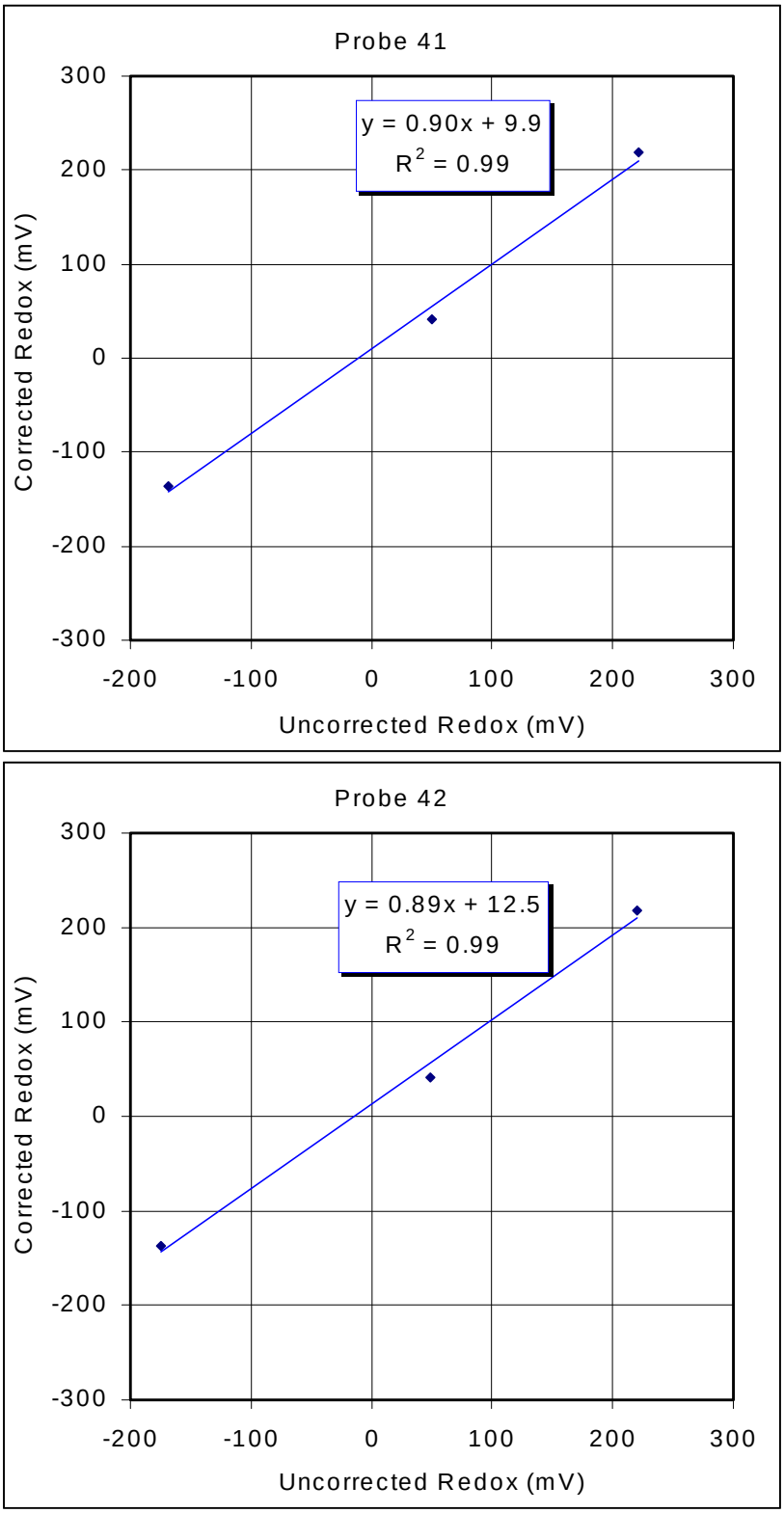


Figure 74. Redox potential calibration curves, PSRF, probes 41 and 42.

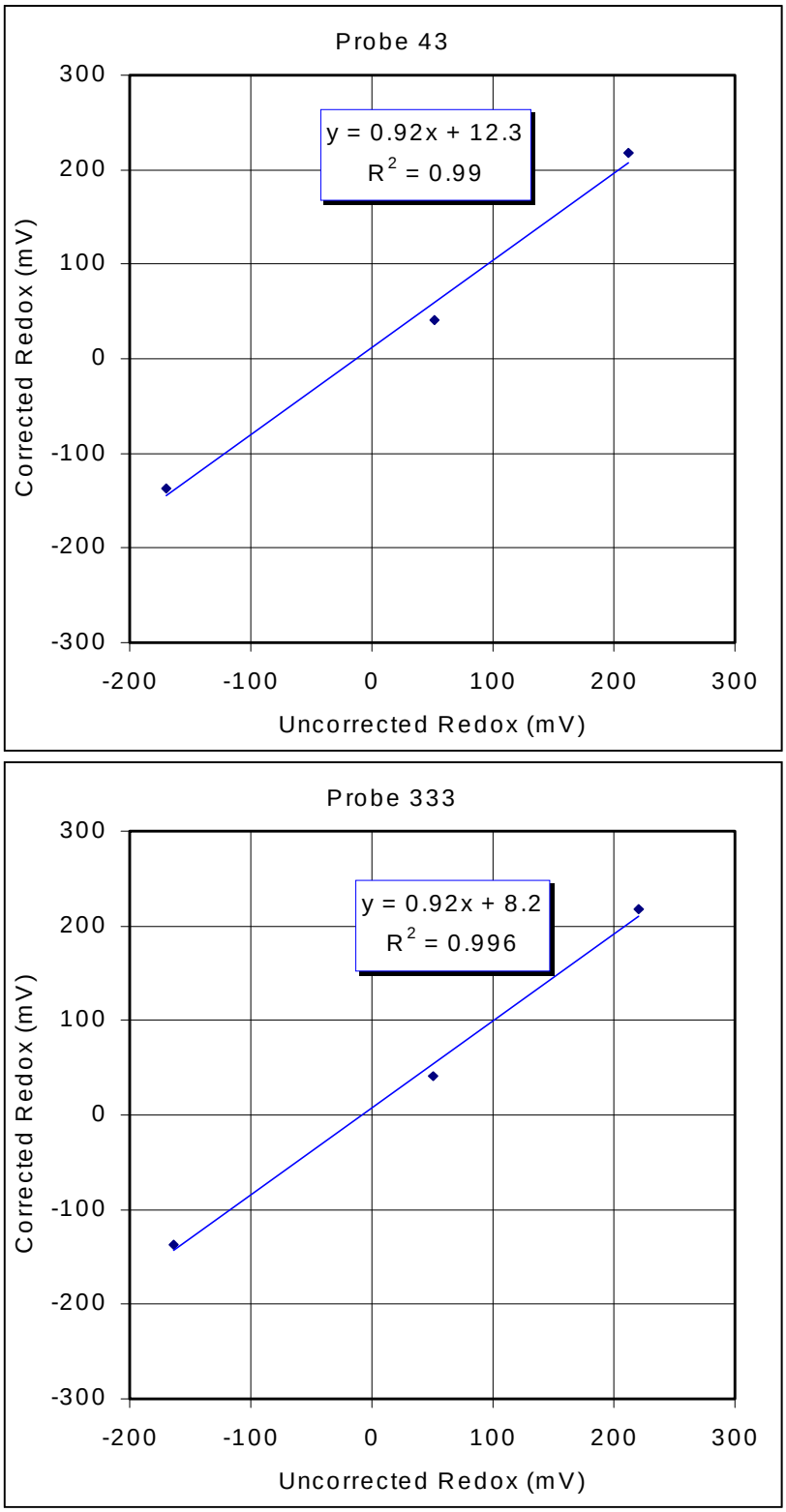


Figure 75. Redox potential calibration curves, PSRF, probes 43 and 333.

APPENDIX C

TEMPERATURE AND GROUNDWATER DESCRIPTIVE STATISTICS

Table 13. Key to abbreviations used in descriptive statistics, DPRS.

DEP_WELL	Depression Groundwater Well Level (cm)
OB_WELL	Overbank Groundwater Well Level (cm)
DP_PPT	Georgia Forestry Commission Weather Station Precipitation (cm)
MEAN_AIR	Mean Air Temperature
ADEP_15	Mean Soil Temperature at 15 cm , Depression
ADEP_30	Mean Soil Temperature at 30 cm , Depression
ADEP_51	Mean Soil Temperature at 51 cm , Depression
AOB_15	Mean Soil Temperature at 15 cm , Overbank
AOB_30	Mean Soil Temperature at 30 cm , Overbank
AOB_51	Mean Soil Temperature at 51 cm , Overbank
MIN_AIR	Minimum Air Temperature
MNDEP_15	Minimum Soil Temperature at 15 cm , Depression
MNDEP_30	Minimum Soil Temperature at 30 cm , Depression
MNDEP_51	Minimum Soil Temperature at 51 cm , Depression
MNOB_15	Minimum Soil Temperature at 15 cm , Overbank
MNOB_30	Minimum Soil Temperature at 30 cm , Overbank
MNOB_51	Minimum Soil Temperature at 51 cm , Overbank
MAX_AIR	Maximum Air Temperature
MXDEP_15	Maximum Soil Temperature at 15 cm , Depression
MXDEP_30	Maximum Soil Temperature at 30 cm , Depression
MXDEP_51	Maximum Soil Temperature at 51 cm , Depression
MXOB_15	Maximum Soil Temperature at 15 cm , Overbank
MXOB_30	Maximum Soil Temperature at 30 cm , Overbank
MXOB_51	Maximum Soil Temperature at 51 cm , Overbank
DEPMEH15	Mean Soil Redox Potential at 15 cm , Depression
DEPMEH30	Mean Soil Redox Potential at 30 cm , Depression
DEPMEH51	Mean Soil Redox Potential at 51 cm , Depression
OBMEH15	Mean Soil Redox Potential at 15 cm , Overbank
OBMEH30	Mean Soil Redox Potential at 30 cm , Overbank
OBMEH51	Mean Soil Redox Potential at 51 cm , Overbank
DEPMIE15	Minimum Soil Redox Potential at 15 cm , Depression
DEPMIE30	Minimum Soil Redox Potential at 30 cm , Depression
DEPMIE51	Minimum Soil Redox Potential at 51 cm , Depression
OBMIE15	Minimum Soil Redox Potential at 15 cm , Overbank
OBMIE30	Minimum Soil Redox Potential at 30 cm , Overbank
OBMIE51	Minimum Soil Redox Potential at 51 cm , Overbank
DEPMXE15	Maximum Soil Redox Potential at 15 cm , Depression
DEPMXE30	Maximum Soil Redox Potential at 30 cm , Depression
DEPMXE51	Maximum Soil Redox Potential at 51 cm , Depression
OBMXE15	Maximum Soil Redox Potential at 15 cm , Overbank
OBMXE30	Maximum Soil Redox Potential at 30 cm , Overbank
OBMXE51	Maximum Soil Redox Potential at 51 cm , Overbank

Table 14. Key to abbreviations used in descriptive statistics, PSRF.

FO_WELL	Forested Groundwater Well Level (cm)
EM_WELL	Emergent Groundwater Well Level (cm)
PS_PPT	PSRF Headquarters Weather Station Precipitation (cm)
M_AIR_PS	Mean Air Temperature
AFO_15	Mean Soil Temperature at 15 cm , Forested
AFO_25	Mean Soil Temperature at 25 cm , Forested
AFO_51	Mean Soil Temperature at 51 cm , Forested
AEM_15	Mean Soil Temperature at 15 cm , Emergent
AEM_25	Mean Soil Temperature at 25 cm , Emergent
AEM_51	Mean Soil Temperature at 51 cm , Emergent
PSMI_AIR	Minimum Air Temperature
MINFO_15	Minimum Soil Temperature at 15 cm , Forested
MINFO_25	Minimum Soil Temperature at 25 cm , Forested
MINFO_51	Minimum Soil Temperature at 51 cm , Forested
MINEM_15	Minimum Soil Temperature at 15 cm , Emergent
MINEM_25	Minimum Soil Temperature at 25 cm , Emergent
MINEM_51	Minimum Soil Temperature at 51 cm , Emergent
PSMX_AIR	Maximum Air Temperature
MAXFO_15	Maximum Soil Temperature at 15 cm , Forested
MAXFO_25	Maximum Soil Temperature at 25 cm , Forested
MAXFO_51	Maximum Soil Temperature at 51 cm , Forested
MAXEM_15	Maximum Soil Temperature at 15 cm , Emergent
MAXEM_25	Maximum Soil Temperature at 25 cm , Emergent
MAXEM_51	Maximum Soil Temperature at 51 cm , Emergent
FOME15	Mean Soil Redox Potential at 15 cm , Forested
FOME25	Mean Soil Redox Potential at 25 cm , Forested
FOME51	Mean Soil Redox Potential at 51 cm , Forested
EMME15	Mean Soil Redox Potential at 15 cm , Emergent
EMME25	Mean Soil Redox Potential at 25 cm , Emergent
EMME51	Mean Soil Redox Potential at 51 cm , Emergent
FOMINE15	Minimum Soil Redox Potential at 15 cm , Forested
FOMINE25	Minimum Soil Redox Potential at 25 cm , Forested
FOMINE51	Minimum Soil Redox Potential at 51 cm , Forested
EMMINE15	Minimum Soil Redox Potential at 15 cm , Emergent
EMMINE25	Minimum Soil Redox Potential at 25 cm , Emergent
EMMINE51	Minimum Soil Redox Potential at 51 cm , Emergent
FOMXE15	Maximum Soil Redox Potential at 15 cm , Forested
FOMXE25	Maximum Soil Redox Potential at 25 cm , Forested
FOMXE51	Maximum Soil Redox Potential at 51 cm , Forested
EMMXE15	Maximum Soil Redox Potential at 15 cm , Emergent
EMMXE25	Maximum Soil Redox Potential at 25 cm , Emergent
EMMXE51	Maximum Soil Redox Potential at 51 cm , Emergent

Table 15. DPRS temperature, precipitation, and water table descriptive statistics (all data, across seasons).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEP_WELL	847	-40.2	-47.3		-103.0	14.3	1811	43	1.5	-0.1	-1.7
OB_WELL	847	-92.2	-98.4		-99.2	13.9	376	19	0.7	4.0	16.7
DP_PPT	1247	0.3	0.0	371.8	0.0	9.3	1	1	0.0	5.0	33.5
MEAN_AIR	851	17.0	19.0		-6.3	29.1	65	8	0.3	-0.7	-0.4
ADEP_15	876	16.8	18.8		0.7	26.5	51	7	0.2	-0.7	-0.7
ADEP_30	807	17.4	19.4		1.9	26.5	49	7	0.2	-0.7	-0.8
ADEP_51	870	17.0	19.1		2.6	25.5	40	6	0.2	-0.8	-0.6
AOB_15	879	17.1	18.8		3.0	25.0	35	6	0.2	-0.6	-0.9
AOB_30	879	17.0	18.7		4.4	24.8	30	6	0.2	-0.6	-0.9
AOB_51	879	17.1	18.9		6.9	22.8	22	5	0.2	-0.6	-0.9
MIN_AIR	851	11.5	13.8		-13.5	24.5	78	9	0.3	-0.6	-0.6
MNDEP_15	803	17.2	18.8		0.7	26.0	45	7	0.2	-0.8	-0.5
MNDEP_30	803	17.0	19.3		-9.0	26.3	51	7	0.3	-0.7	-0.6
MNDEP_51	870	16.9	19.0		2.6	25.5	40	6	0.2	-0.8	-0.7
MNOB_15	879	16.9	18.6		2.9	24.8	35	6	0.2	-0.6	-0.9
MNOB_30	879	16.8	18.6		4.3	24.4	30	6	0.2	-0.6	-0.9
MNOB_51	878	17.0	18.9		6.9	22.8	22	5	0.2	-0.6	-0.9
MAX_AIR	851	23.8	25.8		-0.4	38.9	64	8	0.3	-0.8	0.0
MXDEP_15	876	17.5	19.3		0.7	26.9	50	7	0.2	-0.7	-0.6
MXDEP_30	817	17.6	19.5		1.9	26.6	47	7	0.2	-0.7	-0.7
MXDEP_51	870	17.2	19.2		2.7	25.5	39	6	0.2	-0.8	-0.6
MXOB_15	879	17.4	19.2		3.2	25.2	35	6	0.2	-0.6	-0.9
MXOB_30	879	17.2	18.8		4.5	25.2	30	6	0.2	-0.6	-0.9
MXOB_51	879	17.2	19.0		6.9	22.8	22	5	0.2	-0.6	-0.9

Note: well and precipitation reported in cm, temperature in °C, see Table 13 for abbreviations.

Table 16. DPRS temperature, precipitation, and water table descriptive statistics (winter).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEP_WELL	317	-20.1	1.5		-99.6	14.3	1157	34	1.9	-0.9	-0.8
OB_WELL	317	-92.9	-98.5		-99.2	-37.0	169	13	0.7	2.4	5.0
DP_PPT	317	0.4	0.0	121.7	0.0	9.2	1	1	0.1	4.4	25.1
MEAN_AIR	91	4.8	5.7		-6.3	15.5	25	5	0.5	-0.3	-0.5
ADEP_15	119	5.6	6.2		0.7	13.1	11	3	0.3	0.0	-0.9
ADEP_30	104	6.0	5.9		1.9	13.3	9	3	0.3	0.4	-0.7
ADEP_51	110	6.2	6.0		2.6	11.9	6	2	0.2	0.3	-0.8
AOB_15	119	7.5	7.5		3.0	12.8	5	2	0.2	0.1	-0.6
AOB_30	119	7.8	7.9		4.4	11.9	3	2	0.2	0.1	-0.7
AOB_51	119	9.0	8.8		6.9	12.6	2	1	0.1	0.4	-0.3
MIN_AIR	91	-0.9	-0.6		-13.5	8.5	31	6	0.6	-0.2	-0.9
MNDEP_15	101	5.9	6.2		0.7	12.4	8	3	0.3	-0.1	-0.7
MNDEP_30	110	5.9	5.8		-9.0	12.9	13	4	0.3	-0.5	1.6
MNDEP_51	110	6.0	5.7		2.6	11.8	6	2	0.2	0.3	-0.9
MNOB_15	119	7.2	7.3		2.9	12.4	5	2	0.2	0.0	-0.7
MNOB_30	119	7.7	7.8		4.3	11.8	3	2	0.2	0.1	-0.7
MNOB_51	119	8.9	8.7		6.9	12.5	2	1	0.1	0.5	-0.2
MAX_AIR	91	12.1	10.7		-0.4	26.0	45	7	0.7	0.2	-1.0
MXDEP_15	119	6.1	6.7		0.7	14.1	12	3	0.3	0.0	-0.9
MXDEP_30	110	6.6	7.1		1.9	13.8	11	3	0.3	0.3	-0.8
MXDEP_51	110	6.4	6.2		2.7	12.7	6	3	0.2	0.3	-0.6
MXOB_15	119	7.8	7.9		3.2	13.1	5	2	0.2	0.1	-0.6
MXOB_30	119	8.0	8.0		4.5	12.0	3	2	0.2	0.1	-0.7
MXOB_51	119	9.0	8.9		6.9	12.6	2	1	0.1	0.4	-0.4

Note: well and precipitation reported in cm, temperature in °C, see Table 13 for abbreviations.

Table 17. DPRS temperature, precipitation, and water table descriptive statistics (spring).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEP_WELL	197	-18.2	-0.1		-99.7	14.3	1380	37	2.6	-1.2	-0.1
OB_WELL	197	-80.7	-98.2		-99.2	13.9	1154	34	2.4	2.0	2.5
DP_PPT	306	0.3	0.0	77.3	0.0	6.6	1	1	0.0	4.7	28.7
MEAN_AIR	251	19.5	19.9		6.7	27.6	20	5	0.3	-0.5	-0.5
ADEP_15	248	19.2	19.2		10.6	25.1	12	4	0.2	-0.1	-1.0
ADEP_30	203	18.9	18.5		11.3	24.7	12	3	0.2	0.1	-1.1
ADEP_51	251	18.2	18.5		11.1	23.6	10	3	0.2	0.0	-1.0
AOB_15	251	18.1	18.5		9.6	23.5	11	3	0.2	-0.2	-1.1
AOB_30	251	17.5	17.6		11.5	22.6	10	3	0.2	0.0	-1.3
AOB_51	251	17.2	17.2		10.3	21.5	8	3	0.2	-0.3	-0.9
MIN_AIR	251	13.5	14.3		-1.9	23.1	34	6	0.4	-0.5	-0.5
MNDEP_15	248	18.7	18.7		9.7	24.7	13	4	0.2	-0.2	-1.0
MNDEP_30	203	18.6	18.4		11.1	24.5	12	4	0.2	0.1	-1.2
MNDEP_51	251	18.1	18.3		11.1	23.5	10	3	0.2	0.0	-1.0
MNOB_15	251	17.9	18.3		9.2	23.4	12	3	0.2	-0.2	-1.1
MNOB_30	251	17.4	17.5		11.2	22.6	10	3	0.2	-0.1	-1.3
MNOB_51	250	17.1	17.2		10.2	21.4	8	3	0.2	-0.3	-0.9
MAX_AIR	251	26.3	26.9		12.3	35.3	19	4	0.3	-0.7	0.4
MXDEP_15	248	19.8	19.9		11.5	25.6	11	3	0.2	-0.1	-1.0
MXDEP_30	203	19.1	18.7		11.4	24.9	12	3	0.2	0.1	-1.1
MXDEP_51	251	18.4	18.6		11.2	23.7	10	3	0.2	0.0	-0.9
MXOB_15	251	18.4	18.8		10.3	23.8	11	3	0.2	-0.2	-1.1
MXOB_30	251	17.7	17.8		11.8	22.7	9	3	0.2	0.0	-1.4
MXOB_51	251	17.2	17.2		10.3	21.5	8	3	0.2	-0.3	-0.9

Note: well and precipitation reported in cm, temperature in °C, see Table 13 for abbreviations.

Table 18. DPRS temperature, precipitation, and water table descriptive statistics (summer).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEP_WELL	98	-95.2	-98.2		-98.7	-66.4	63	8	0.8	3.0	8.3
OB_WELL	98	-98.2	-98.2		-98.7	-97.5	0	0	0.0	0.1	-1.4
DP_PPT	260	0.3	0.0	65.0	0.0	4.9	1	1	0.0	3.9	16.9
MEAN_AIR	260	24.1	24.3		14.9	29.1	7	3	0.2	-0.8	0.5
ADEP_15	260	23.5	23.8		18.9	26.5	3	2	0.1	-0.7	0.0
ADEP_30	255	23.8	24.2		16.7	26.5	2	1	0.1	-0.9	1.3
ADEP_51	260	22.9	22.6		20.5	25.5	2	1	0.1	0.3	-0.9
AOB_15	260	23.0	23.2		19.4	25.0	2	1	0.1	-0.9	0.3
AOB_30	260	22.6	22.7		19.6	24.8	1	1	0.1	-0.6	-0.1
AOB_51	260	21.8	21.9		20.1	22.8	0	1	0.0	-0.9	0.4
MIN_AIR	260	19.0	19.6		7.6	24.5	10	3	0.2	-1.1	1.2
MNDEP_15	260	23.0	23.4		18.4	26.0	3	2	0.1	-0.7	-0.2
MNDEP_30	252	23.7	24.1		20.5	26.3	2	1	0.1	-0.6	-0.4
MNDEP_51	260	22.8	22.5		20.5	25.5	2	1	0.1	0.3	-0.9
MNOB_15	260	22.8	23.1		19.0	24.8	2	1	0.1	-0.9	0.3
MNOB_30	260	22.4	22.5		19.5	24.4	1	1	0.1	-0.7	0.0
MNOB_51	260	21.7	21.8		20.1	22.8	0	1	0.0	-0.9	0.3
MAX_AIR	260	30.5	30.8		18.0	38.9	12	3	0.2	-0.5	0.8
MXDEP_15	260	24.0	24.3		19.3	26.9	3	2	0.1	-0.8	0.1
MXDEP_30	255	24.0	24.3		20.7	26.6	2	1	0.1	-0.6	-0.3
MXDEP_51	260	23.0	22.7		20.6	25.5	2	1	0.1	0.3	-0.9
MXOB_15	260	23.3	23.6		19.8	25.2	2	1	0.1	-0.9	0.3
MXOB_30	260	22.7	22.9		19.7	25.2	1	1	0.1	-0.5	-0.2
MXOB_51	260	21.8	21.9		20.1	22.8	0	1	0.0	-0.9	0.4

Note: well and precipitation reported in cm, temperature in °C, see Table 13 for abbreviations.

Table 19. DPRS temperature, precipitation, and water table descriptive statistics (fall).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEP_WELL	235	-62.9	-66.4		-103.0	7.4	1068	33	2.1	1.0	0.0
OB_WELL	235	-98.4	-98.4		-99.2	-97.2	0	0	0.0	-0.1	0.2
DP_PPT	364	0.3	0.0	107.7	0.0	9.3	1	1	0.0	5.6	41.1
MEAN_AIR	249	11.6	12.9		-6.1	24.1	45	7	0.4	-0.3	-0.9
ADEP_15	249	13.0	14.7		1.9	22.8	34	6	0.4	-0.3	-1.3
ADEP_30	245	14.2	15.7		3.1	24.0	35	6	0.4	-0.2	-1.3
ADEP_51	249	14.5	16.5		3.8	22.0	29	5	0.3	-0.4	-1.3
AOB_15	249	14.6	15.7		5.0	22.1	21	5	0.3	-0.3	-1.4
AOB_30	249	15.0	16.0		6.5	21.5	17	4	0.3	-0.3	-1.4
AOB_51	249	16.0	16.9		9.3	21.1	12	3	0.2	-0.4	-1.3
MIN_AIR	249	6.1	6.3		-10.7	22.1	61	8	0.5	0.0	-0.9
MNDEP_15	194	13.4	15.9		1.7	22.3	34	6	0.4	-0.5	-1.1
MNDEP_30	238	13.8	15.0		3.0	23.3	36	6	0.4	-0.2	-1.4
MNDEP_51	249	14.3	16.4		3.7	21.6	29	5	0.3	-0.4	-1.3
MNOB_15	249	14.3	15.4		4.9	22.0	21	5	0.3	-0.3	-1.4
MNOB_30	249	14.8	15.8		6.3	21.2	17	4	0.3	-0.3	-1.4
MNOB_51	249	15.9	16.9		9.1	21.0	12	3	0.2	-0.4	-1.3
MAX_AIR	249	18.6	19.1		0.4	29.5	40	6	0.4	-0.6	-0.3
MXDEP_15	249	13.8	15.7		2.0	23.3	33	6	0.4	-0.3	-1.3
MXDEP_30	249	14.7	16.1		3.2	25.1	34	6	0.4	-0.2	-1.3
MXDEP_51	249	14.8	16.6		3.9	24.1	29	5	0.3	-0.4	-1.3
MXOB_15	249	15.0	16.2		5.3	22.3	21	5	0.3	-0.3	-1.4
MXOB_30	249	15.2	16.2		6.8	21.7	17	4	0.3	-0.3	-1.4
MXOB_51	249	16.1	17.0		9.5	21.2	12	3	0.2	-0.4	-1.3

Note: well and precipitation reported in cm, temperature in °C, see Table 13 for abbreviations.

Table 20. PSRF temperature, precipitation, and water table descriptive statistics (all data, across seasons).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
EM_WELL	505	-23.3	-43.3		-45.5	66.1	859	29	1.3	1.1	-0.1
FO_WELL	582	-25.9	-13.5		-72.2	9.4	1049	32	1.3	-0.4	-1.6
PS_PPT	1247	0.3	0.0	359.7	0.0	10.7	1	1	0.0	5.4	40.8
M_AIR_PS	438	16.3	17.7		-4.1	29.5	70	8	0.4	-0.5	-0.8
AFO_15	437	15.9	17.2		4.5	24.7	29	5	0.3	-0.4	-1.1
AFO_25	438	16.7	18.5		5.2	25.8	32	6	0.3	-0.5	-1.1
AFO_51	478	16.2	17.9		5.9	23.4	27	5	0.2	-0.4	-1.3
AEM_15	452	14.5	15.6		2.2	25.6	42	6	0.3	-0.3	-1.2
AEM_25	479	15.1	16.4		3.5	24.1	36	6	0.3	-0.3	-1.3
AEM_51	463	14.1	15.1		3.8	24.9	31	6	0.3	-0.2	-1.3
PSMI_AIR	456	10.4	11.7		-11.7	23.2	78	9	0.4	-0.4	-1.0
MINFO_15	456	15.4	16.9		3.9	24.1	29	5	0.3	-0.5	-1.1
MINFO_25	456	16.6	18.3		4.7	25.4	32	6	0.3	-0.5	-1.1
MINFO_51	478	16.1	17.7		5.8	23.3	27	5	0.2	-0.4	-1.3
MINEM_15	452	13.8	15.1		2.1	23.3	40	6	0.3	-0.3	-1.3
MINEM_25	479	14.8	16.0		3.5	23.6	36	6	0.3	-0.3	-1.3
MINEM_51	464	13.9	15.1		3.7	24.7	31	6	0.3	-0.2	-1.3
PSMX_AIR	456	23.5	24.7		0.1	38.5	71	8	0.4	-0.7	-0.2
MAXFO_15	456	16.9	18.2		5.0	27.1	29	5	0.3	-0.5	-0.9
MAXFO_25	453	17.4	19.0		5.5	27.3	33	6	0.3	-0.5	-1.0
MAXFO_51	477	16.3	18.2		5.9	23.5	26	5	0.2	-0.4	-1.3
MAXEM_15	448	15.3	16.1		2.3	26.6	44	7	0.3	-0.3	-1.1
MAXEM_25	479	15.4	16.6		3.6	24.6	36	6	0.3	-0.3	-1.3
MAXEM_51	466	14.1	15.2		0.0	24.6	33	6	0.3	-0.3	-1.2

Note: well and precipitation reported in cm, temperature in °C, see Table 14 for abbreviations.

Table 21. PSRF temperature, precipitation, and water table descriptive statistics (winter).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
EM_WELL	101	-0.6	0.0		-44.5	66.1	1112	33	3.3	0.0	-1.3
FO_WELL	137	6.0	6.1		1.7	9.0	1	1	0.1	-0.5	1.7
PS_PPT	317	0.4	0.0	123.2	0.0	8.1	1	1	0.1	4.2	21.4
M_AIR_PS	113	5.9	5.4		-4.1	17.0	27	5	0.5	0.1	-0.9
AFO_15	113	8.6	8.6		4.5	14.2	5	2	0.2	0.2	-0.5
AFO_25	113	8.9	9.0		5.2	14.1	5	2	0.2	0.0	-0.6
AFO_51	135	9.6	9.5		5.9	13.6	4	2	0.2	0.1	-1.3
AEM_15	136	6.7	6.6		2.2	12.7	7	3	0.2	0.3	-1.0
AEM_25	136	7.5	7.2		3.5	12.8	5	2	0.2	0.3	-0.9
AEM_51	136	7.1	6.9		3.8	11.2	4	2	0.2	0.3	-1.0
PSMI_AIR	113	-0.8	-1.2		-11.7	11.0	23	5	0.4	0.2	-0.5
MINFO_15	113	7.9	8.0		3.9	13.7	4	2	0.2	0.1	-0.4
MINFO_25	113	8.5	8.7		4.7	13.9	4	2	0.2	0.0	-0.6
MINFO_51	135	9.4	9.4		5.8	13.4	4	2	0.2	0.1	-1.3
MINEM_15	136	6.0	6.2		2.1	11.8	6	2	0.2	0.3	-0.9
MINEM_25	136	7.2	6.9		3.5	12.6	5	2	0.2	0.3	-0.9
MINEM_51	136	6.9	6.7		3.7	11.1	3	2	0.2	0.3	-1.0
PSMX_AIR	113	13.9	13.7		0.1	28.5	47	7	0.6	0.0	-0.8
MAXFO_15	113	9.4	9.2		5.0	15.5	6	3	0.2	0.3	-0.6
MAXFO_25	113	9.4	9.4		5.5	14.4	5	2	0.2	0.1	-0.6
MAXFO_51	135	9.7	9.8		5.9	13.7	4	2	0.2	0.1	-1.2
MAXEM_15	136	7.4	7.2		2.3	13.7	8	3	0.2	0.3	-0.9
MAXEM_25	136	7.8	7.5		3.6	12.9	6	2	0.2	0.3	-0.9
MAXEM_51	136	7.3	7.1		3.8	11.4	4	2	0.2	0.3	-1.0

Note: well and precipitation reported in cm, temperature in °C, see Table 14 for abbreviations.

Table 22. PSRF temperature, precipitation, and water table descriptive statistics (spring).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
EM_WELL	109	-3.4	-6.5		-43.8	37.6	956	31	3.0	0.0	-1.7
FO_WELL	109	-26.1	-13.8		-72.0	9.4	981	31	3.0	-0.4	-1.6
PS_PPT	306	0.3	0.0	82.3	0.0	6.9	1	1	0.0	4.8	30.1
M_AIR_PS	109	19.4	20.4		7.6	28.4	24	5	0.5	-0.5	-0.7
AFO_15	108	16.9	17.4		11.3	21.6	9	3	0.3	-0.1	-1.3
AFO_25	109	17.3	17.9		12.0	22.3	10	3	0.3	-0.1	-1.5
AFO_51	109	17.3	17.8		12.9	23.1	9	3	0.3	0.0	-1.6
AEM_15	109	16.9	17.1		11.1	23.5	13	4	0.3	0.2	-1.1
AEM_25	109	17.2	17.5		11.9	23.0	12	3	0.3	0.1	-1.3
AEM_51	109	15.7	15.7		10.8	21.8	10	3	0.3	0.3	-1.1
PSMI_AIR	109	13.0	13.8		-1.7	21.6	36	6	0.6	-0.4	-0.9
MINFO_15	109	16.1	16.7		9.9	21.0	10	3	0.3	-0.1	-1.3
MINFO_25	109	16.9	17.6		11.3	21.7	11	3	0.3	-0.1	-1.5
MINFO_51	109	17.2	17.5		12.6	21.5	9	3	0.3	0.0	-1.6
MINEM_15	109	16.0	16.3		9.7	22.8	13	4	0.4	0.1	-1.2
MINEM_25	109	16.8	17.2		11.3	22.5	12	3	0.3	0.1	-1.4
MINEM_51	109	15.5	15.6		10.6	21.1	10	3	0.3	0.2	-1.2
PSMX_AIR	109	26.5	27.3		11.6	35.9	25	5	0.5	-0.7	0.2
MAXFO_15	109	17.8	18.4		11.7	22.2	8	3	0.3	-0.1	-1.3
MAXFO_25	108	17.8	18.4		12.9	22.3	9	3	0.3	0.0	-1.5
MAXFO_51	108	17.4	17.9		13.0	21.7	8	3	0.3	-0.1	-1.7
MAXEM_15	109	18.1	18.3		12.3	25.6	14	4	0.4	0.4	-0.8
MAXEM_25	109	17.7	18.1		12.5	23.6	12	3	0.3	0.2	-1.2
MAXEM_51	109	15.8	16.0		11.0	22.2	10	3	0.3	0.3	-1.1

Note: well and precipitation reported in cm, temperature in °C, see Table 14 for abbreviations.

Table 23. PSRF temperature, precipitation, and water table descriptive statistics (summer).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
EM_WELL	149	-42.1	-44.1		-45.5	-0.1	60	8	4.2	4.2	17.8
FO_WELL	154	-60.8	-71.5		-72.2	-6.6	359	19	1.5	1.6	1.1
PS_PPT	260	0.2	0.0	50.4	0.0	4.1	0	1	0.0	4.1	18.7
M_AIR_PS	121	24.3	24.5		16.7	29.5	8	3	0.3	-0.7	0.2
AFO_15	121	21.6	21.8		18.5	23.8	1	1	0.1	-0.9	1.0
AFO_25	121	22.7	22.8		19.5	24.8	1	1	0.1	-0.6	0.8
AFO_51	121	21.8	21.9		20.2	23.4	0	1	0.1	-0.4	0.4
AEM_15	110	21.6	21.5		18.1	25.6	2	1	0.1	0.2	0.1
AEM_25	121	21.6	21.6		18.9	24.1	1	1	0.1	0.0	-0.2
AEM_51	110	20.4	20.3		18.3	24.9	1	1	0.1	0.7	1.7
PSMI_AIR	121	19.2	19.8		8.4	23.2	8	3	0.3	-1.3	2.0
MINFO_15	121	21.0	21.2		17.8	23.7	1	1	0.1	-0.8	1.0
MINFO_25	121	22.4	22.5		19.3	24.7	1	1	0.1	-0.6	0.8
MINFO_51	121	21.7	21.9		20.1	23.3	0	1	0.1	-0.5	0.2
MINEM_15	110	20.9	21.0		17.0	23.3	2	1	0.1	-0.6	0.3
MINEM_25	121	21.4	21.5		18.5	23.6	1	1	0.1	-0.3	-0.2
MINEM_51	110	20.3	20.3		18.1	22.5	1	1	0.1	0.1	-0.5
PSMX_AIR	121	30.8	31.0		18.1	38.5	16	4	0.4	-0.7	0.3
MAXFO_15	121	22.3	22.5		19.0	24.4	1	1	0.1	-0.8	0.7
MAXFO_25	121	23.1	23.1		19.5	26.4	1	1	0.1	-0.3	1.3
MAXFO_51	121	21.9	22.0		20.3	23.5	0	1	0.1	-0.4	0.5
MAXEM_15	106	22.5	22.1		19.3	26.6	3	2	0.2	0.8	0.3
MAXEM_25	121	21.9	21.9		19.3	24.6	2	1	0.1	0.3	-0.1
MAXEM_51	109	20.5	20.5		18.4	23.8	1	1	0.1	0.4	0.0

Note: well and precipitation reported in cm, temperature in °C, see Table 14 for abbreviations.

Table 24. PSRF temperature, precipitation, and water table descriptive statistics (fall).

Variable	Valid N	Mean	Median	Sum	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
EM_WELL	146	-34.6	-44.0		-44.7	22.3	296	17	1.4	1.8	2.6
FO_WELL	182	-20.2	-13.2		-71.5	8.8	637	25	1.9	-0.7	-0.9
PS_PPT	364	0.3	0.0	103.8	0.0	10.7	1	1	0.0	6.5	57.7
M_AIR_PS	95	14.8	16.3		0.0	26.0	29	5	0.6	-0.7	0.1
AFO_15	95	16.3	16.7		9.4	24.7	9	3	0.3	-0.1	0.7
AFO_25	95	17.9	18.5		10.5	25.8	8	3	0.3	-0.5	1.6
AFO_51	113	17.1	18.2		10.2	21.3	11	3	0.3	-0.9	-0.5
AEM_15	97	14.8	15.6		6.3	24.0	17	4	0.4	-0.7	-0.4
AEM_25	113	15.2	16.4		7.6	20.9	15	4	0.4	-0.6	-0.9
AEM_51	108	14.7	15.4		7.8	23.2	13	4	0.3	-0.6	-0.6
PSMI_AIR	113	9.7	10.4		-6.1	22.4	34	6	0.6	-0.3	-0.3
MINFO_15	113	16.4	16.7		9.0	24.1	11	3	0.3	-0.2	-0.1
MINFO_25	113	18.2	18.4		10.3	25.4	10	3	0.3	-0.3	0.6
MINFO_51	113	16.9	18.1		10.1	21.2	11	3	0.3	-0.9	-0.6
MINEM_15	97	14.3	15.3		5.9	23.2	17	4	0.4	-0.7	-0.5
MINEM_25	113	14.9	16.0		7.4	20.7	15	4	0.4	-0.6	-1.0
MINEM_51	109	14.7	15.3		7.6	24.7	14	4	0.4	-0.4	-0.4
PSMX_AIR	113	22.2	23.3		4.0	35.6	38	6	0.6	-0.7	0.6
MAXFO_15	113	17.9	18.0		9.8	27.1	14	4	0.4	0.0	0.1
MAXFO_25	111	19.2	19.2		10.6	27.3	13	4	0.3	0.0	0.4
MAXFO_51	113	17.2	18.5		10.2	21.4	11	3	0.3	-0.9	-0.5
MAXEM_15	97	15.4	16.1		6.7	25.4	18	4	0.4	-0.6	-0.4
MAXEM_25	113	15.4	16.5		7.7	21.0	15	4	0.4	-0.6	-0.9
MAXEM_51	112	14.4	15.4		0.0	24.6	20	5	0.4	-1.2	1.9

Note: well and precipitation reported in cm, temperature in °C, see Table 14 for abbreviations.

APPENDIX D

REDOX POTENTIAL DESCRIPTIVE STATISTICS

Table 25. DPRS redox potential descriptive statistics (all data, across seasons).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEPMEH15	879	227	118	-414	1432	162034	403	13.6	0.6	-0.4
DEPMEH30	879	197	104	-187	790	98307	314	10.6	0.5	-1.3
DEPMEH51	879	33	-125	-259	758	90432	301	10.1	0.9	-0.9
OBMEH15	879	619	622	203	1028	2733	52	1.8	0.5	12.3
OBMEH30	879	722	725	186	1203	6274	79	2.7	-0.2	5.7
OBMEH51	879	787	814	197	1208	17602	133	4.5	-1.3	3.5
DEPMIE15	879	196	97	-462	1395	146726	383	12.9	0.6	-0.4
DEPMIE30	879	186	100	-234	779	96450	311	10.5	0.5	-1.3
DEPMIE51	879	19	-133	-282	744	86014	293	9.9	1.0	-0.8
OBMIE15	879	600	605	160	816	3141	56	1.9	-1.9	12.4
OBMIE30	879	692	697	110	1000	8618	93	3.1	-2.0	8.9
OBMIE51	879	761	783	156	1020	16334	128	4.3	-1.5	3.8
DEPMXE15	879	266	135	-400	1533	191277	437	14.8	0.7	-0.4
DEPMXE30	879	209	110	-183	815	102213	320	10.8	0.5	-1.3
DEPMXE51	879	50	-120	-257	796	98963	315	10.6	0.9	-0.9
OBMXE15	879	635	638	216	1148	3685	61	2.0	2.7	26.0
OBMXE30	879	748	756	208	1327	7635	87	2.9	1.0	10.0
OBMXE51	879	811	841	213	1339	20187	142	4.8	-1.0	3.3

Note: redox potential reported in millivolts (mV), see Table 13 for abbreviations.

Table 26. DPRS redox potential descriptive statistics (winter).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEPMEH15	119	283	202	-37	837	77828	279	26	0.2	-1.6
DEPMEH30	119	265	186	-6	685	64943	255	23	0.4	-1.4
DEPMEH51	119	84	-80	-153	489	61246	247	23	0.5	-1.6
OBMEH15	119	590	582	433	655	1727	42	4	-0.4	0.3
OBMEH30	119	692	675	308	852	7086	84	8	-1.2	4.3
OBMEH51	119	762	731	633	959	11690	108	10	0.3	-1.6
DEPMIE15	119	246	190	-55	692	68325	261	24	0.3	-1.5
DEPMIE30	119	249	178	-9	679	62254	250	23	0.5	-1.3
DEPMIE51	119	60	-97	-208	486	58572	242	22	0.6	-1.4
OBMIE15	119	566	558	344	648	3488	59	5	-1.4	2.9
OBMIE30	119	632	661	110	828	19557	140	13	-1.8	3.6
OBMIE51	119	719	663	538	917	9687	98	9	0.6	-1.1
DEPMXE15	119	350	211	-33	1099	125885	355	33	0.5	-1.0
DEPMXE30	119	292	194	-3	690	73154	270	25	0.3	-1.6
DEPMXE51	119	123	-76	-150	597	76741	277	25	0.4	-1.6
OBMXE15	119	608	620	503	669	1675	41	4	-0.3	-1.4
OBMXE30	119	734	733	396	890	5617	75	7	-0.5	2.0
OBMXE51	119	795	821	635	1003	15300	124	11	0.0	-1.7

Note: redox potential reported in millivolts (mV), see Table 13 for abbreviations.

Table 27. DPRS redox potential descriptive statistics (spring).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEPMEH15	251	51	-132	-253	1384	156829	396	25	2.1	3.7
DEPMEH30	251	24	-105	-187	700	57603	240	15	1.5	1.2
DEPMEH51	251	-129	-194	-259	543	35497	188	12	2.5	5.5
OBMEH15	251	616	609	203	1028	4870	70	4	0.8	13.0
OBMEH30	251	698	692	186	1203	9413	97	6	0.7	7.6
OBMEH51	251	742	790	197	1208	33999	184	12	-1.1	1.3
DEPMIE15	251	25	-143	-462	1350	142613	378	24	2.0	3.6
DEPMIE30	251	10	-108	-234	683	54412	233	15	1.4	1.1
DEPMIE51	251	-146	-196	-282	517	26602	163	10	2.8	7.7
OBMIE15	251	594	597	160	816	4817	69	4	-2.6	15.6
OBMIE30	251	666	661	131	1000	9603	98	6	-1.4	7.0
OBMIE51	251	712	733	156	1020	31416	177	11	-1.3	1.2
DEPMXE15	251	77	-111	-247	1441	173942	417	26	2.1	3.6
DEPMXE30	251	37	-102	-183	710	63041	251	16	1.4	1.0
DEPMXE51	251	-112	-191	-257	561	46514	216	14	2.3	4.1
OBMXE15	251	637	625	216	1148	7975	89	6	2.9	18.4
OBMXE30	251	727	725	208	1327	14477	120	8	1.9	10.3
OBMXE51	251	769	817	213	1339	39588	199	13	-0.8	1.5

Note: redox potential reported in millivolts (mV), see Table 13 for abbreviations.

Table 28. DPRS redox potential descriptive statistics (summer).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEPMEH15	260	289	242	-414	1432	225815	475	29	0.2	-1.1
DEPMEH30	260	205	46	-184	790	117925	343	21	0.4	-1.5
DEPMEH51	260	85	-94	-246	758	113757	337	21	0.6	-1.4
OBMEH15	260	635	630	541	742	1792	42	3	0.4	0.0
OBMEH30	260	742	743	579	898	4226	65	4	0.0	-0.7
OBMEH51	260	823	821	690	979	6753	82	5	0.1	-1.1
DEPMIE15	260	249	228	-429	1395	203126	451	28	0.2	-1.1
DEPMIE30	260	193	32	-192	779	115089	339	21	0.4	-1.5
DEPMIE51	260	70	-107	-251	744	108000	329	20	0.6	-1.4
OBMIE15	260	614	610	476	734	2411	49	3	0.0	0.3
OBMIE30	260	715	713	494	882	4784	69	4	-0.2	0.1
OBMIE51	260	797	789	685	971	5840	76	5	0.3	-1.0
DEPMXE15	260	336	254	-400	1533	263671	513	32	0.4	-1.0
DEPMXE30	260	217	52	-180	815	122250	350	22	0.4	-1.5
DEPMXE51	260	102	-78	-244	796	124139	352	22	0.7	-1.2
OBMXE15	260	653	646	549	755	1777	42	3	0.4	-0.1
OBMXE30	260	765	770	603	916	4812	69	4	-0.1	-0.8
OBMXE51	260	844	846	698	995	7948	89	6	-0.1	-1.2

Note: redox potential reported in millivolts (mV), see Table 13 for abbreviations.

Table 29. DPRS redox potential descriptive statistics (fall).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
DEPMEH15	249	315	284	-84	813	98113	313	20	0.1	-1.6
DEPMEH30	249	331	333	-12	694	85100	292	18	0.1	-1.6
DEPMEH51	249	120	-103	-158	558	98174	313	20	0.5	-1.7
OBMEH15	249	619	628	538	688	1387	37	2	-0.3	-1.0
OBMEH30	249	740	750	628	831	3157	56	4	-0.2	-1.2
OBMEH51	249	809	845	579	962	11209	106	7	-0.3	-1.5
DEPMIE15	249	291	271	-86	702	88174	297	19	0.0	-1.6
DEPMIE30	249	326	328	-21	689	83984	290	18	0.1	-1.6
DEPMIE51	249	114	-105	-162	550	96777	311	20	0.5	-1.7
OBMIE15	249	608	616	533	671	1228	35	2	-0.2	-0.9
OBMIE30	249	722	728	619	822	2658	52	3	-0.1	-1.0
OBMIE51	249	792	820	567	947	9852	99	6	-0.3	-1.4
DEPMXE15	249	344	287	-83	927	115631	340	22	0.2	-1.5
DEPMXE30	249	336	335	-10	702	86112	293	19	0.1	-1.6
DEPMXE51	249	126	-96	-155	567	99507	315	20	0.5	-1.7
OBMXE15	249	629	640	543	709	1635	40	3	-0.3	-0.9
OBMXE30	249	757	775	635	861	3805	62	4	-0.2	-1.2
OBMXE51	249	826	867	590	990	12776	113	7	-0.3	-1.5

Note: redox potential reported in millivolts (mV), see Table 13 for abbreviations.

Table 30. PSRF redox potential descriptive statistics (all data, all seasons).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
FOME15	485	339	323	72	821	15594	125	5.7	1.3	2.7
FOME25	485	385	336	185	817	18431	136	6.2	1.3	1.0
FOME51	485	311	300	97	660	12570	112	5.1	0.8	1.1
EMME15	485	207	264	-105	446	13506	116	5.3	-0.4	-1.0
EMME25	485	228	266	-106	346	7090	84	3.8	-1.5	1.9
EMME51	484	232	245	-71	395	4544	67	3.1	-0.6	0.8
FOMINE15	485	272	266	-134	807	20468	143	6.5	0.6	2.3
FOMINE25	485	344	292	128	795	18515	136	6.2	1.6	1.9
FOMINE51	485	282	281	92	642	11664	108	4.9	1.2	2.1
EMMINE15	485	179	206	-243	437	12368	111	5.0	-0.4	-0.5
EMMINE25	485	197	242	-108	328	9569	98	4.4	-1.1	0.4
EMMINE51	485	196	192	-92	393	5230	72	3.3	-0.4	0.8
FOMXE15	485	416	385	205	864	18004	134	6.1	1.1	1.1
FOMXE25	485	435	383	193	838	23745	154	7.0	0.9	-0.4
FOMXE51	485	355	328	101	688	19374	139	6.3	0.6	-0.1
EMMXE15	485	250	290	-98	735	21943	148	6.7	0.2	0.1
EMMXE25	485	268	279	-101	704	10867	104	4.7	0.1	3.6
EMMXE51	485	265	279	-45	661	7035	84	3.8	0.3	2.4

Note: redox potential reported in millivolts (mV), see Table 14 for abbreviations.

Table 31. PSRF redox potential descriptive statistics (winter).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
FOME15	137	275	278	72	414	3499	59	5	-0.6	1.1
FOME25	137	329	322	197	523	2624	51	4	0.7	1.4
FOME51	137	282	293	185	456	2050	45	4	0.4	1.2
EMME15	137	164	128	58	342	8207	91	8	0.4	-1.5
EMME25	137	271	273	-3	338	1662	41	3	-5.4	33.4
EMME51	137	221	195	127	348	3332	58	5	0.5	-1.2
FOMINE15	137	193	221	-134	362	10107	101	9	-1.4	1.7
FOMINE25	137	296	282	128	463	3691	61	5	0.0	1.1
FOMINE51	137	260	272	160	400	2194	47	4	0.1	0.2
EMMINE15	137	147	118	51	328	6550	81	7	0.6	-1.0
EMMINE25	137	257	267	-17	300	2171	47	4	-4.5	23.8
EMMINE51	137	203	191	109	292	2864	54	5	0.3	-1.1
FOMXE15	137	365	355	238	628	4420	66	6	0.9	1.7
FOMXE25	137	364	362	274	591	2568	51	4	0.8	2.2
FOMXE51	137	309	301	210	496	3405	58	5	0.9	1.0
EMMXE15	137	184	139	60	415	11852	109	9	0.5	-1.3
EMMXE25	137	290	279	4	431	2311	48	4	-1.8	15.8
EMMXE51	137	240	199	130	377	4834	70	6	0.6	-1.2

Note: redox potential reported in millivolts (mV), see Table 14 for abbreviations.

Table 32. PSRF redox potential descriptive statistics (spring).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
FOME15	110	298	302	81	421	9166	96	9	-0.3	-1.2
FOME25	110	334	303	185	612	13964	118	11	1.1	0.5
FOME51	110	244	228	97	409	10965	105	10	0.0	-1.7
EMME15	110	162	110	-90	388	18258	135	13	0.2	-1.6
EMME25	110	233	244	116	346	3756	61	6	-0.1	-0.9
EMME51	109	229	245	104	395	8047	90	9	-0.1	-1.4
FOMINE15	110	228	266	-70	397	18217	135	13	-0.5	-1.1
FOMINE25	110	308	287	174	610	12365	111	11	1.6	2.1
FOMINE51	110	225	189	92	400	9017	95	9	0.1	-1.6
EMMINE15	110	142	97	-243	357	16444	128	12	0.1	-1.0
EMMINE25	110	206	235	20	328	5180	72	7	-0.5	-0.5
EMMINE51	110	196	200	0	393	8089	90	9	0.3	-1.0
FOMXE15	110	356	360	205	746	10344	102	10	0.5	0.6
FOMXE25	110	372	326	193	658	20654	144	14	0.7	-0.8
FOMXE51	110	277	272	101	667	19689	140	13	0.7	-0.1
EMMXE15	110	186	124	-50	558	23752	154	15	0.4	-1.3
EMMXE25	110	254	250	132	613	6043	78	7	0.9	2.8
EMMXE51	110	251	280	0	410	9985	100	10	-0.2	-1.4

Note: redox potential reported in millivolts (mV), see Table 14 for abbreviations.

Table 33. PSRF redox potential descriptive statistics (summer).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
FOME15	122	430	380	217	821	23712	154	14	1.0	0.2
FOME25	122	474	466	274	817	24019	155	14	0.6	-0.6
FOME51	122	371	330	132	660	16202	127	12	0.6	-0.1
EMME15	122	254	293	-93	446	12922	114	10	-1.1	0.8
EMME25	122	192	208	-46	329	9465	97	9	-0.7	-0.3
EMME51	122	235	249	-71	344	4591	68	6	-2.0	6.2
FOMINE15	122	365	295	195	807	23860	154	14	1.5	1.2
FOMINE25	122	406	297	269	795	28677	169	15	1.1	-0.3
FOMINE51	122	325	289	128	642	15794	126	11	1.2	0.8
EMMINE15	122	217	266	-111	437	13393	116	10	-0.8	0.5
EMMINE25	122	138	121	-103	302	11398	107	10	-0.1	-0.9
EMMINE51	122	182	191	-92	317	6755	82	7	-1.0	1.3
FOMXE15	122	520	545	253	864	28888	170	15	0.2	-1.0
FOMXE25	122	562	595	274	838	30446	174	16	-0.2	-1.3
FOMXE51	122	450	480	136	688	26451	163	15	-0.1	-1.4
EMMXE15	122	331	338	-74	735	26812	164	15	0.2	0.7
EMMXE25	122	273	289	-28	704	23206	152	14	0.7	1.0
EMMXE51	122	291	282	-45	661	9552	98	9	0.7	5.2

Note: redox potential reported in millivolts (mV), see Table 14 for abbreviations.

Table 34. PSRF redox potential descriptive statistics (fall).

Variable	Valid N	Mean	Median	Min.	Max.	Variance	Std.Dev.	Std.Error	Skewness	Kurtosis
FOME15	116	357	334	107	751	12226	111	10	0.7	0.7
FOME25	116	407	345	229	773	20781	144	13	1.1	-0.3
FOME51	116	346	309	114	636	12685	113	10	0.9	0.3
EMME15	116	253	282	-105	405	7597	87	8	-1.9	4.1
EMME25	116	211	268	-106	331	10488	102	10	-1.3	0.7
EMME51	116	247	253	72	335	2356	49	5	-1.1	1.4
FOMINE15	116	307	287	65	641	12312	111	10	0.6	0.3
FOMINE25	116	371	293	155	734	22747	151	14	1.2	0.0
FOMINE51	116	318	284	110	601	14361	120	11	0.9	0.3
EMMINE15	116	210	248	-111	384	9571	98	9	-1.7	2.6
EMMINE25	116	179	239	-108	291	12453	112	10	-1.1	0.0
EMMINE51	116	204	202	-19	326	3535	59	6	-0.5	1.0
FOMXE15	116	422	392	206	861	12336	111	10	1.0	1.7
FOMXE25	116	445	390	247	797	18200	135	13	1.0	-0.4
FOMXE51	116	383	341	119	673	12370	111	10	0.7	0.3
EMMXE15	116	304	323	-98	568	8657	93	9	-1.6	4.9
EMMXE25	116	250	294	-101	368	11757	108	10	-1.4	1.3
EMMXE51	116	281	292	101	353	2492	50	5	-1.5	2.1

Note: redox potential reported in millivolts (mV), see Table 14 for abbreviations.