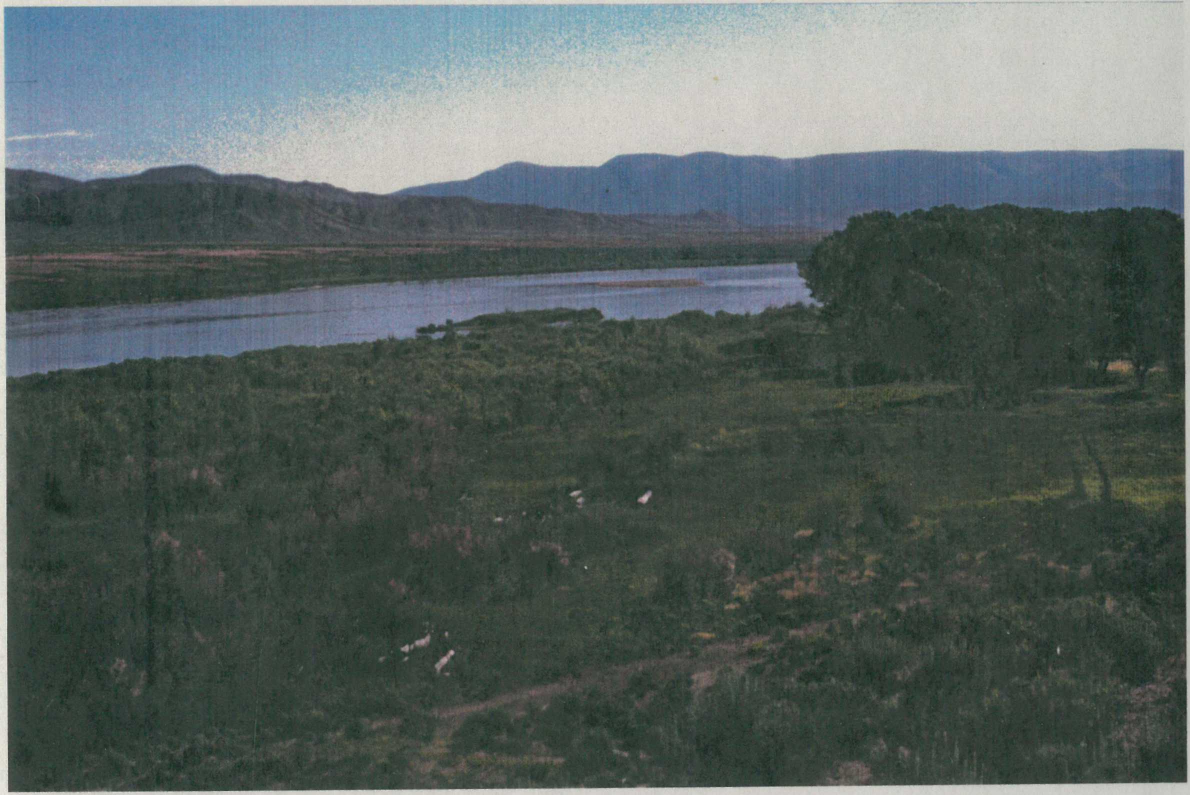
WAT-1998-01

CHARACTERIZATION AND FUNCTIONAL ASSESSMENT OF REFERENCE WETLANDS IN COLORADO

A PRELIMINARY INVESTIGATION OF HYDROGEMORPHIC (HGM) CLASSIFICATION AND FUNCTIONS FOR COLORADO'S WETLANDS



June 1998

Submitted to
Colorado Department of Natural Resources and
U.S. Environmental Protection Agency, Region VIII
as part of the 104(B)(3) State Wetlands Grant Program

Prepared by
Colorado Geological Survey, Colorado Department Of Natural Resources
Colorado School of Mines, Division of Environmental Science and Engineering
Colorado State University, Department of Earth Resources

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Frontpiece Photograph

This photograph, taken near the Deerlodge Park reference wetland in Moffat County, Colorado, shows some of the geomorphic and hydrologic factors that influence wetlands. Four distinct geomorphic and vegetative zones are present: 1) non-vegetated sand bars, seen in the middle of the Yampa River (center of photograph); 2) low, seasonally flooded floodplain terraces and emergent bars populated by a dense stand of willows and young cottonwood, seen beside the river (left center); 3) a higher, occasionally flooded floodplain terrace covered with grasses, shrubs, and older cottonwoods, running parallel to the river (lower left to right center); and 4) a dryland slope consisting of alluvial fan and Mancos Shale deposits populated by sage and cheatgrass (foreground). The lowest floodplain terraces are inundated annually by overbank flooding. The 1997 runoff along the Yampa River, which peaked at 20,000 cfs at Deerlodge Park, flooded parts of the next-higher terrace and the older cottonwoods, leaving behind a thi layer of carbon- and nitrogen-rich, muddy sediment. A broken line of driftwood and wrack (lower cente denotes the high-water mark. Riverbanks, such as those along the far side of the river, occasionally cave into the river and are a sediment source for the system. The river is the primary source of ground water beneath the wetland during flooding. A secondary, sulfate-rich source of ground water comes from poin along the valley side, from the upland alluvial-fan deposits. The wetland becomes a sulfate sink during times of falling and low river flow, but sulfate is flushed during the spring flooding season.

(Photograph by David C. Noe, Colorado Geological Survey).

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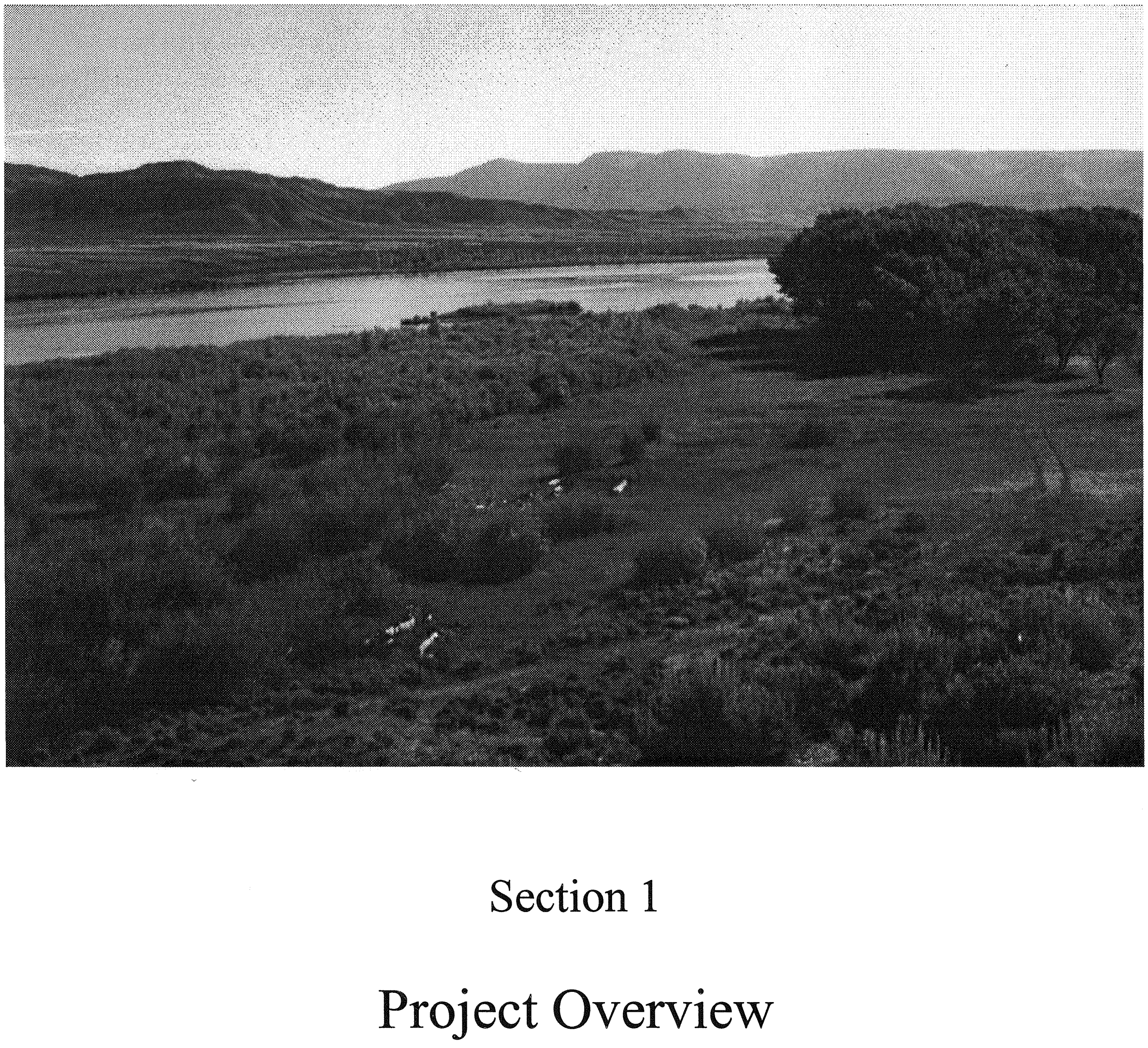


Section 1

Project Overview and Summary

PROJECT OVERVIEW AND SUMMARY

David C. Noe
Colorado Geological Survey, Colorado Department of Natural Resources
1313 Sherman Street, Room 715, Denver, CO 80203

June 1998

Introduction

This report is the result of a two-year, EPA-funded wetlands grant project. It contains an investigation of the status of wetlands management practices in Colorado; a first approximation of a hydrogeomorphic (HGM) classification of Colorado's wetlands; the results of field and laboratory investigations from five reference wetland sites; and a first approximation of HGM hydrochemical, geochemical, sediment-retention, and carbon-storage/export variables and functional equations for Colorado wetlands. The results presented herein offer a starting point for the creation of regional HGM guidebooks to be used for future wetland-management activities. However, the HGM classifications, variables, functions, and functional equations from this report need to be assessed and tested by professional practitioners before being incorporated into any future HGM guidebooks.

This part of the report (Section 1) contains an introduction and overview of the project and the activities that were conducted, and a brief summary of pertinent findings and recommendations from the report's four stand-alone sections (Sections 2-5).

Background and Need

Colorado contains a wide variety of wetland types, although its semi-arid climate supports a relatively small percentage of its total land area as wetlands (1.5%; Dahl, 1990). These include riparian wetlands, wet meadows, fens, carrs, and marshes in the Rocky Mountains, Eastern Plains, and the Colorado Plateau. The variety among Colorado wetlands is directly related to the broad range of physiographic, hydrologic, and climatic factors found in the State. In addition to their limited extent, these wetlands are considered significant because of their perceived ecological functions, such as water control, water quality, and fish and wildlife habitat. Such wetlands are also vulnerable to degradation and loss from development of natural resources, agriculture, water use and population pressures. Estimates of loss or degradation to date are as high as 90% for many types (ibid.), although precise figures on existing wetlands or wetlands loss are not available.

No comprehensive classification or inventory of Colorado's wetlands yet exists, and the State does not have a comprehensive wetlands protection program. Various federal, state, and local-government agencies and private organizations have conducted their own wetland surveys for conservation and land-use planning purposes. The U.S. Fish and Wildlife Service has delineated approximately 4/7 of total wetlands acreage in Colorado for the National Wetlands Inventory (NWI). The NWI maps classify wetlands according to the system of Cowardin and others (1979), which uses hydrology, vegetation, and substrate to effect a general classification of wetlands (i.e., riverine, lacustrine, and palustrine); however, these classes are broad, and each class encompasses a wide variety of wetland types. Various private organizations, including The Nature Conservancy and the Colorado Natural Heritage Program, are inventorying wetlands in specific areas of the state, while the Colorado Division of Parks and Outdoor Recreation is inventorying wetlands on state parklands. These projects utilize traditional ecological tools such as vegetative community analysis and species abundance rather than geomorphic or hydrologic characteristics; they are limited in scope, and have no immediate regulatory application.

Water quality in Colorado wetlands is regulated by the Water Quality Control Division of the Colorado Department of Public Health and Environment, through the State's promulgated surface water quality standards. Under this system, a wetland is subject to the same water quality standards as the nearest, hydrologically connected stream segment on an interim basis. However, the water quality regulation allows Colorado to adopt a site-specific wetland water-quality classification based on the *functions* of the wetland in question when it can be demonstrated that the existing surface-water-quality classification and standards do not adequately protect the functions and values of the wetland. These functions might include ground water recharge or discharge, sediment or pollutant retention, flood control, biological diversity, nutrient production or removal, and recreation.

Other impacts to Colorado's wetlands such as cutting, dredging, and filling, are regulated by the U.S. Army Corps of Engineers or the U.S. Natural Resources Conservation Service (for wetlands on agricultural lands), through Section 404 of the Clean Water Act. The Section 404 permitting regulations require the use of a standardized, functional-evaluation tool to quantify a wetland's ability to perform specified functions and indicate relative differences in functional quality. Such a tool provides a useful means for assigning values to functions when assessing the impacts of a project within or near a wetland. Functional evaluation can provide a basis for management decisions regarding wetlands development and conservation, as well as assist in determining mitigation and restoration options.

Few studies of wetland function have been conducted in Colorado (Cooper and Severn, 1992), and the functions occurring in wetlands of the western U.S. are poorly understood in general. National-level functional assessment techniques such as the Wetland Evaluation Technique (WET)(Adamus and others 1987) have been used in Colorado. The WET contains a large number of physical, chemical or biological characteristics for consideration as a composite of all wetland types. However, this technique has serious limitations (e.g., Dougherty, 1989; Smith and others, 1995). Particularly, the WET has not been sufficiently tailored to reflect the wetland types, functions, and functional characteristics of a particular ecoregion, such as the Rocky Mountains, and it relies on largely subjective observations by the practitioner.

A relatively new classification and functional assessment technique, called the *hydrogeomorphic* approach (*HGM*)(Brinson, 1993) is being developed by the U.S. Army Corps of Engineers in cooperation with other federal and state government agencies as a replacement to the WET (Smith and others, 1995). As a classification system, HGM groups functionally similar wetlands by evaluating three main types of information: 1) geomorphic setting; 2) water source and transport; and 3) hydrodynamics. It differs from the Cowardin classification system in that vegetation is not a primary basis of the classification, although vegetation characteristics may be used as indicators of some underlying physical or chemical property. The methodology assumes that the function is largely, if not entirely, dependent on physical and chemical factors essential to the maintenance of the wetland and the ecosystem it supports. Its major assumption is that wetlands with similar hydrogeomorphic properties will perform similar functions.

The HGM approach has technical and regulatory advantages in the Rocky Mountain region. It allows a wide variety of wetland types to be grouped by characteristics which correspond to function, so that only those functions characteristic of the group are evaluated. A focused functional evaluation can then provide answers about the relative values of those wetlands, rather than comparing wetlands that perform entirely different functions against an absolute standard. The HGM classification emphasizes abiotic criteria, such as topography, geology, and hydrology, allowing for the assessment of functions that are critical to water supply and water quality in arid or semi-arid regions. Finally, the approach calls for the establishment of *reference wetlands*, which represent benchmarks against which other wetlands can be compared for purposes such as assessment, mitigation, and restoration (Brinson, 1993). Thorough scientific studies of the reference wetlands can help identify functions and indicator parameters.

Author's note: The preceding section on Background and Need is adapted and modified from the original project proposal, which was written by Alison E. [illegible] and David C. Noe.

Purpose and Objectives

The purpose of this project is to develop a methodology for classifying wetlands in Colorado based on the hydrologic and geomorphic processes that support the biotic and abiotic functions of these ecosystems. The implementation of a hydrogeomorphic (HGM) classification procedure will provide a basis for developing a functional assessment technique adapted to the Rocky Mountain region that can be used in the inventory and management of Colorado wetlands.

The major study objectives are as follows:

1. Compile and assess information about prevailing approaches to wetlands management among county and municipal government agencies in Colorado.
2. Develop a regional, *hydrogeomorphic* (*HGM*) classification of Colorado's wetlands into classes and subclasses having similar functions, based on both the abiotic and biotic characteristics of wetlands.
3. Identify a set of potential HGM *reference wetlands* for the wetland classes and subclasses identified in objective 2.
4. Conduct field description and monitoring studies on certain selected reference wetlands, involving hydrology, geology, and ecology, for the purpose of identifying qualitative and quantitative indicators of *function*.

Report Contents

The report is divided into five sub-reports, or sections:

- Section 1. Project Overview and Summary;
- Section 2. Wetland Management Practices in Colorado;
- Section 3. HGM Classification of Colorado Wetlands;
- Section 4. HGM Hydrological and Geochemical Functions; and
- Section 5. HGM Sediment Retention and Carbon Storage/Export Functions.

Report Section 2 is based on a questionnaire that was sent to local-government agencies across Colorado as part of the project during 1996. Section 3 is based on statistical analyses of existing stand data from numerous locations throughout Colorado, while Section 4 and Section 5 are based on field and laboratory investigations at five reference-wetland study sites.

Reference-Wetland Study Sites

The project team conducted field investigations at five reference-wetland study sites in north-central and northwestern Colorado (Fig. 1). The sites were chosen to include a wide degree of variation in landscape position, wetland types, and human-caused impacts. Together, these five sites represent a gradient of Colorado wetlands, from high-altitude, subalpine wetlands near the Continental Divide westward to lower-altitude, riverine wetlands in the Colorado Plateau area. An introductory description of these sites is given in the following paragraphs:

The *Peru Creek* site (Fig. 2) contains a high-altitude slope wetland that has been impacted by acid-mine drainage from the nearby Pennsylvania Mine. The site is located in eastern Summit County, in Arapaho National Forest, at an elevation of about 10,860 feet. It is located near the bottom of a u-shaped glacial valley that has been modified by post-glacial, slope-wash processes. The wetland is bounded on the sides to the east and west by slightly steeper, forested ground, to the south (uphill) by the Pennsylvania Mine workings, and to the north by Peru Creek. The wetland is a fen that has mixed stands of emergents and shrubs (e.g., sedge, tufted hairgrass, willows, bog birch). Peat has formed beneath much of the wetland. Low-pH, mineral-laden

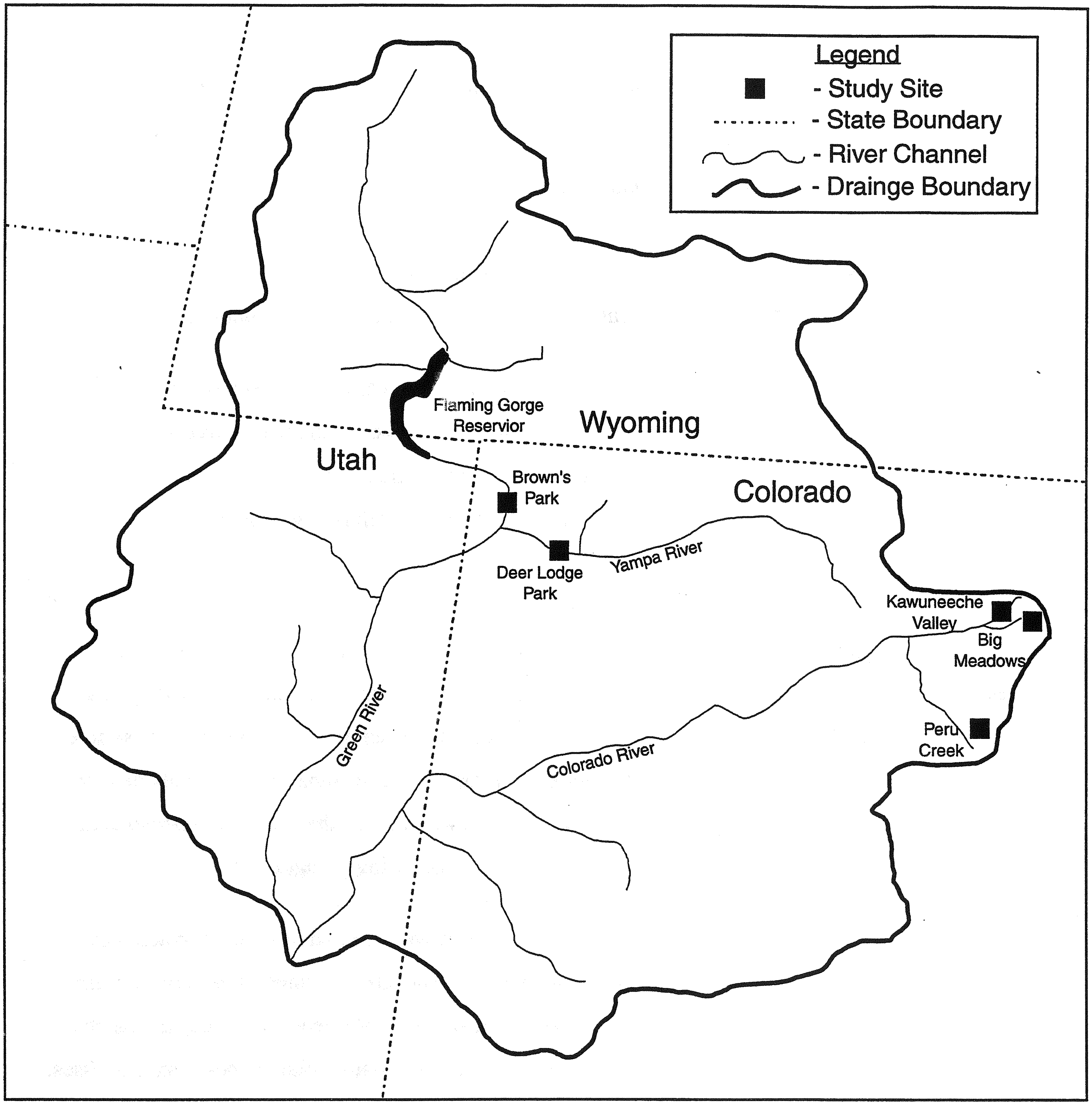


Figure 1. Study area map of the Upper Colorado River watershed, showing the location of the five reference wetland sites.

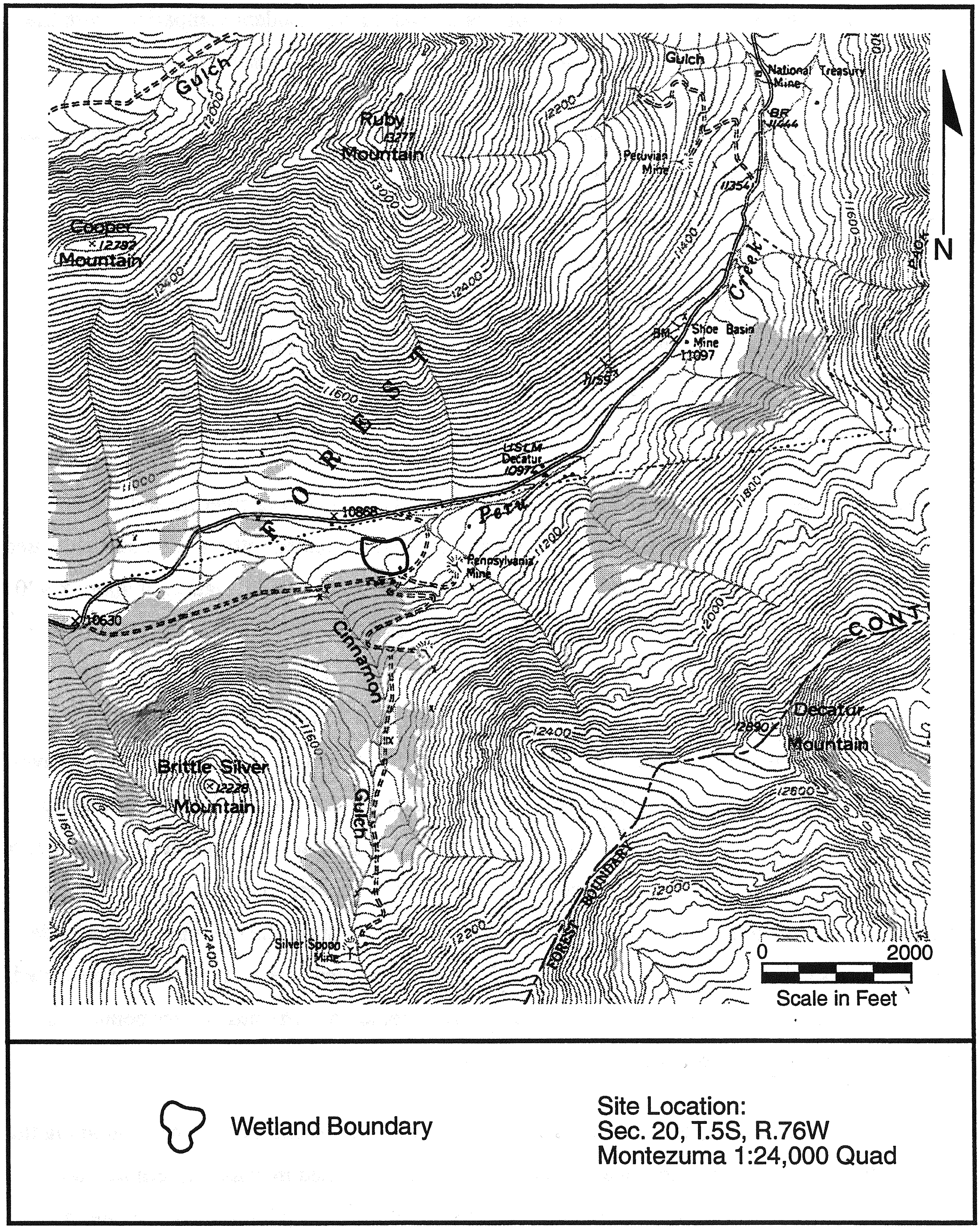


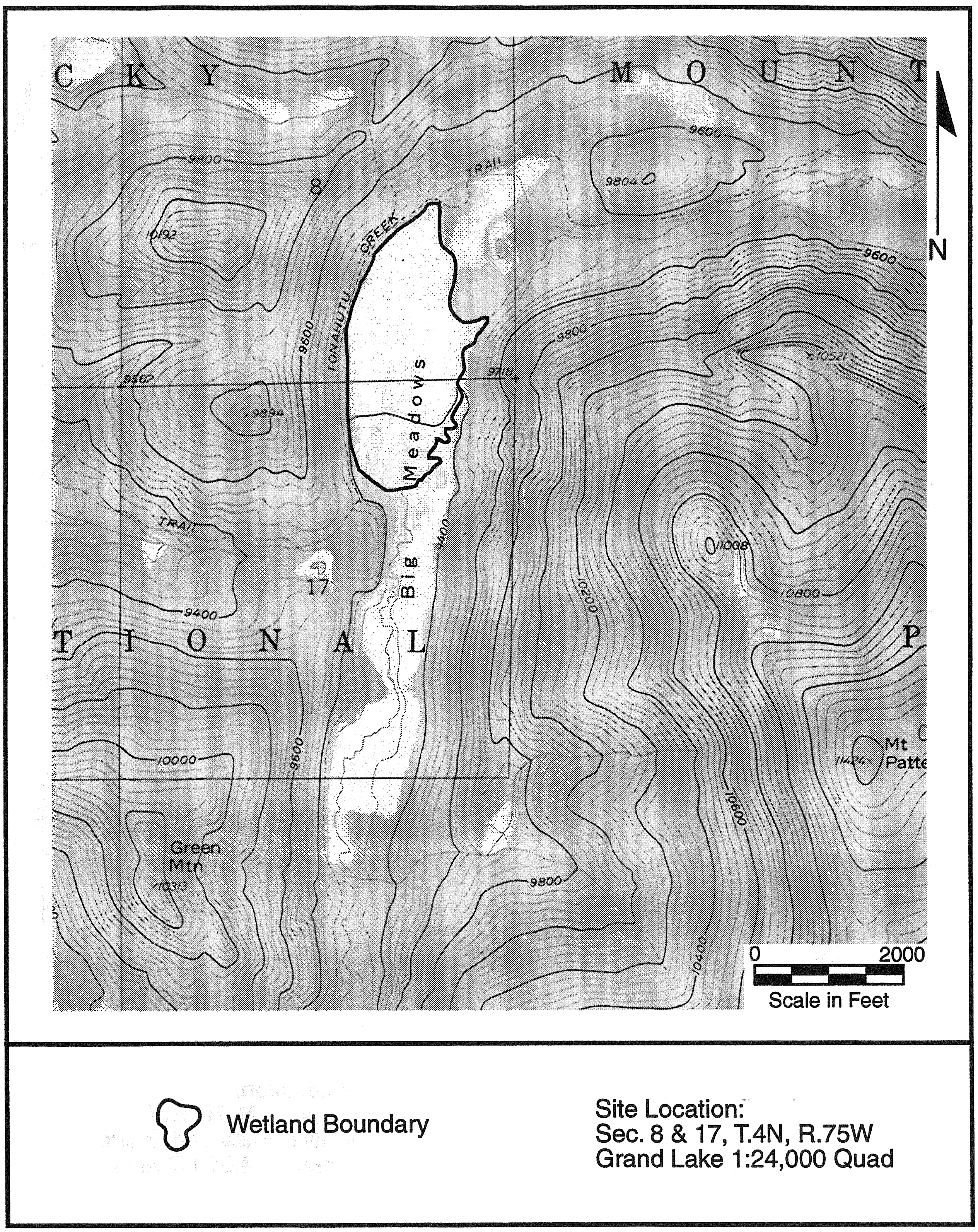
Figure 2. Peru Creek reference wetland site in Arapaho National Forest, Summit County, Colorado.

ground water sources the Peru Creek wetland; this allows for an excellent comparison with the Big Meadows slope wetland, where no mining-related impacts have occurred.

The *Big Meadows* site (Fig. 3) contains a high-altitude slope wetland in a relatively unimpacted setting. The site is located in northeastern Grand County, in Rocky Mountain National Park, at an elevation of 9,405 feet. It occupies the bottom of a large, u-shaped glacial valley and is bounded on the west by forested, moraine-covered side slopes and on the east by Tonahutu Creek. The wetland is a sedge-dominated fen with occasional stands of willows and tufted hairgrass. A thick peat deposit has formed in the east-central part of the wetland. The Big Meadows wetland appears to be sourced almost entirely by ground water moving down the valley and from the valley side; Tonahutu Creek has little direct influence on the wetland.

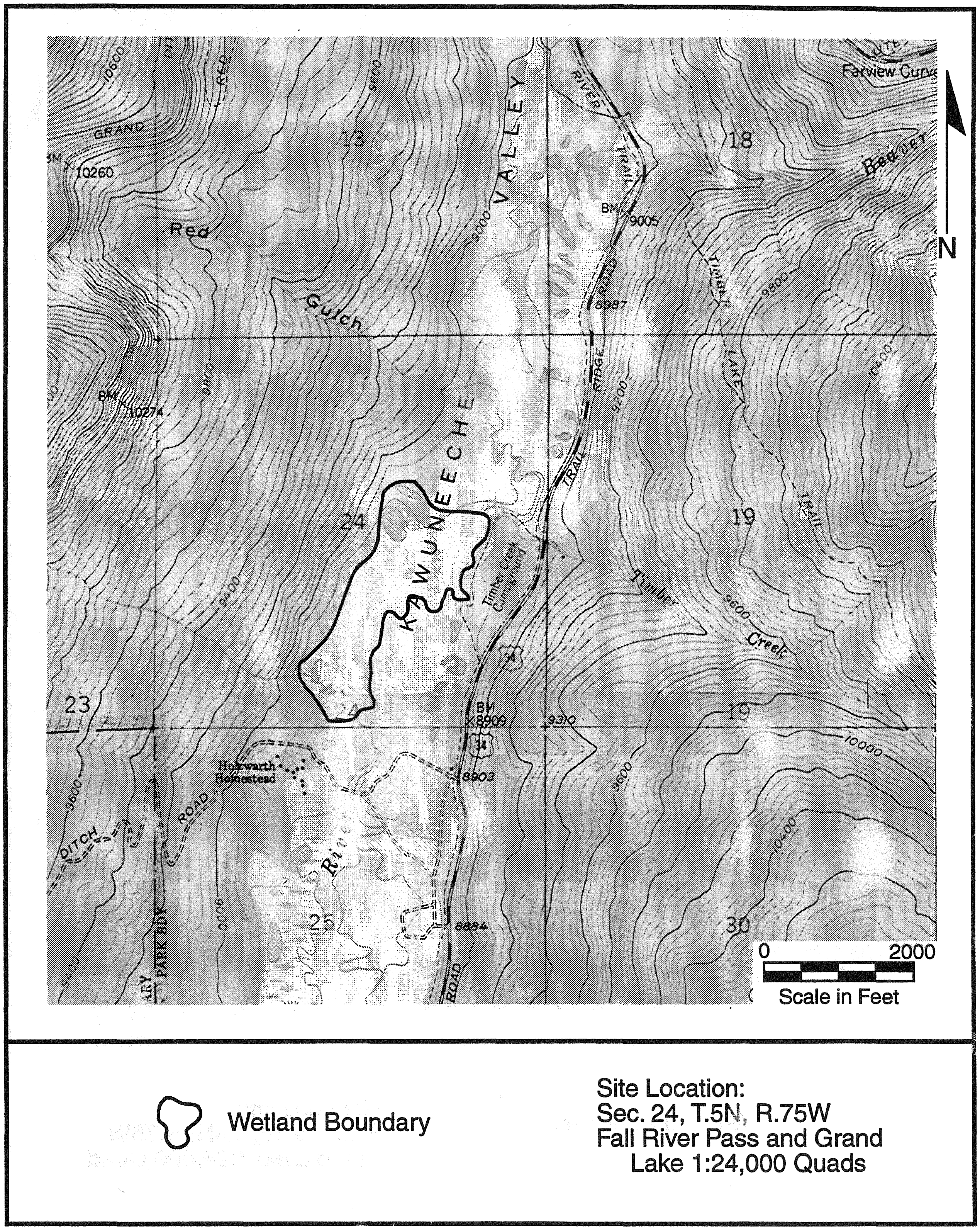
The *Kawuneeche Valley* site (Fig. 4) contains a high-altitude, low-order riverine and slope wetland complex along the Colorado River in a relatively unimpacted setting. The site is located in northeastern Grand County, in Rocky Mountain National Park, at an elevation of about 8,920 feet. It occupies the bottom of a very large, u-shaped glacial valley and is bounded to the west by a forested, moraine-covered side slope and to the east by the Colorado River. The site is partially bounded on its north and south sides by alluvial fan deposits. Willows, with interspersed areas of sedges dominate the wetland. There is evidence of past and present beaver activity. The Colorado River, a small, headwater stream at this location, is highly undersized with respect to the width of the glacial valley and does not appear to have a great direct influence on the wetland. Therefore, the Kawuneeche Valley wetland appears to be sourced largely by ground water moving down the valley, as well as ground water from the moraine-covered side slopes. Two small side streams, Red Gulch and another unnamed stream, have been intercepted by the Grand Ditch since the early 1900s. The wetland contains numerous beaver ponds and evidence of abandoned, now-drained beaver ponds.

The *Deerlodge Park* site (Fig. 5) contains a lower-altitude, high-order riverine wetland along the Yampa River in a relatively unimpacted setting. The site is located in southwestern Moffat County, in Dinosaur National Monument, at an elevation of about 5,620 feet. It occupies a single, large meander bar along the south side of the river, and is bounded to the south by an apron of coalescing alluvial fans that issue from a number of small, upland arroyos. The wetland



Site Location:
Sec. 8 & 17, T.4N, R.75W
Grand Lake 1:24,000 Quad

Figure 3. Big Meadows reference wetland site in Rocky Mountain National Park, Grand County, Colorado.



Wetland Boundary

Site Location:
Sec. 24, T.5N, R.75W
Fall River Pass and Grand
Lake 1:24,000 Quads

Figure 4. Kawuneeche Valley reference wetland site in Rocky Mountatin National Park, Grand County, Colorado.

contains a number of well-defined geomorphic and vegetated zones. These include unvegetated, actively migrating sand bars along the river; regularly flooded, mud-draped meander scrolls colonized by dense stands of willows and young cottonwoods; higher, occasionally flooded meander terraces populated by grasses and older cottonwoods; alluvial-fan (wetland fringe) deposits populated by greasewood; and finally, the sage-and-cheatgrass covered uplands (see frontpiece photograph). The Deerlodge Park wetlands is sourced primarily by ground water and overbank flooding from the Yampa River, which peaked at 21,000 cfs during the 1997 field season. There is a secondary, geochemically different source of ground water (and surface water during flash floods) from the arroyo systems to the south.

The *Browns Park*, or *Allen Bottom* site (Fig. 6) contains a lower-altitude, high-order riverine wetland along the Green River that has been impacted by regulation of flow from the Flaming Gorge dam since the early 1960s. The site is located in northwestern Moffat County, in Browns Park National Wildlife Refuge, at an elevation of about 5,345 feet. It occupies a single, large meander bar along the southwest side of the river, and is bounded to the south by an apron of alluvial-fan and slopewash deposits along the valley side. The site has undergone a great degree of vegetative succession since the early 1960s, when overbank flooding ceased due to the completion of Flaming Gorge dam upstream. Today, only a small portion along the eastern and northern edges of the meander bar is a wetland. This area consists of a network of flood channels and a chute bar which are located within or adjacent to the present, incised river channel. The chute bar is an island, covered with willows and tamarisks on its upstream and middle parts and largely unvegetated and sandy on its actively aggrading, lower end. Reeds and rushes populate the channels. The larger area of former wetlands marked by scattered galleries of old-growth cottonwood trees, and is now populated by an understory of rabbitbrush, white top, cheatgrass, and other dryland plants. The active Browns Park wetland is sourced by rare overbank flows during release events from Flaming Gorge dam. The peak of 8,000 cfs during the 1997 field season is anomalously high for this regulated part of the Green River, and may be the highest flow through Browns Park since the dam was built. Even so, the flow only reached bankfull on the incised channel along the river. The extensive, non-wetland part of the meander bar is sourced almost exclusively by ground water flowing down the alluvial valley, with possible minor additions of ground and surface water from the adjacent hillside.

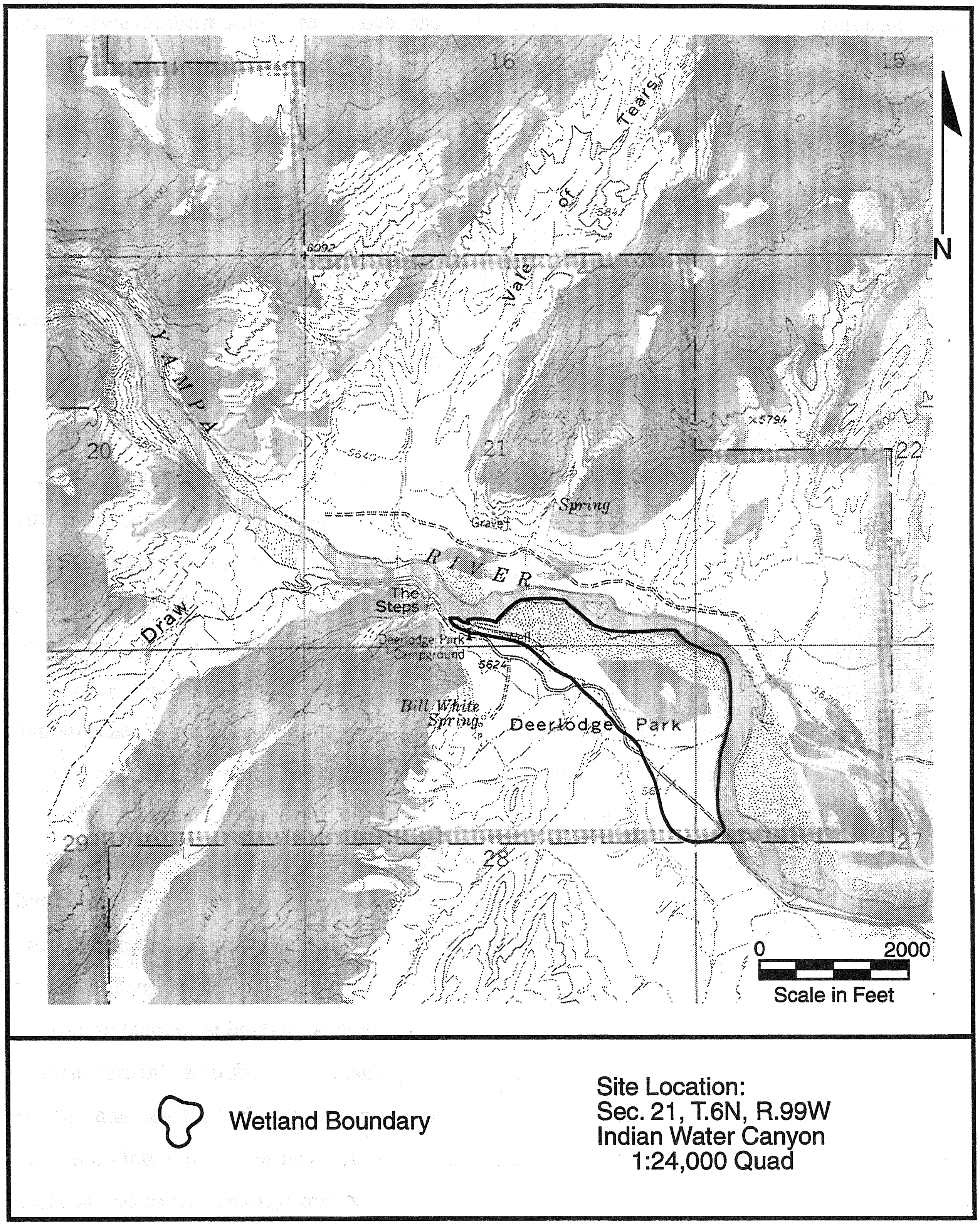


Figure 5. Deerlodge Park reference wetland site in Dinosaur National Monument, Moffat County, Colorado.

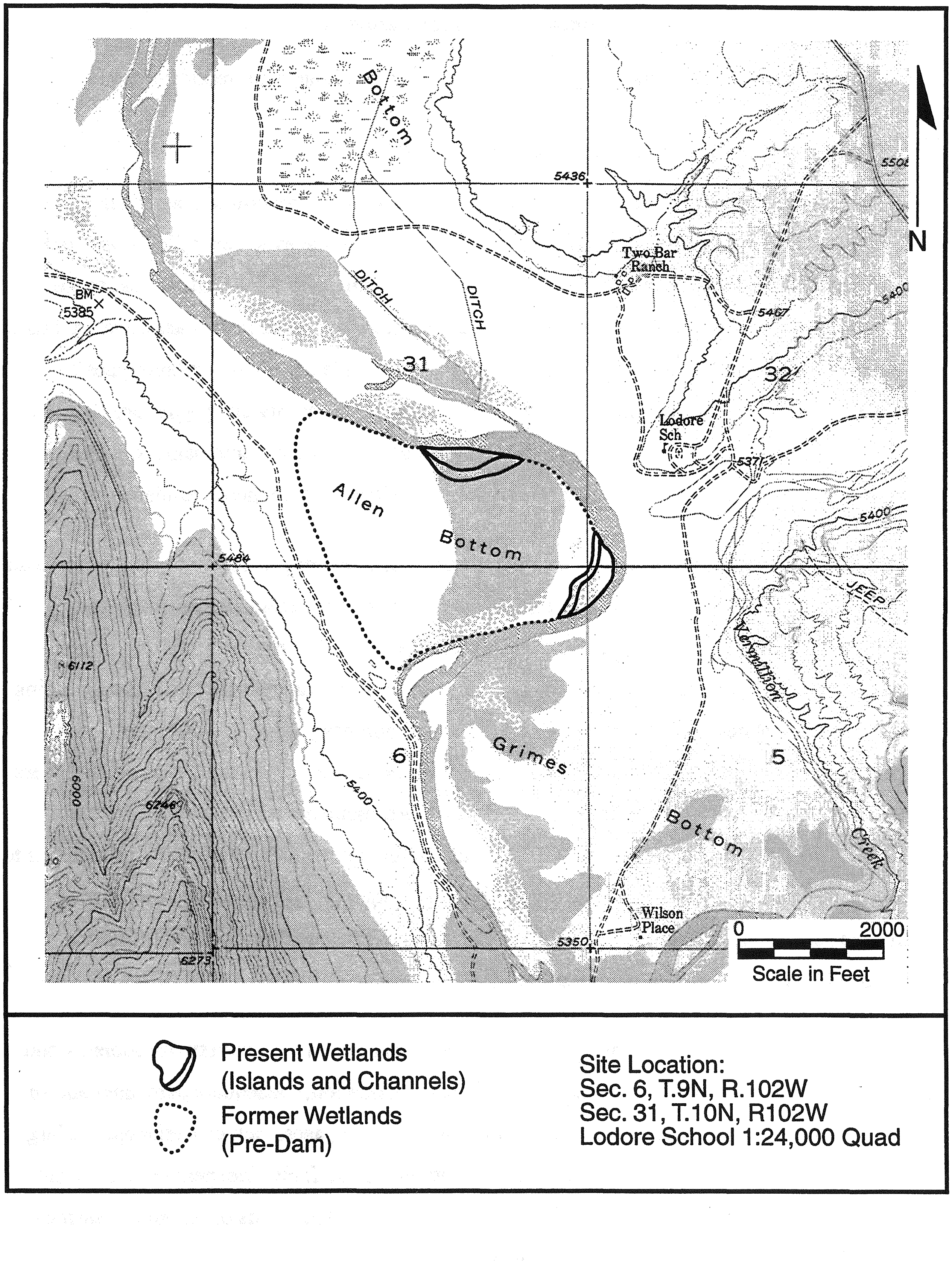


Figure 6. Browns Park (Allen Bottom) reference wetland site in Browns Park National Wildlife Refuge, Moffat County, Colorado.

Summary of Major Findings

The following paragraphs contain a summary of the major findings from report Sections 2-5:

Wetland Management Practices in Colorado (from Section 2)

The Colorado Geological Survey sent 240 questionnaires to local-government agencies in Colorado in 1996. The questionnaires were designed to reveal the existence of local wetland programs, technical tools, maps, inventories, classification methods, and need for assistance. Responses were received from 32 counties and 52 municipalities. The results are given in Tables 1-2 and are also shown on color GIS maps (Figs. 1-12). A wide variety of wetland types are recognized within the counties and municipalities; the most commonly cited types are riparian wetlands, wet meadows, and prairie potholes. Several of the smaller municipalities in eastern and southern Colorado do not recognize any types of wetlands within their boundaries.

A majority of the respondents do not have a wetlands management program, nor do they have an inventory or classification of their wetlands. Those local governments having a wetlands management program are located along the Front Range Urban Corridor or in the resort areas in the Rocky Mountains. Those communities rely on a variety of management strategies including management ordinances, regulations, and volunteer and purchase programs. Many of those programs require delineation of jurisdictional wetlands using the U.S. Army Corps of Engineers Delineation Manual, as well as mitigation of impacts. Assessment and evaluation of wetland functions is required by 24 of the respondents, while some others may defer such requirements to the Corps of Engineers. The Wetlands Evaluation Technique (WET) appears to be the most-often used functional evaluation method, although locally developed approaches (usually a modified WET) are used in eight communities.

Wetland management by local Colorado government is hampered by a variety of problems and deficiencies. The respondents cited lack of technical information, inadequate personnel and/or funds, lack of training, and lack of local support (and, in some cases, lack of wetlands). A large majority of the respondents (over 85%) would be interested in a rapid, inexpensive functional assessment methodology for wetlands (such as HGM) and/or other kinds of technical assistance from the Colorado Department of Natural Resources.

HGM Classification of Colorado Wetlands (from Section 3)

Dr. David Cooper, Colorado State University, presents a first-approximation of a hierarchical, HGM classification of Colorado's wetlands in this report. The classification is based upon multivariate statistical analyses of high-quality data sets for 3,625 vegetation stands, representing thirty-seven wetlands across Colorado. Two integrated data sets were constructed for each stand: 1) vegetation composition, and 2) environmental variables that describe abiotic influences on each stand (location, elevation, soil texture and organic content, channel gradient, bedrock type, surficial geology, Strahler stream order, inundation, soil moisture, water source, and hydrologic disturbance). The data sets were analyzed simultaneously using direct gradient analyses. The resulting ordination statistics and graphics were used to subdivide the data sets into groups having characteristic hydrologic regimes, geomorphic processes, and vegetation structure.

Excellent ordination plots and statistics were produced from the data sets. The resulting patterns are interpreted to be a product of elevation, hydrologic regime, geomorphic processes, and salinity gradients. The widest range of wetland types occurs at the higher- and lower-elevation areas of Colorado; the wetlands in the middle elevations (i.e., foothills and lower-elevation mountains) are relatively similar with regard to floristic composition. The major ordination axis appears to be driven by two environmental groupings: elevation, glacial landscapes, and peat soils to one direction versus high-order streams, alluvial landscapes, and coarse-textured soils in the other. The secondary ordination axis appears to be driven by duration of inundation.

Four main HGM classes and fifteen subclasses are identified and delineated based on the ordination plots: 1) *riverine* (five subclasses); 2) *slope* (four subclasses); 3) *depression* (five subclasses); and 4) *mineral-soil flat* (one subclass). Potential reference wetland sites are proposed for each subclass; many of these are sites where detailed, scientific studies have already been conducted.

An ordination analysis of species data confirms that many species favor a certain wetland class or subclass; however, other species may be transitional between of two or more wetland classes. The use of certain abiotic environmental indicators such as inundation duration, in addition to species lists, may prove useful for distinguishing between HGM classes in the field.

HGM Hydrological and Geochemical Functions (from Section 4)

Dr. Kenneth Kolm, Dr. John Emerick, and Ruth Harper-Arabie, Colorado School of Mines, present the results of an investigation of HGM hydrological and geochemical functions for wetlands in Colorado. These functions were studied at four locations in the Colorado River watershed, ranging from high to low elevation, at Peru Creek, Big Meadows, Deerlodge Park, and Browns Park (see site descriptions, p. 5-13). The study objectives include the following: 1) develop a step-by-step, hydrogeomorphic approach that could be used to classify wetlands; 2) provide a framework for determining hydrological functions and variables; and 3) identify the variables that could be used to determine geochemical functions. The investigators attempted to quantify the basic functions using direct measurements and laboratory analyses, rather than relying on functional variables and equations from the existing HGM literature. This was done because the existing information was formulated elsewhere and may not be appropriate for Colorado wetlands because of differences in climate, elevation, and other environmental factors.

The investigators' approach to wetland characterization and HGM classification is modified from an ASTM-standard, ground-water flow systems methodology (ASTM-STP-1288) by Kolm and others (1996). This approach has advantages in that it is non-invasive, and the subsurface framework and ground-water flow system can be estimated with minimal time being spent on-site. It is also well-suited for HGM work because the methodologies focus on the same physical attributes and processes. The field studies were conducted using the following steps at each site: 1) surface characterization (including vegetation, soil, surface water, climate, topography, and animal attributes); 2) subsurface characterization (including hydrogeomorphology, geology, hydrogeology, hydrostructure, ground-water movement, and boundary condition attributes); 3) ground-water system characterization (combining 1 and 2); and 4) wetland classification (based on 3). Two HGM classes of wetlands were recognized from the 1997 study sites, *slope* wetlands at Peru Creek and Big Meadows and *riverine* wetlands at Deerlodge and Browns Parks. (It should be noted that the two other HGM classes from the Section 3 classification, *depression* and *mineral-soil flat*, are not included; these classes were not studied in the field for this project.)

The geochemical characterization focuses on three major factors. First, the site hydrology was established using the hydrologic characterization (see previous paragraph) and water samples were taken. Then, the soils and plant-community production were assessed by taking soil and plant samples from selected locations at each site. Water samples were taken during the spring runoff, mid-summer, and fall of 1997. The water samples were analyzed for dissolved oxygen, conductivity, Eh, pH, and temperature in the field. In the laboratory, anion analyses for fluoride, chloride, phosphate, nitrate, and sulfate content were run on an ion chromatograph, and analyses for twenty nine cation contents were run on an inductively coupled plasma – atomic emission spectrometer. Soil samples were analyzed for percent organic matter, particle size, total pore space, and cation content. Plant samples were analyzed for plant biomass and cation content. The results of the water, soil, and plant geochemical tests were analyzed using ANOVA, linear regression, correlation, and spatial analysis. The overall results show that the retention, transport, and chemical reactions of metals and other nutrients is influenced both directly and indirectly by the spatial hydrology, soils, and biological activity of the wetlands.

As a result of the reference-site analyses and HGM-method development, the authors propose fifteen hydrologic functions and six geochemical functions, and related functional equations and variables, for southern Rocky Mountain wetlands. The hydrologic functions involve atmospheric processes (two functions), surface water processes (seven), and ground-water processes (six). The geochemical functions involve movement and storage of chemicals (two functions) and movement and conversion of cations (two) and anions (two). For a full analysis of these geochemical functions, it is necessary to include information about several of the hydrologic variables and functions as well. The authors include a proposed listing of HGM variables, variable rankings, and functional equations for each hydrologic and geochemical function.

<u>HGM Sediment Retention and Carbon Storage/Export Functions</u> (from Section 5)

Dr. David Cooper, Christopher Arp, and Rodney Chimner, Colorado State University, present the results of an investigation of functions that are considered crucial in terms of the Clean Water Act: the retention and export of sediment, carbon, and nitrogen in wetlands. These functions were studied at four reference wetlands in the Colorado River watershed, ranging from high to low elevation, at Big Meadows, Kawuneeche Valley, Deerlodge Park, and Browns Park (see site descriptions, p. 5-13). The purpose of the study was to determine where, and quantify to what degree these functions are being performed in the watershed. The investigators attempted to quantify the basic functions using direct measurements and laboratory analyses, rather than relying on functional variables and equations from the existing HGM literature. This was done because the existing information was formulated elsewhere and may not be appropriate for Colorado wetlands because of differences in climate, elevation, and other environmental factors.

Sediment deposition rates were measured at geomorphic numerous locations within the four reference wetland sites during 1997, and streambank retreat was measured at three sites. The volume and bulk density of the sediments was calculated and used to determine total mass gain, total mass loss, and the mass balance between deposition and erosion for each wetland. The sediment deposition rates increased by approximately one order of magnitude from the high-elevation to the low-elevation sites. There was an order of magnitude of variance between sample locations at each of the three riverine sites, while uniformly low deposition rates were measured from the Big Meadows peatland. Erosion rates were an order of magnitude higher for the Deerlodge and Browns Park sites than at the Kawuneeche Valley site. A net loss of sediment occurred at the Browns Park (-96.53 Mt ha^{-1} yr^{-1}; gain/loss ratio 0.26) and the Deerlodge Park (-15.47; 0.64) sites as a result of streambank erosion associated with high runoff flows. Deposition at those sites occurred mainly on active chute bars and on meander scrolls in the lee of young cottonwood trees. The Kawuneeche Valley site experienced a modest net gain (+0.80; 1.43), of which 91% occurred on narrow point bars in the Colorado River. The entire Big Meadows site may be functioning as a sediment deposition area, although the sediment is almost entirely organic and the rate of accumulation is low (+1.34).

Carbon and nitrogen concentrations were measured for each sedimentation and bank-retreat zone at the four sites. The total deposition and erosion of C and N, as a part of the sediment that was actively transported in 1997, was calculated using the sediment mass balance equations. In addition, measurements were made at numerous geomorphic locations to determine total organic soil carbon (from in-place soils), above-ground net primary productivity (from vegetation clippings), below-ground primary productivity (from in-growth root bags), and carbon dioxide and methane fluxes (from on-site gas chambers). The Big Meadows fen was found to have the highest concentrations of C and N (37.3% and 0.53%). Sediment deposited in the lower floodplain positions at Deerlodge and Browns Parks contained the largest total amounts of C and N, although the concentrations were smaller by as much as one order of magnitude. The higher floodplains and terraces contained higher concentrations of C and N, although the total amount of sediment, C, and N were small. Net losses of C and N (in sediment) occurred at Kawuneeche Valley and Brown's Park, while losses matched gains at Deerlodge Park. A miniscule gain of C and N occurred at Big Meadows; loss measurement was not attempted at this site.

Carbon budgets were developed for the four sites. Big Meadows has the lowest rate of not primary productivity but the greatest rate of long-term carbon storage. This result suggests that decomposition, not net primary productivity, controls carbon storage in high-altitude peatlands. Sediment erosion and deposition was found to play an important role in carbon storage functions at the riverine wetland sites. The authors hypothesize that, although much more carbon can be exported from the riverine wetlands on an acre-by-acre basis, the carbon export function for high-altitude peatlands may be higher on a *cumulative* basis for a given watershed; this is because of the large number and cumulative acreage of small peatlands along tributary streams.

The development of a carbon budget for a wetland site is costly, and may be near-impossible for large, heterogeneous sites. An alternative approach is offered, using percent soil carbon as a long-term measure of carbon storage. The authors have formulated a watershed-scale, conceptual model for predicting and estimating carbon storage based on gradients of elevation and period of saturation. Incorporation of the study data into the model show a good agreement when elevation is plotted against the log of percent soil carbon.

Based on the study results, the authors analyze existing HGM functional models and variables from Brinson and others (1995) and Hauer and Cook (1996), and give several suggestions for modifications that could make the models suitable for wetland functional evaluation in Colorado and other southwestern states. The models include the following: 1) retention of particulates (sediment trapping); 2) removal of elements and compounds; 3) organic carbon export (aquatic food chain support); and 4) organic carbon accumulation (long-term). The sediment deposition model needs to be modified to include sediment erosion using a sediment budget approach. Similarly, the organic carbon export function needs to be modified to account for carbon export due to streambank sloughing and carbon-rich sediment deposition. As discussed in the previous paragraph, the authors have formulated a conceptual model as a means of estimating long-term, organic carbon accumulation.

Recommendations

1) The Colorado Department of Natural Resources should use the results from the wetlands questionnaire (Section 2) to determine the need for, and content of technical-assistance programs for local-government agencies throughout Colorado.

2) The HGM classification for Colorado's wetlands (Section 3) should be tested in a variety of wetland settings, and modified as is necessary.

3) The HGM classification for Colorado's wetlands (Section 3) should be expanded to include a third additional level of hierarchical classification (sub-subclass), the HGM alliance level.

4) A hierarchical, three- or four-level classification of Colorado wetland *vegetation* should be developed using the data sets that were used for the HGM classification (Section 3).

5) The step-wise approach to HGM site characterization and the hydrologic and geochemical functional models (Section 4) should be tested and calibrated in a variety of wetland settings, and should be modified as is necessary.

6) The long-term carbon storage functional model (Section 5) should be tested and calibrated in a variety of wetland settings in Colorado, and modified as is necessary.

7) Existing HGM functional models for retention of particulates and organic carbon export should be modified to include the effects of streambank sloughing and erosion for use in Colorado and other dry climate areas of the southwestern United States.

Acheivement of Project Objectives

Successes

We have accomplished the following: 1) demonstrated the need for technical assistance with wetland programs and the development of a rapid, inexpensive method of functional assessment in Colorado, as expressed by a large number of county and municipal government agencies; 2) developed a class- and subclass-level HGM classification for Colorado's wetlands based on biotic and abiotic data from representative wetlands across the state; 3) developed a step-wise, investigative sequence and preliminary models for assessing HGM hydrologic and geochemical functions; and 4) suggested modifications to existing HGM functional models for sediment and carbon retention and export.

Failures

Most of the project's purpose and objectives were met by the study team. Unfortunately, one of the five reference wetland sites was not fully investigated for the hydrologic and geochemical study (Section 4), and another was not fully investigated for the sediment and carbon retention study (Section 5). The reasons for this are not clear, but may have something to do with an academic-institutional turf battle for ownership of certain data from certain wetland sites. For future planning purposes, investigators should ascertain the availability of existing and concurrently generated data from all parties at a site if it is to be used as a reference wetland.

Lessons Learned

We have learned that the basic assumptions of the hydrogeomorphic approach are appropriate for Colorado's wetlands because of the tremendous degree to which the state's physical setting controls wetland occurrence, morphology, and function. However, some of the existing HGM variables, functions, and functional equations may not be appropriate for use in Colorado because they were formulated in the eastern and southern United States, in a markedly different climatic and topographic regime. For example, some wetlands in Colorado lose sediment in addition to retaining sediment, a process that is not accounted for in existing HGM models. Our approach of conducting basic scientific measurements in reference wetlands and developing functional models from those results appears to have merit, based on our findings and experiences. We hope that the information from this report will be of use to other wetland researchers, and that this investigative process will continue.

Acknowledgements and Project Personnel

The U.S. Environmental Protection Agency (EPA) provided financial support for this project through their 104(b)(3) State Wetlands Grant program, grants CD998004-03-0 and –03-01. In-kind financial support was provided by Colorado Geological Survey (CGS), Colorado School of Mines (CSM), and Colorado State University (CSU). The CGS Water Quality Data program provided additional funding for research activities. The Colorado Department of Natural Resources (DNR) served as the state coordinating agency and administered these grants. We wish to thank Sarah Fowler and David Rathke, EPA Region VIII; Pat Rogers and Matt Sares, CGS Water Quality Data program; and Doug Robotham and Deborah Mellblom, DNR, for their support and assistance.

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We owe a great deal of thanks to the Project Advisory Committee (The "A-Team") who helped us formulate a work plan the project. The following individuals participated in this role: Gene Reetz, U.S. EPA; Mark Gershman, City of Boulder; Katherine Walton-Day, U.S. Geological Survey; John Scherschlight, Water Quality Control Division, Colorado Department of Public Health and Environment; John Sanderson, Colorado Natural Heritage Program; Michael Scott, U.S. Fish and Wildlife Service; Steve Dougherty, ERO Resources; Robert Henke, SAIC; and Jim Ringelman, Colorado Department of Wildlife. The project benefited greatly from discussions with wetland researchers from other states: Nancy Keate, State of Utah; Mike Gilbert and Ellis Clairain, U.S. Army Corps of Engineers; Rick Hauer, University of Montana; and Mark Brinson, East Carolina University.

Finally, we thank Alison Barry, who served as the primary grant-proposal author and project manager for CGS during the planning and background-research phases of the project. She was lured away to the beltway in Washington, D.C., to become a solicitor for the U.S. Department of the Interior. We dedicate this report to Alison in appreciation of her vision and insight.

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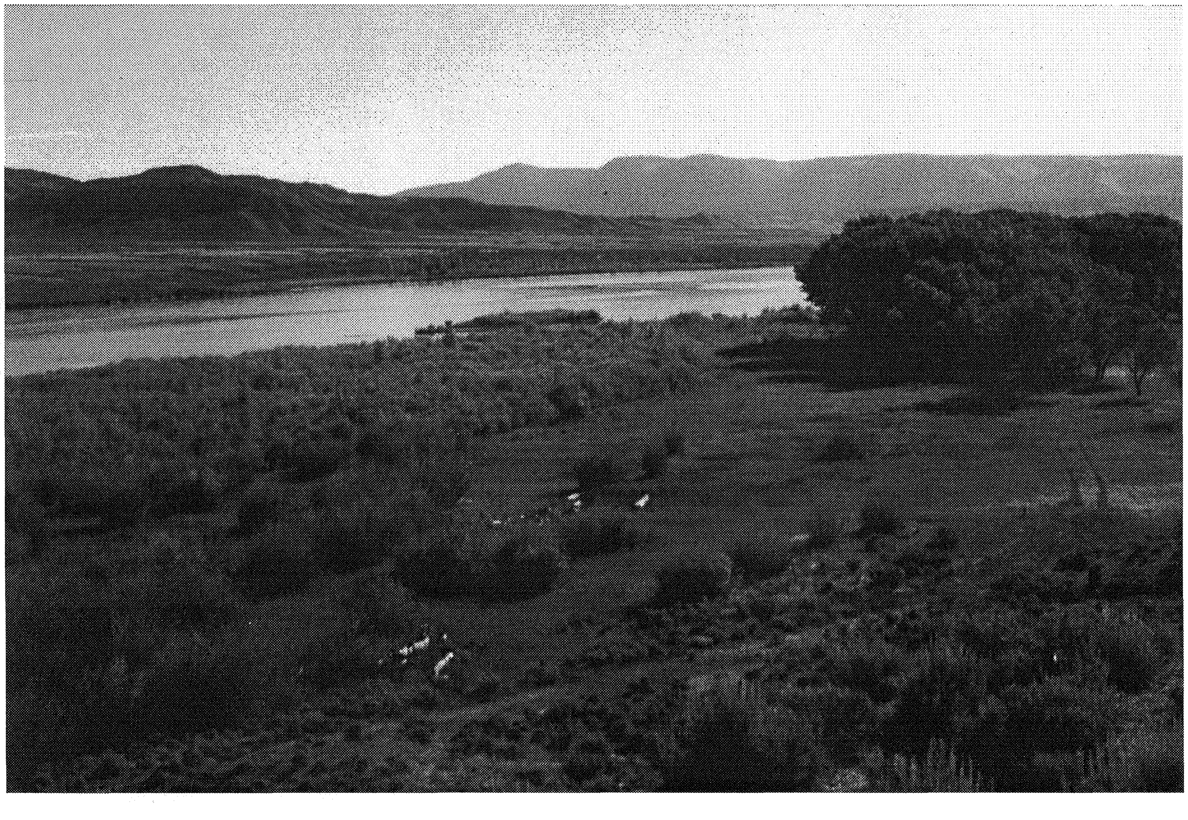
CHARACTERIZATION AND FUNCTIONAL ASSESSMENT OF REFERENCE WETLANDS IN COLORADO

A PRELIMINARY INVESTIGATION OF HYDROGEMORPHIC (HGM) CLASSIFICATION AND FUNCTIONS FOR COLORADO'S WETLANDS



Section 2

Colorado Wetlands Management Questionnaire

SUMMARY OF RESULTS FROM THE 1996 WETLANDS MANAGEMENT QUESTIONNAIRE

Alison Barry, Monica Pavlik, and David C. Noe
Colorado Geological Survey
Colorado Department of Natural Resources
July 1997

The Colorado Geological Survey (CGS) conducted a brief survey of planning or land-use officials in Colorado county and municipal governments during the summer of 1996. Out of 240 questionnaires sent out, approximately ninety were returned to CGS during the following two months. Approximately half of the county governments, and about one quarter of the municipalities, responded to the survey questionnaire.

Questionnaire Design

The survey questionnaire was designed to reveal the following:

1) whether or not local governments in Colorado were engaged in wetlands management (through land use or environmental ordinances, regulations or policies);
2) the technical tools used in local wetlands programs;
3) the existence of local wetland maps, inventories or classification schemes;
4) types of wetlands recognized by local officials; and
5) the level of interest in technical assistance from the Colorado Department of Natural Resources (DNR).

Summary of Results

Over 85% of the county respondents expressed interest in some form of technical assistance from the state DNR, such as access to data, help with wetlands assessment techniques, support for identification, mapping and classification program, or training for local land use personnel. Riparian wetlands and wet alpine and subalpine meadows were most frequently identified as common local wetland types. Negative interest at the county level was expressed primarily through unresponsiveness. Most of the respondent counties are located along the Front Range or the mountain western areas of the state.

Respondents from the municipalities indicated similar needs. The Front Range and mountain resort municipalities were most likely to express interest in receiving technical assistance from the DNR, and were the most likely to be involved already in some form of wetlands management. The Eastern Plains municipalities were the most likely to express negative or indifferent views regarding wetlands management, based on distrust or dislike of state involvement in land use issues and/or the perceived absence (perceived or actual) of wetlands within municipal boundaries.

Of those county and municipal governments who expressed some degree of interest in state wetlands research and technical assistance, many also requested further information from the CGS regarding its ongoing research project.

Survey Questions and Tally of Replies

The following is a listing of the survey questions and a tally of the replies. Individual responses are shown in a series of tables (Table 1 for county responses; Table 2 for municipality responses), and a series of color figures (Figures 1-12) that were compiled from the tables using a computerized Geographic Information System (GIS).

Total County Responses: 32	(Table 1; Fig. 1)
Total Municipal Responses: 52	(Table 2; Fig. 2)

1. *Does your community have a program to manage wetlands located within its jurisdictional boundaries?*

County:	YES - 5	NO - 27	(Fig. 3)
Municipal:	YES - 16	NO - 35	(Fig. 4)

2. *If yes, is this program based on…*

a. *Voluntary cooperation of landowners with local policy initiatives:*

County: 2 Municipal: 9

b. *Local regulations or ordinances:*

County: 1 Municipal: 12

c. *County regulations or ordinances:*

County: 8 Municipal: 4

d. *Purchase (in fee or less than fee title) of wetlands:*

County: 1 Municipal: 5

e. *Other:*

County: 4 Municipal: 8

3. *Does the program involve…*

a. *Delineation using the Army Corps of Engineer's Delineation manual:*

County: 7 Municipal: 13

b. *Assessment or evaluation of functions:*

County: 2 Municipal: 10

c. *Mitigation (including restoration and replacement):*

County: 7 Municipal: 14

4. *If your community requires or recommends any kind of functional assessment procedures in order to approve an activity that has the potential to impact a wetland, what techniques are commonly used?*

a. *Army Corps of Engineers' Wetlands Evaluation Technique (WET):*

County: 14 Municipal: 10

b. *Habitat Evaluation Procedure (HEP):*

County: 3 Municipal: 2

c. *Locally developed approach:*

County: 1 Municipal: 7

(Fig. 5) (Fig. 6)

5. *Does your community have a wetlands inventory?*

County: YES - 6 (most in progress or need update)
NO - 26

Municipal: YES - 7 (most need update, or are partial or unsure)
NO - 46

6. *Does your community classify wetlands? If yes, how?*

County: YES - 4 (Call Corp or NRCS)
NO – 27 (Fig. 7)

Municipal: YES - 7 (usually for site-specific development)
NO – 42 (Fig. 8)

7. *If your community does not have a wetlands management program, is it because of ...*

a. *Inadequate information about wetlands identification/functions in your area?*

County: 17 Municipal: 26

b. *Inadequate resources (personnel and funds) to devote to wetlands protection?*

County: 19 Municipal: 33

c. *Lack of personnel with training in ecology or wetlands science?*

County: 16 Municipal: 34

d. *Lack of local support for such a program?*

County: 13 Municipal: 20

(Fig. 9) (Fig. 10)

8. *Would you be interested in a rapid, inexpensive assessment tool tailored to the types of wetlands commonly found in your area? If so, please list the wetland types (e.g., riparian, fens/carrs, wet meadows, "prairie potholes" or kettles) you are aware of in your area.*

County:	YES - 21	Maybe - 3	NO - 4	(Fig. 11)
Municipal:	YES - 33	Maybe - 2	NO - 3	(Fig. 12)

Most wetland types recognized were riparian, wet meadows, and prairie potholes

9. *What do you think is the most significant wetlands-associated problem facing your community (e.g. lack of scientific data, assessment techniques, technical support for implementation of local programs) that the Department of Natural Resources can help you to address?*

County and municipal responses were similar. Most of the comments were along the lines of needing more technical expertise, scientific data, resources (technical training and financial), development guidelines, and an example of a management plan that works and is implemented by another county or municipality

Figure 1

Counties Responding to DNR/CGS 1996 Wetland Survey

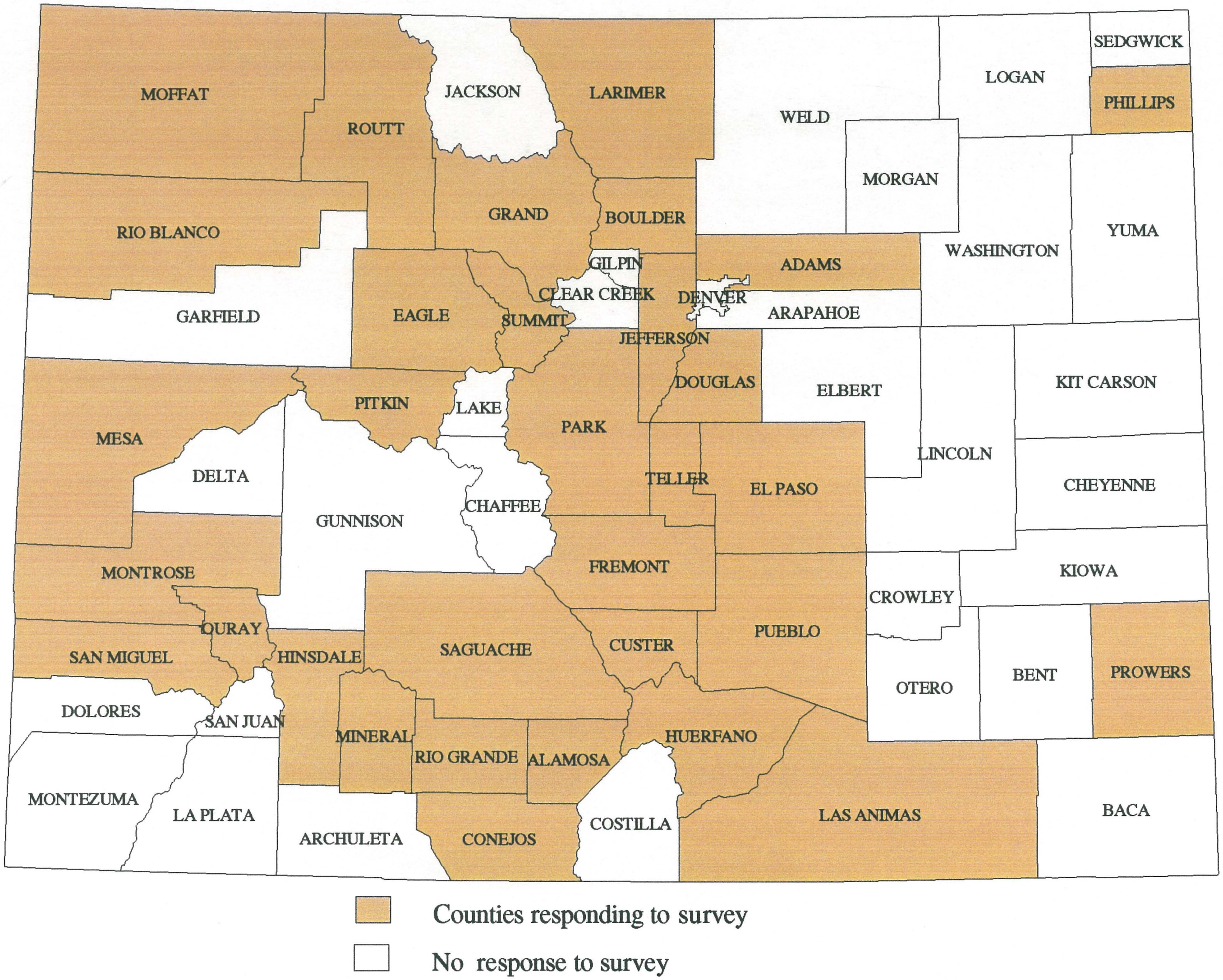


Figure 2

Municipalities Responding to DNR/CGS 1996 Wetland Survey

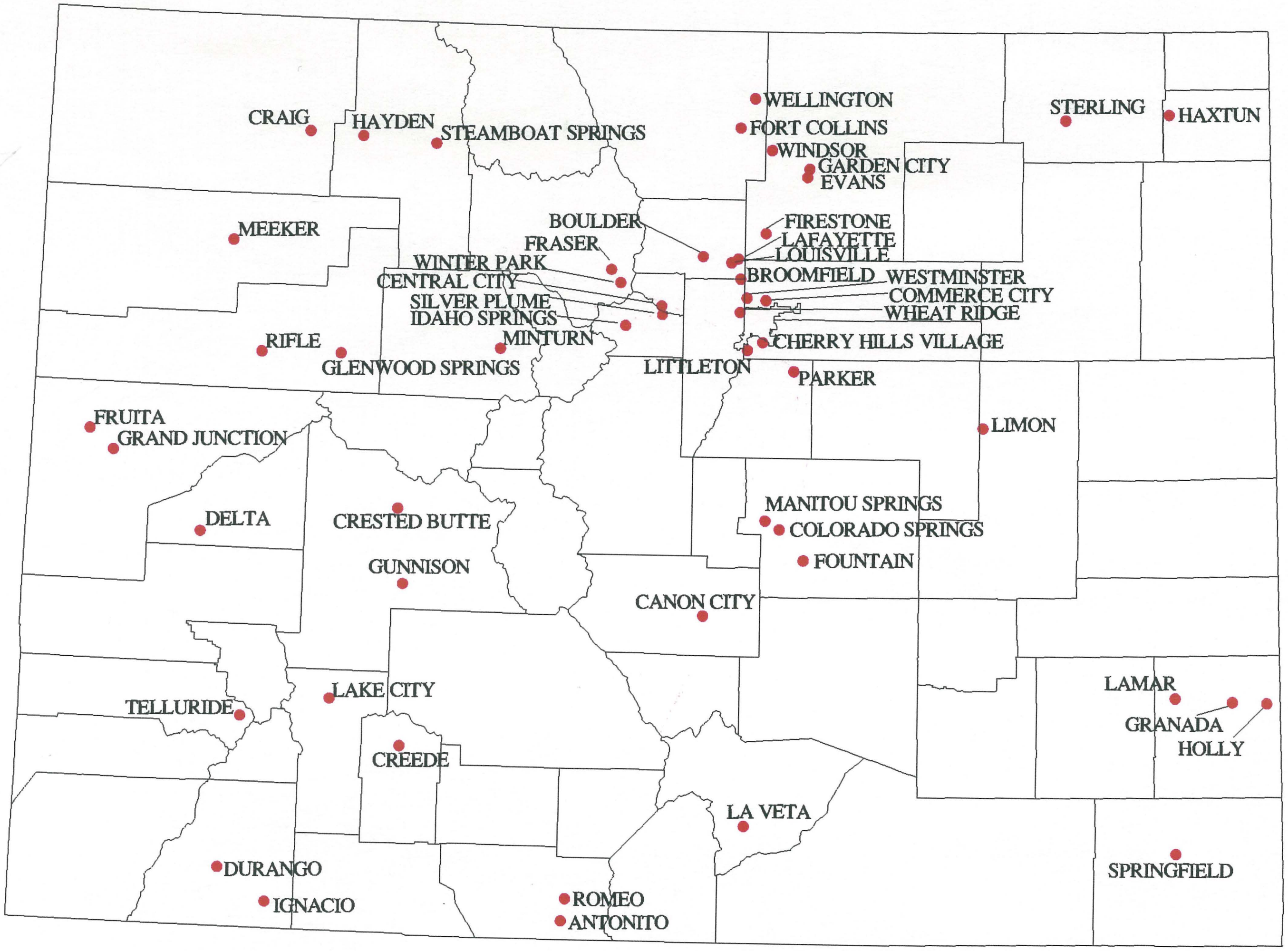


Figure 3

Basis of County Wetland Programs

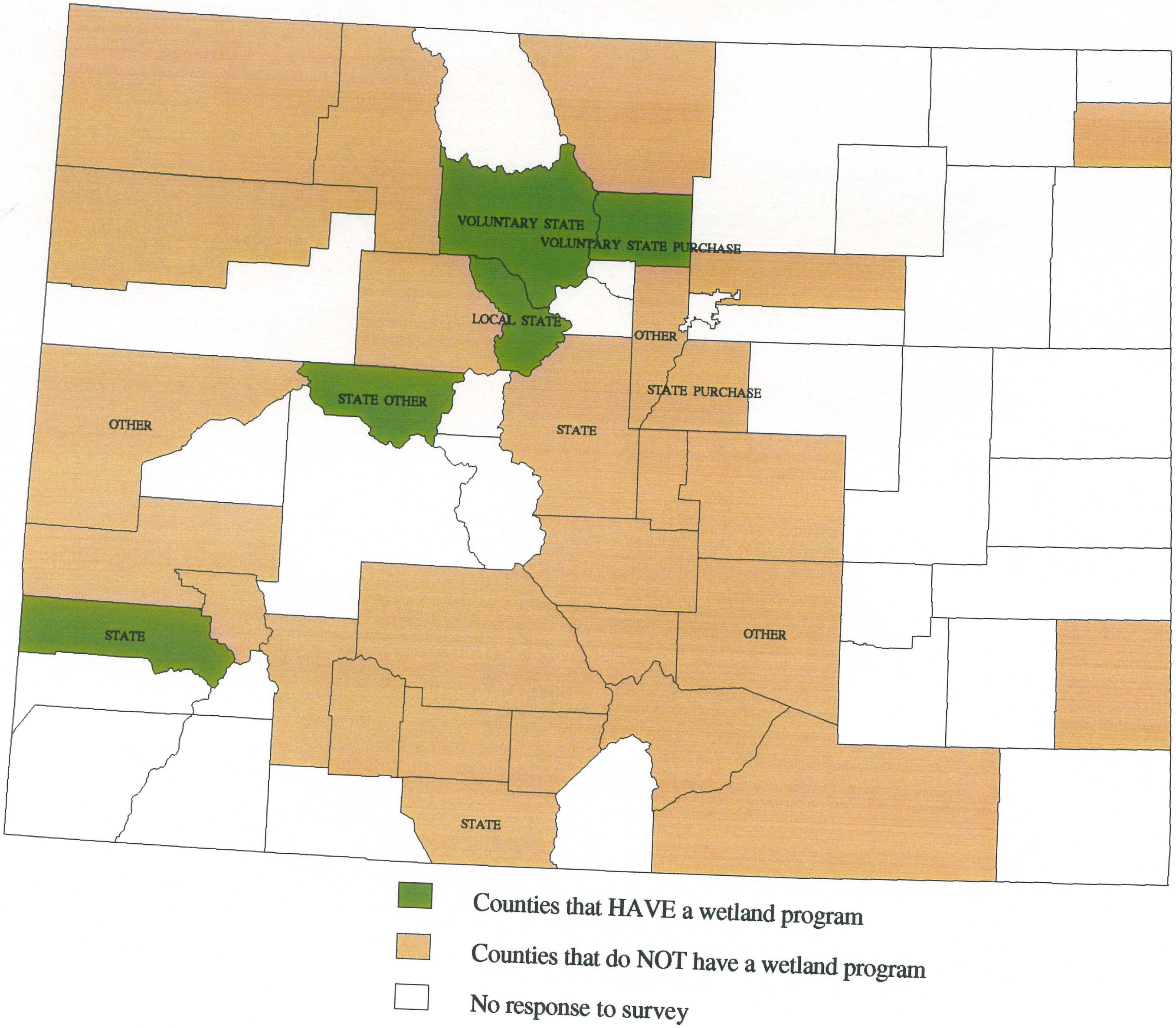
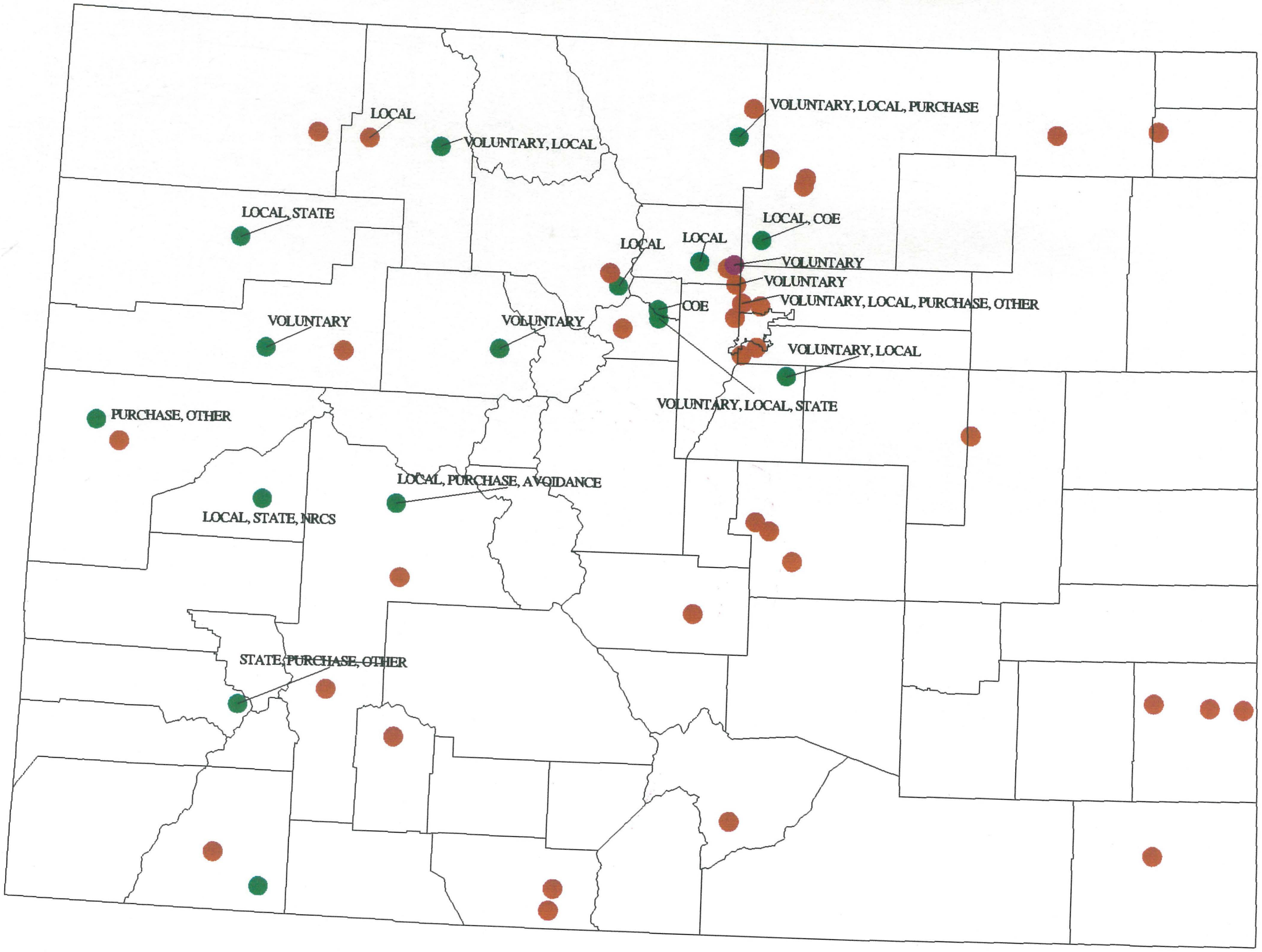


Figure 4

Basis of Municipality Wetland Programs



🟢 Municipalities that HAVE a wetland program

🟠 Municipalities that do NOT have a wetland program

🟣 Municipality not sure

Figure 5

County Required or Recommended Functional Assessment Procedures

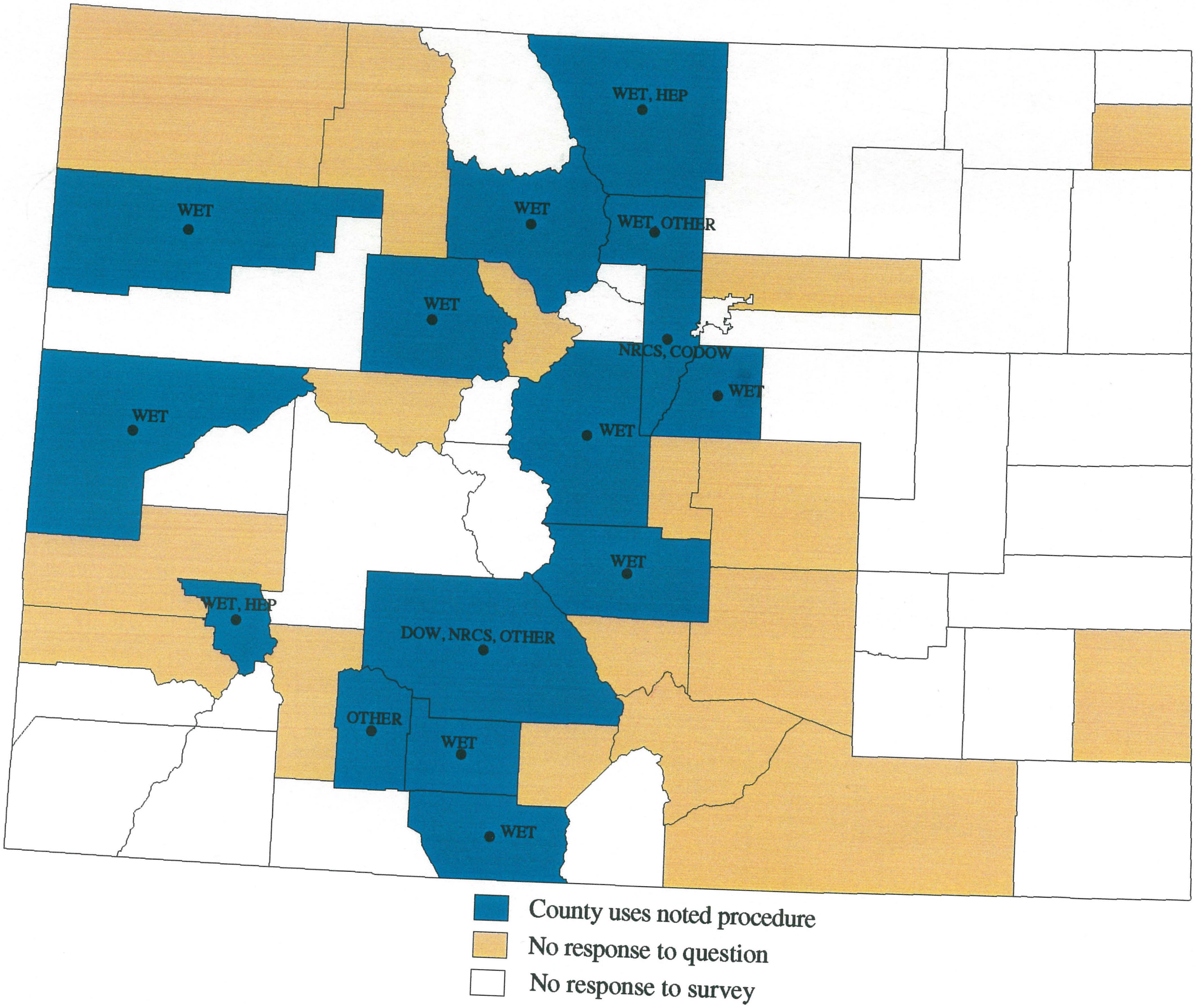


Figure 6

Municipality Required or Recommended Functional Assessment Procedures

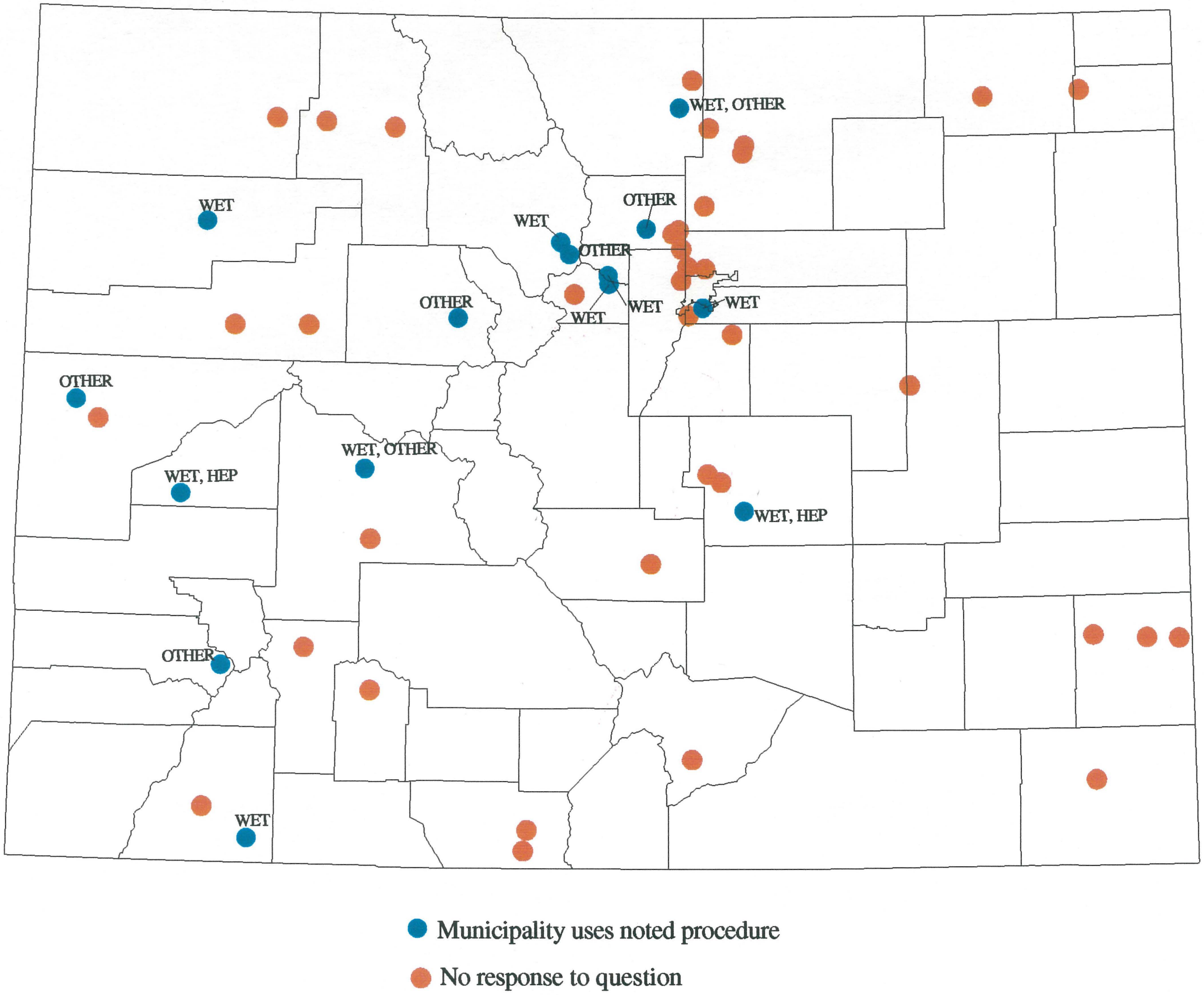


Figure 7

County Wetland Inventory Status

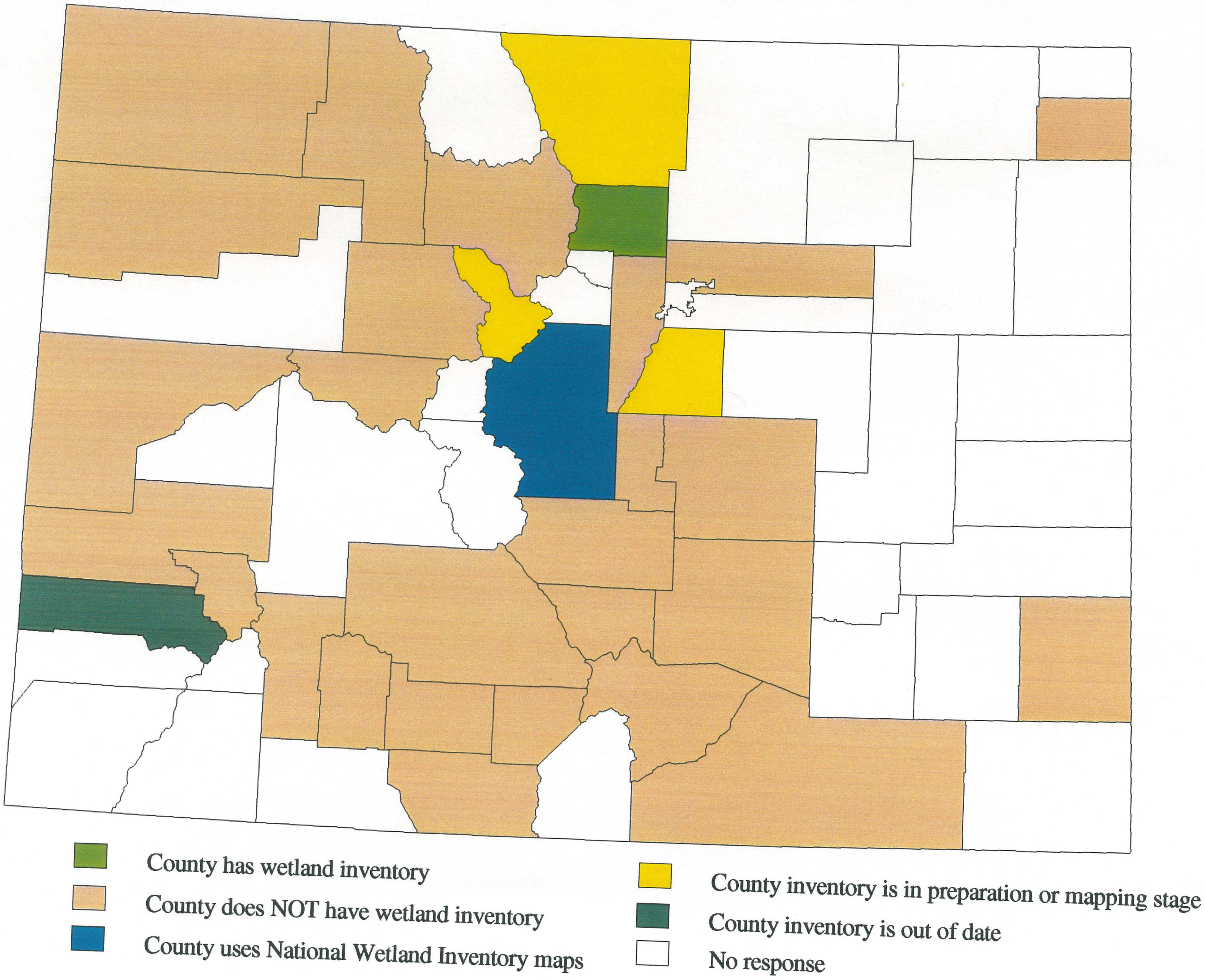
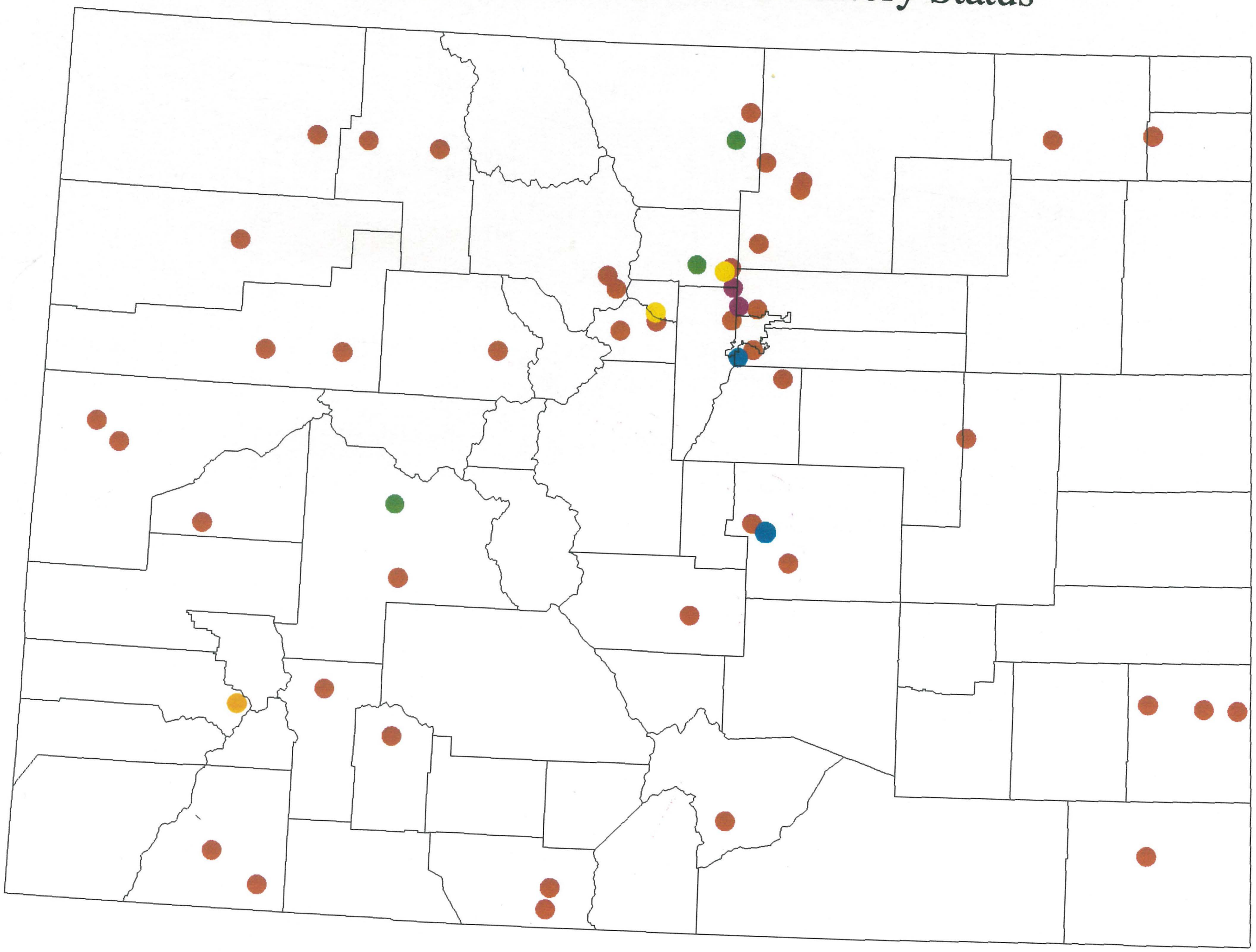


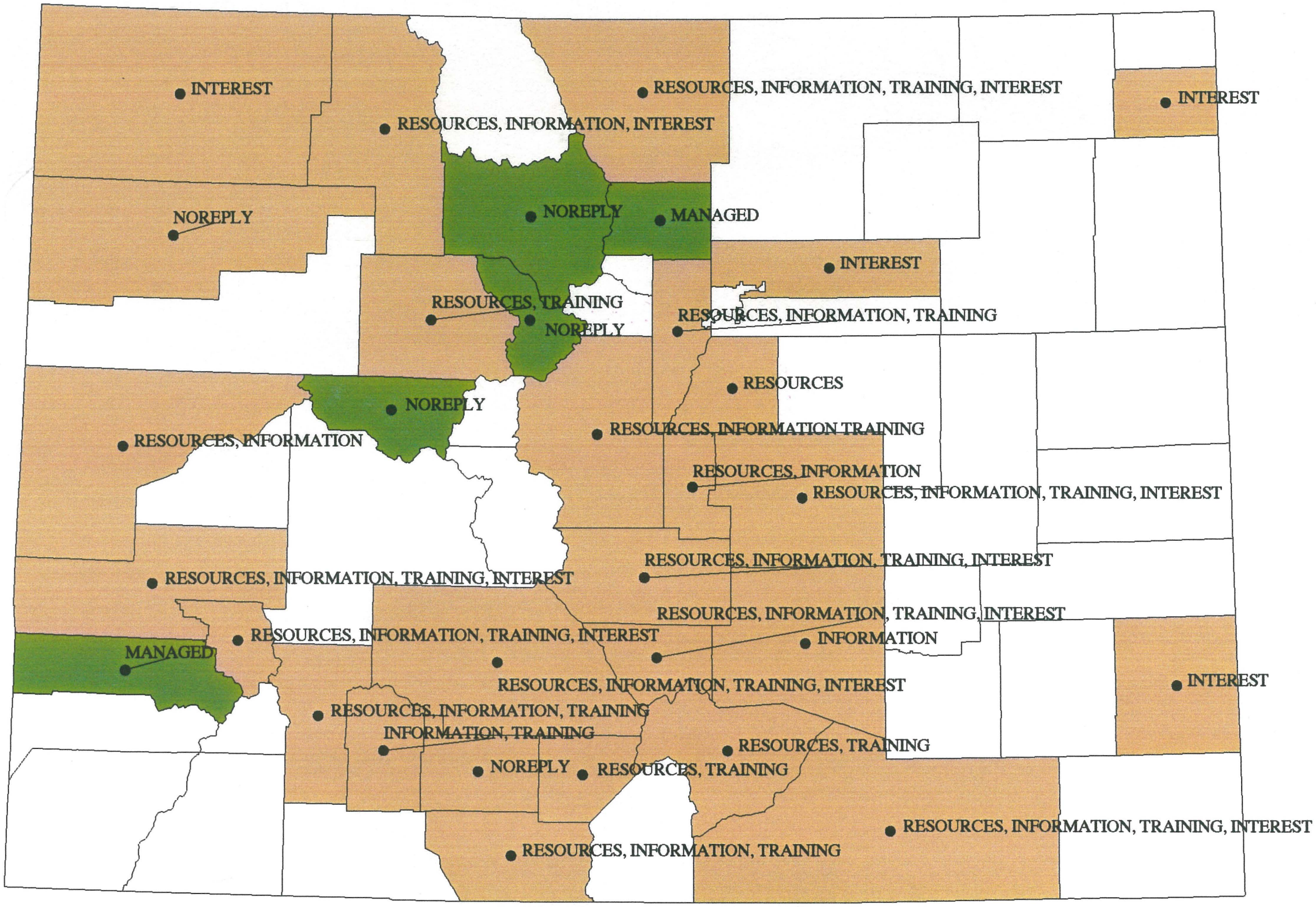
Figure 8
Municipality Wetland Inventory Status



- ● Municipality has wetland inventory
- ● Municipality does NOT have wetland inventory
- ● Municipality has a partial inventory
- ● Municipality uses National Wetland Inventory maps
- ● Municipality inventory is out of date
- ● Municipality not sure

Figure 9

County Responses to Reasons for Not Having a Wetland Program

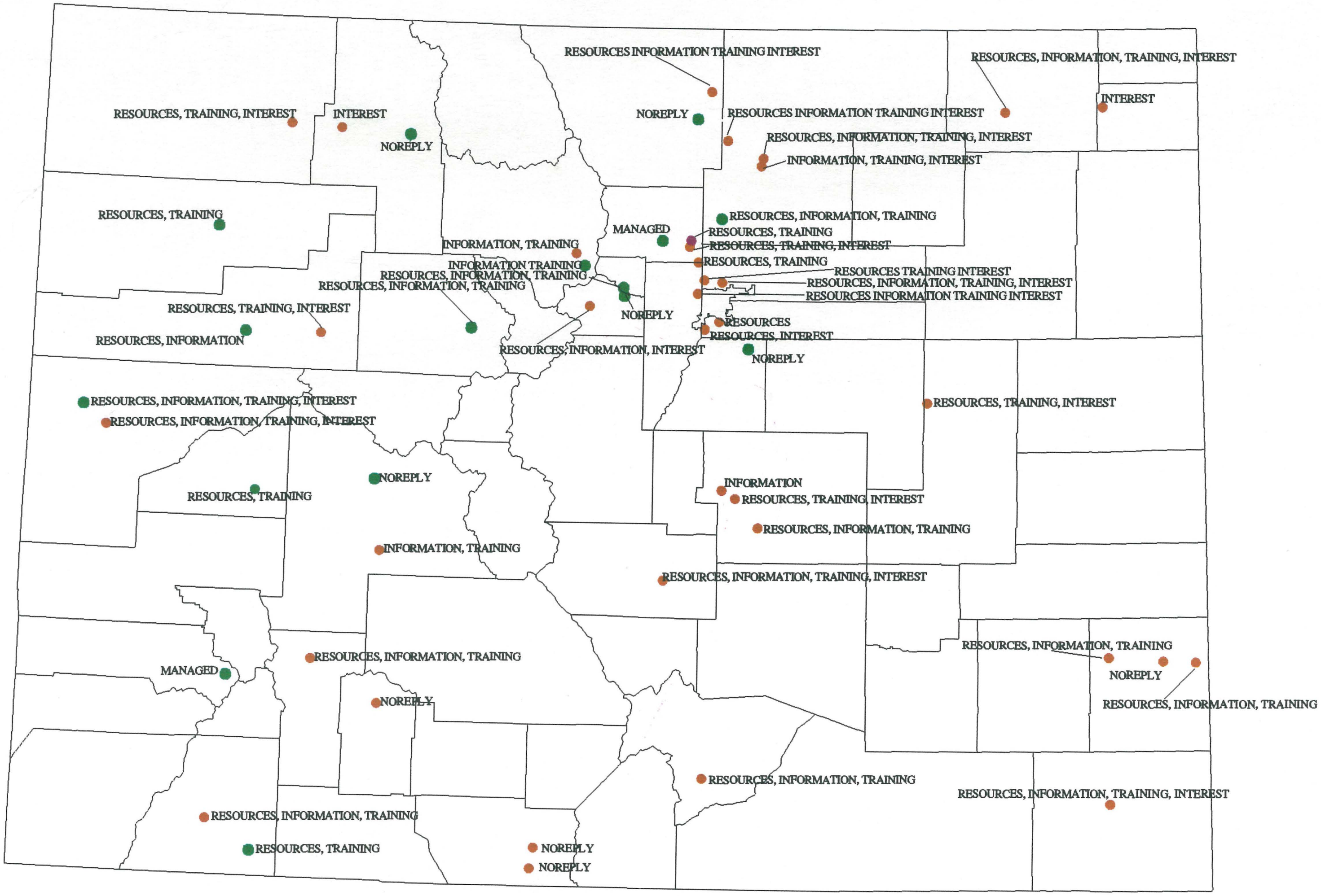


Options offered are: Resources, Information, Training, Interest/Support

Colors same as "Basis of County Wetland Programs" map (Fig 3)

Figure 10

Municipality Responses to Reasons for Not Having a Wetland Program



Options offered are: Resources, Information, Training, Interest/Support

Colors same as "Basis of Municipality Wetland Programs" map (Fig 4)

Figure 11

Counties Interested in Rapid Functional Assessment Tool Tailored to Local Wetlands

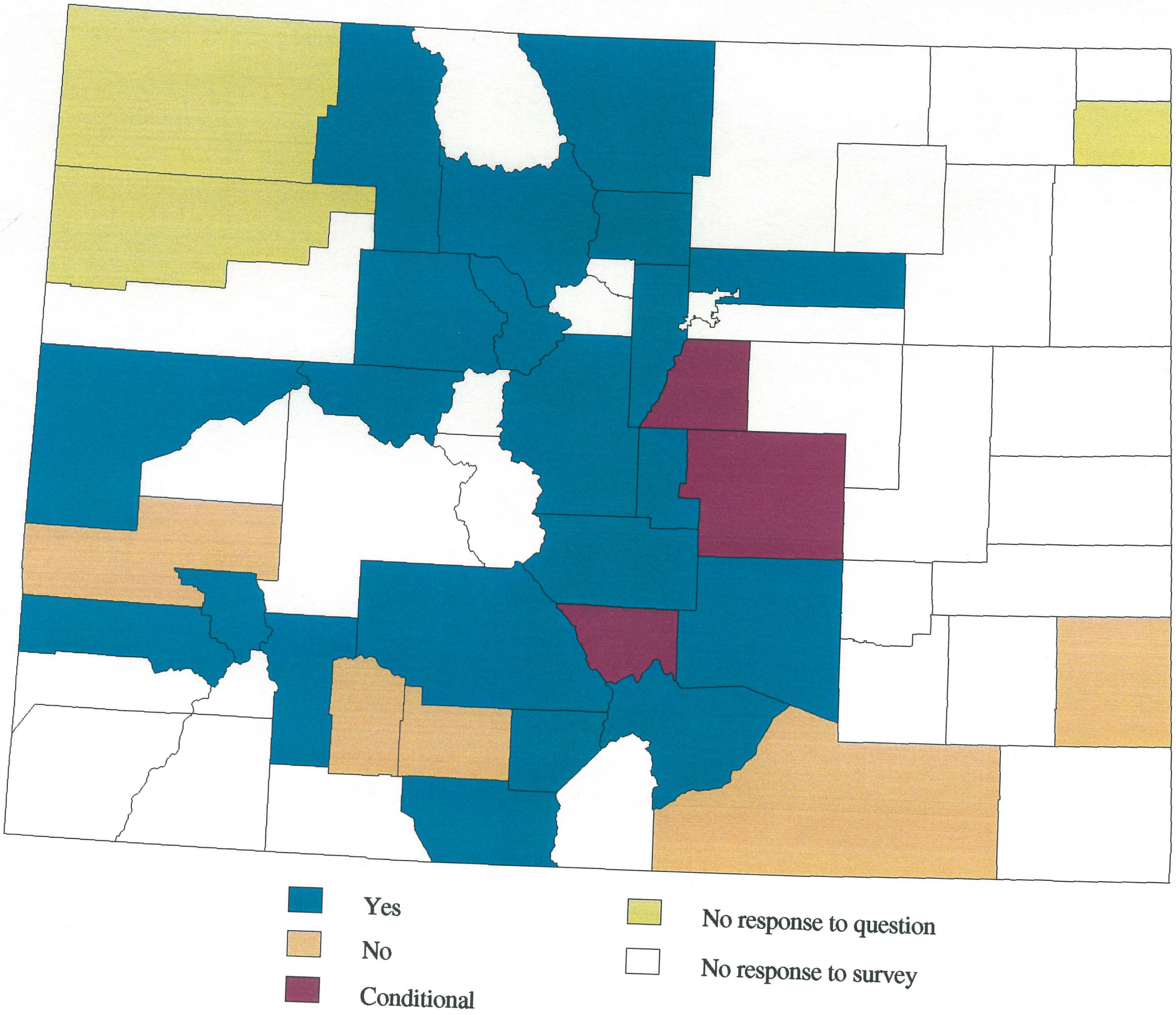


Figure 12

Municipalities Interested in a Rapid Functional Assessment Tool Tailored to Local Wetlands

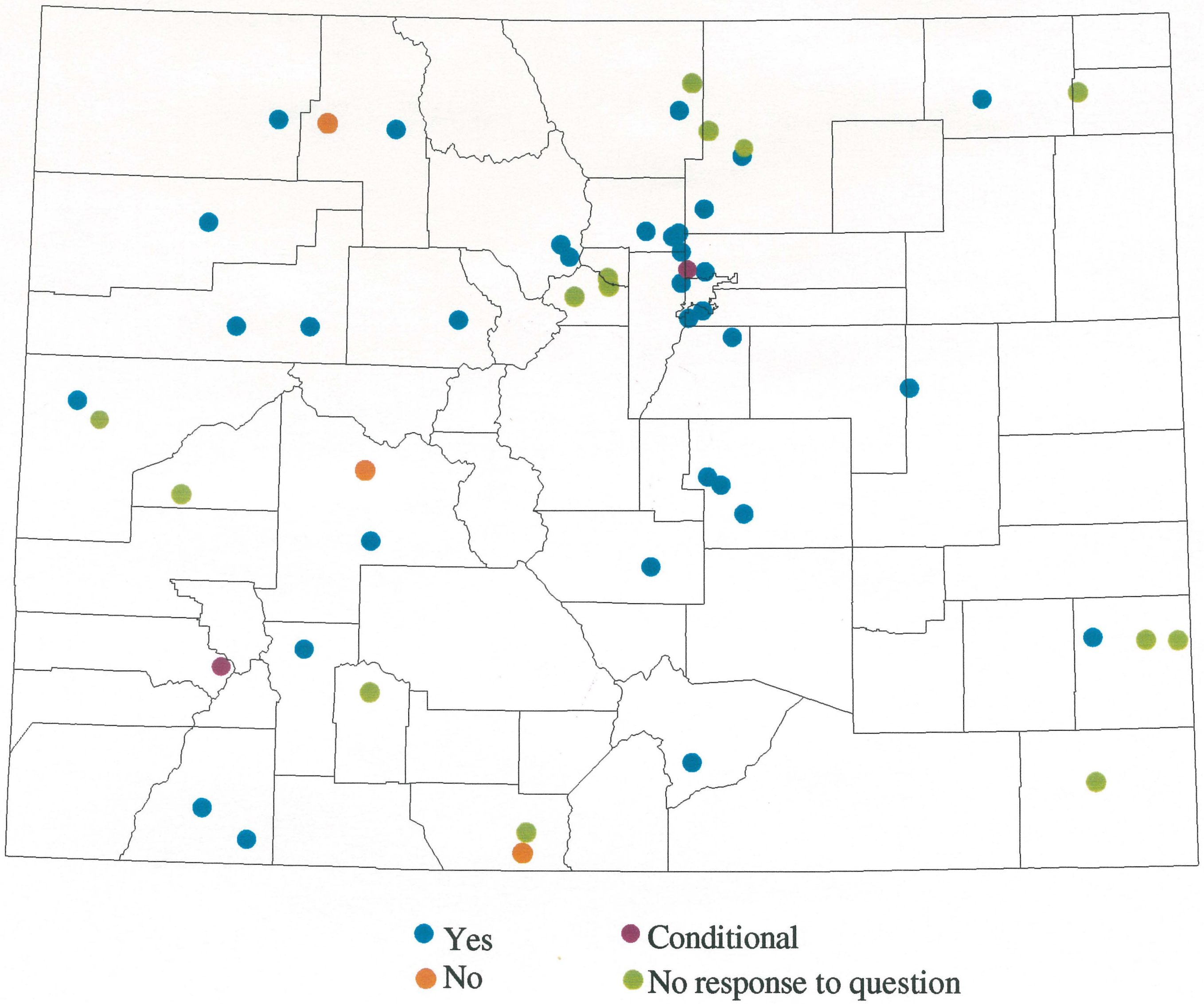


Table 1. County Responses to CGS Wetland Questionnaire

COUNTY[1]	WETLANDS PROGRAM	PROGRAM BASED ON[2]	PROGRAM INVOLVES[4]	PROCEDURES USED[5]	WETLAND INVENTORY	WETLAND CLASS'N[6]	TYPES IDENTIFIED[7]	REASONS FOR NOT MANAGING[8]	MANAGEMENT PROBLEMS	INTEREST IN ASSMT TOOL
Adams	no	nr[3]	nr	nr	no	no	rip, oth	supp	data	yes
Alamosa	no	nr	nr	nr	no	no	unk	pers, res	tech support	yes
Boulder	yes	colo, pur, vol	coe, func, mit	loc, wet	yes	yes	all	n/a	cumulative-loss assessment	yes
Conejos	no	colo	nr	wet	no	no	rip, wmd, pot	info, pers, res	assessment, data, resources	yes
Custer	no	nr	nr	nr	no	no	nr	info, pers, res, supp	nr	don't know
Douglas	no	loc, pur	coe, mit	wet	in progress	nrcs	unk	res	protection beyond land use regs	maybe
Eagle	no	nr	nr	wet	no	no	all	pers, res	assessment, mitigation	yes
El Paso	no	nr	nr	nr	no	no	rip, wmd, pot	info, pers, res, supp	info, resources, training, political	maybe
Fremont	no	nr	coe	wet	no	no	all	info, pers, res, supp	info, resources, training	yes
Grand	yes	colo, vol	coe, func	wet	no	coe	rip, wmd	n/a	assessment	yes
Hinsdale	no	nr	nr	nr	no	no	unk	info, pers, res	don't know	yes
Huerfano	no	nr	nr	nr	no	no	rip	pers, res	assessment, info, tech support	yes
Jefferson	no	loc	mit	cdow, nrcs	no	no	rip, wmd	info, pers, res	classification, identification	yes
Larimer	no	nr	nr	hep, wet	in progress	in progress	rip, pal, litt, wmd	info, pers, res, supp	tech support	yes
Las Animas	no	nr	nr	nr	no	no	nr	info, pers, res, supp	nr	no
Mesa	no	usbr	mit	wet	no	no	rip	info, res	data	yes
Mineral	no	nr	nr	geo	no	no	rip	info, pers	development pressure	no
Moffat	no	nr	nr	nr	no	no	nr	supp	ESA issues, property rights	no
Montrose	no	nr	coe	nr	no	no	nr	info, pers, res, supp	nr	no; use COE instead
Ouray	no	nr	nr	hep, wet	no	no	rip, wmd	info, pers, res, supp	identification, classification	yes
Park	no	colo; peat	nr	wet	needs update	in progress	rip,carr,fen,wmd	info, pers, res	assessment, data, tech support	yes
Phillips	no	nr	nr	nr	no	nrcs	nr	supp	wetland issues not a problem	yes
Pitkin	yes	colo; 1041	mit	nr	no	no	rip, wmd, carr	n/a	data, inventory	yes
Prowers	no	nr	nr	nr	no	no	nr	supp	none	not now
Pueblo	no	flood	nr	nr	no	no	rip	info	assessment, inventory, tech support	yes
Rio Blanco	no	nr	nr	wet	no	nr	nr	nr	nr	yes
Rio Grande	no	nr	nr	wet	no	no	nr	nr	nr	no
Routt	no	nr	nr	nr	no	no	rip	info, res, supp	program development, resources	yes
Saguache	no	nr	nr	cdow, nrcs	no	no	rip, gmd, litt	info, pers, res, supp	funding, personnel, tech support	yes
San Miguel	yes	colo	coe, mit	nr	needs update	no	rip, gmd	n/a	mapping assistance	yes
Summit	yes	colo; loc	coe, mit	nr	in progress	in progress	all	n/a	assessment, info, techniques	yes
Teller	no	nr	nr	nr	no	no	rip, wmd	info, res	data	yes

Table 1. County Responses to CGS Wetland Questionnaire

NOTES

1 Counties not responding to survey: Arapahoe, Archuleta, Baca, Bent, Chaffee, Cheyenne, Clear Creek, Costilla, Crowley, Delta, Denver, Dolores, Elbert, Garfield, Gilpin, Gunnison, Jackson, Kiowa, Kit Carson, Lake, La Plata, Lincoln, Logan, Montezuma, Morgan, Otero, Rio Blanco, San Juan, Sedgewick, Washington, Weld, Yuma

2 Abbreviations: colo = state land use regulations; flood = floodplain regulations; loc = local land use regulations; peat = peat mining regulations; pur = purchase programs; usbr = U.S. Bureau of Reclamation salinity control regulations; vol = voluntary programs; 1041 = HB1041(1974) natural hazards reviews

3 Abbreviations: nr = no reply to question

4 Abbreviations: coe = Corps of Engineers delineations; func = functional assessments; mit = mitigation of impacts

5 Abbreviations: cdow = CDOW referral; geo = geotechnical studies; hep = HEP method; loc = local method; nrcs = NRCS referral; wet = WET method

6 Abbreviations: coe = Corps of Engineers referral; nrcs = NRCS referral

7 Abbreviations: all = all types; carr = carrs; fen = fens; gmd = glacial montane/alpine meadows; litt = littoral; oth = other types; pal = palustrine; pot = prairie potholes; rip = riparian; unk = unknown; wmd = wet meadows

8 Abbreviations: info = inadequate information; n/a - not applicable; pers = lack of trained personnel; res = inadequate resources; supp = lack of local support/interest

Table 2. Municipality Responses to CGS Wetland Questionnaire

MUNICIPALITY[1]	WETLANDS PROGRAM	PROGRAM BASED ON[2]	PROGRAM INVOLVES[4]	PROCEDURES USED[5]	WETLAND INVENTORY	WETLAND CLASS'N[6]	TYPES IDENTIFIED[7]	REASONS FOR NOT MANAGING[8]	MANAGEMENT PROBLEMS	INTEREST IN ASSMT TOOL
Limon	no	nr	nr	nr	no	no	unk	pers, res, supp	tech support	yes
Littleton	no	nr	nr	nr	nwi	no	litt, rip	res, supp	expertise, non-native species	yes
Louisville	no	sproj	func, mit	nr	needs update	no	pot, rip, wtm	pers, res, supp	assessment, tech support	yes
Manitou Spgs	no	nr	nr	nr	no	no	rip	info	assessment, information	yes
Meeker	yes	colo, loc	coe	wet	no	yes	rip, wtn	pers, res	same as previous column	yes
Mintern	yes	vol	func	loc	no	no	rip, wtm	info, pers, res	assessment, classification, data	yes
Parker	yes	loc, vol	coe	nr	no	no	rip	n/a	assessment, inventory, mitigation	yes
Rifle	yes	nr	coe	nr	no	no	nr	info, res	data	yes
Romeo	no	nr	nr	nr	no	no	none	nr	no wetlands to manage	no
Silver Plume	no	nr	nr	nr	no	no	nr	info, res, supp	inventory	nr
Springfield	no	nr	nr	nr	no	no	unk	info, pers, res, supp	expertise, classification	nr
Steamboat Spgs	yes	loc, vol	coe, mit	nr	no	yes	rip,wtm	n/a	expertise	yes
Sterling	no	nr	nr	nr	no	no	nr	info, pers, res, supp	resources, tech support	yes
Telluride	yes	colo, loc, pur	coe, mit	unsure	needs update	no/plng	rip, wtm	n/a	contradictions between experts	conditional
Wellington	no	nr	nr	nr	no	no	nr	info, pers, res, supp	nr	nr
Westminster	no	loc, pur, sproj	func, mit	nr	partial	no	rip, wtm	pers, res, supp	relative value rankings	maybe
Wheat Ridge	no	nr	nr	nr	no	no	rip, wtm	info, pers, res, supp	assessment, data, tech support	yes
Windsor	no	nr	nr	nr	no	no	nr	info, pers, res, supp	nr	nr
Winter Park	yes	loc	func, mit	eis	no	no	rip, wtm	info, pers	assessment, mapping, training	yes

Table 2. Municipality Responses to CGS Wetland Questionnaire

NOTES

1 Responding municipalities only; 125 municipalities did not respond to questionnaire
2 Abbreviations: avd = avoidance; coe = Corps of Engineers 404 permit; colo = state land use regulations; flood = floodplain regulations; loc = local land use regulations;
nrcs = NRCS referral; pur = purchase programs; sproj = special projects; vol = voluntary programs
3 Abbreviations: nr = no reply to question
4 Abbreviations: coe = Corps of Engineers delineations; func = functional assessments; mit = mitigation of impacts
5 Abbreviations: cdow = CDOW referral; eis = environmental imapct statements; grav = gravel pit restoration; hep = HEP method; loc = local method; wet = WET method
6 Abbreviations: nwi = USFWS national wetlands inventory maps
7 Abbreviations: coe = Corps of Engineers referral; no/plng = no, but done at time of site-specific planning
8 Abbreviations: all = all types; flat = salt flats; litt = littoral; oth = other types; pal = palustrine; pot = prairie potholes; rip = riparian; unk = unknown; wmd = wet meadows
9 Abbreviations: info = inadequate information; n/a - not applicable; pers = lack of trained personnel; res = inadequate resources; supp = lack of local support/interest

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Antonito	no	nr[3]	nr	nr	no	nr	nr	nr	no wetlands to manage	no
Boulder	yes	loc	coe, func, mit	loc	yes	no	rip,pot,flat,wmd	n/a	regulation compliance	yes
Broomfield	no	vol	mit	nr	partial	no	unk	pers, res	quantification of impacts	yes
Canon City	no	nr	nr	nr	no	no	rip	info, pers, info, supp	educational training, scientific data	yes
Central City	yes	coe	coe, mit	wet	not sure	coe	nr	info, pers, res	depend only on 404 permit	yes
Cherry Hills Vlg	no	nr	nr	wet	no	no	rip	res	nr	yes
Colorado Spgs	no	nr	nr	nr	nwi	no	rip	pers, res, supp	tech support	yes
Commerce City	no	nr	nr	nr	no	no	rip	info, pers, res	data, assessment, tech support	yes
Craig	no	nr	nr	nr	no	no	rip	pers, res, supp	same as previous column	yes
Creede	no	nr	nr	nr	no	no	none	nr	no wetlands to manage	no
Crested Butte	yes	avd, loc, pur	coe, func	loc, wet	yes	no	nr	n/a	tech support	no
Delta	nr	colo, loc, nrcs	coe, mit	hep, wet	no	yes	nr	pers, res	nr	nr
Durango	no	nr	nr	nr	no	no	rip, wmd	info, pers, res	data, i.d., assessment, tech support	yes
Evans	no	nr	nr	nr	no	no	rip	info, pers, supp	inventory	yes
Firestone	yes	coe, loc	coe, mit	nr	no	no	rip, pot	info, pers, res	assessment, tech support	yes
Fort Collins	yes	loc, pur, vol	coe, func, mit	cdow, wet	yes	yes	all	cost of purchasing	guideline development	yes
Fraser	no	nr	nr	wet	no	no	unk	info, pers	same as previous column	yes
Fruita	yes	pur, sproj	func, mit	grav	no	no	rip, wtm	info, pers, info, supp	awareness, data, tech support	yes
Fountain	no	nr	nr	hep, wet	no	no	nr	info, pers, res	same as previous column	yes
Garden City	no	nr	nr	nr	no	no	nr	info, pers, info, supp	no wetlands to manage	no
Glenwood Spgs	no	nr	nr	nr	no	no	rip	pers, res, supp	awareness, appreciation	yes
Granada	no	nr	nr	nr	no	no	none	nr	no wetlands to manage	no
Grand Junction	no	nr	nr	nr	no	no	unk	info, pers, info, supp	political will	nr
Gunnison	no	nr	nr	nr	no	no	rip, oth	info, pers	data, assessment, examples	yes
Haxtun	no	nr	nr	nr	no	no	none	supp	no wetlands to manage	no
Hayden	no	loc, flood	nr	nr	no	no	nr	supp	state and federal leadership	no
Holly	no	nr	nr	nr	no	no	nr	info, pers, res	nr	nr
Idaho Spgs	yes	colo, loc, vol	coe, func, mit	wet	no	no	nr	n/a	nr	nr
Ignacio	yes	nr	nr	wet	no	no	rip	pers, res	staffing	yes
Lafayette	yes - sort of	vol	coe, func, mit	nr	no	no	rip	pers, res	tech support	yes
Lake City	no	nr	nr	nr	no	no	litt, rip	info, pers, res	same as previous column	yes
Lamar	no	nr	nr	nr	no	no	rip	info, pers, res	floodway maintenance	yes
La Veta	no	nr	nr	nr	no	no	rip, wtm	info, pers, res	assessment, examples, tech support	yes

CHARACTERIZATION AND FUNCTIONAL ASSESSMENT OF REFERENCE WETLANDS IN COLORADO

A PRELIMINARY INVESTIGATION OF HYDROGEMORPHIC (HGM) CLASSIFICATION AND FUNCTIONS FOR COLORADO'S WETLANDS

Section 3

HGM Classification of Colorado's Wetlands

Classification of Colorado's Wetlands
For Use In
HGM Functional Assessment:
A First Approximation

Report Prepared for:

Colorado Geological Survey
Colorado Department of Natural Resources

by:

David J. Cooper
Watershed Sciences
Department of Earth Resources
Colorado State University
Fort Collins, Colorado 80523

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Introduction

Wetlands in the United States are regulated under the federal Clean Water Act, two executive orders, and a number of other federal, state and local programs. The goal of these programs is to maintain wetland functions including water quality improvement, habitat, flood attenuation, and bank stabilization. Permits for dredge and fill activities in wetlands within the federal jurisdiction may be issued by the U.S. Army Corps of Engineers (COE) under Section 404 of the Clean Water Act. Part of the COE permit application review is an analysis of the effects of the proposed activity on wetland functions. Thus, activities in wetlands proposed by government agencies and the public are regulated based upon wetland functions, and permits may be issued or denied based upon the perceived, evaluated, or measured functions.

A method that accurately evaluates wetland functions is necessary for the fair review of wetland permit applications, and the protection of the beneficial functions of wetlands. A number of methods have been developed for evaluating wetland functions (World Wildlife Fund 1992). The Adamus method was the first national approach used to assess wetland functions (Adamus and Stockwell 1983, Adamus 1983). This approach was later expanded, termed the Wetland Evaluation Technique (WET) and a computer program included to assist in evaluating the functions (Adamus et al. 1987, 1991). However, the WET technique, and other functional assessment methods did not receive widespread use or acceptance in Section 404 permit application analysis because they were not applicable over wide geographic areas, could not assess all wetland functions, and did not appear to be accurate when independently evaluated (Smith et al. 1995, Dougherty 1989).

The Hydrogeomorphic Approach (HGM) to wetland functional assessment has the potential to be a valuable tool because it is based upon the driving forces of wetlands, their hydrologic regime and geomorphic setting and processes (Brinson 1993). Because this approach is based upon abiotic features that are independent of wetland plant and animal composition the overall approach is national or global in scope. The vegetation of any wetland however, does provide important clues on the hydrologic and geomorphic processes operating in any wetland, and the vegetation structure is critical to certain wetland functions, such as habitat and food chain support.

The first step in creating a regional HGM assessment approach is the development of a hydrogeomorphic classification of wetlands into types with similar functions (Brinson 1993). The regional classification should focus on both the abiotic characteristics of wetlands (eg. water source and hydrologic regime, watershed bedrock type, geomorphic processes, climate and elevation) as well as their biotic characteristics (eg. vegetation structure) to develop a classification that will include the full range of environmental and ecological variation in wetlands. The classification guides the selection of reference wetlands for each unit in the classification which are used to set reference standards to which other wetlands are compared.

In the mountainous western U.S. relatively little is known about the types of wetlands occurring, or their functions. Therefore, the development of an HGM classification and the selection of reference wetlands could be arbitrary and biased by the personal experience of investigators. The first step in developing a new approach to wetland functional analysis to be used for wetland regulatory decisions should be the development of an objective classification based upon the best data available analyzed in an appropriate manner.

This report provides the first approximation of a hydrogeomorphic classification of Colorado's wetlands based upon multivariate statistical analyses of the best data available. Most Colorado wetland data has been collected during stand surveys for floristic-sociological analysis, classification, and conservation planning purposes. Few data sets include extensive measured abiotic data. Therefore, each data set required extensive review and analysis prior to use for the present analyses. Each data set was used to construct two integrated data sets, (1) data on the vegetation composition of each stand, and (2) environmental variables that describe the abiotic environment influencing each stand. These data sets were developed for 3,625 stands representing thousands of wetlands across Colorado. The vegetation and environmental data sets were analyzed simultaneously using direct gradient analysis methods to produce ordination statistics and graphics which are useful for subdividing the data set into groups with characteristic hydrologic regimes, geomorphic processes, and vegetation structure.

The data sets have been collected from throughout Colorado, on the eastern plains and eastern mountain front, mountain canyons, mountain valleys, and summits, as well as the major intermountain basins, and western valleys, and appears to represent the full range of Colorado wetland types. Since the data sets analyzed were not collected specifically for this project, the selection of study sites was not random, and reflects the bias of other project needs. For example, extensive analysis of montane stream-sides by the Colorado Natural Heritage Program (CNHP) has produced a large data set for similar elevation and hydrogeomorphic landscapes around Colorado. In general, the CNHP inventory work is extensive, meaning that stands were analyzed throughout watersheds without intensively working smaller areas. These data are almost entirely from stands along stream banks and on floodplains, a landscape that is typically referred to as "riparian". The other extensive data sets used in the present analysis are from my own wetland survey work in Colorado. In contrast to the CNHP data sets, my data sets are generally intensive, with all wetland types in relatively small areas being sampled. The combination of approaches provides a powerful data set for ordination, classification, and the development of an HGM classification for Colorado.

This report provides a first approximation of an HGM classification for Colorado wetlands. It was developed from multivariate analyses of the entire stand and environmental data sets. I present classes and subclasses as the beginnings of a hierarchical classification. Two additional approximations of this work will be performed. The first will include a third level of a hierarchical classification, which I will call HGM alliances. The last approximation will be a hierarchical classification of Colorado wetland vegetation including three or four levels.

Methods

Data Sets

Thirty seven data sets are utilized in the present classification (Table 1). Each data set is comprised of individual stand analyses. Each stand analysis includes a complete list of plant species present and a measure of abundance for each species. Each stand include a geographic location, or sufficient information to locate stands and determine their elevation, latitude and longitude. Stand data sheets also include notes and/or measurements of hydrologic regime, water source, water table depth, frequency and/or duration of inundation or flooding, soil texture and other abiotic factors.

The plant composition of stands for each study was measured or estimated using a variety of different methods. For example, plot size varied from < $20m^2$ (0.002 ha) to 0.1 ha. Stand analyses were considered suitable if, after reviewing the plant composition of stands, I determined that plots were from homogenous stands, and plot size was appropriate for the vegetation structure being analyzed. For example, smaller plots are appropriate for herbaceous vegetation stands and larger plots for forested stands. Plots that are too large for the types of vegetation analyzed and the topographic and ecological complexity occurring on site are just as problematical as plots that are too small for that vegetation type. Certain studies were not utilized in the present analyses because I felt that the size stands were too large for the stands being analyzed to be homogenous.

Investigators in the studies used here measured plant species abundance with a variety of scales ranging from percent cover by species (0 to 100% cover), to cover classes for each species (typically classes are 1-5 or 1-6, Mueller-Dombois and Ellenberg 1974). All species abundance scales were converted to a 100% scale, with all species having cover values in the range from 0.01% to 100%. For studies that recorded species by percent cover those values were used directly. For studies that used cover classes we used the mid-point of that cover class as the cover value for that species. For example, in the Braun-Blanquet system, cover classes from 1 to 5 are used. Cover class 2 is given to species whose canopy coverage ranges from 5-25 percent, and the cover class would have a mid-point of 15%. Rare or uncommon species assigned a "+" or an "r" would be assigned cover classes of 0.1, and 0.01, respectively.

Plant nomenclature used in the 37 studies varied due to changes in plant nomenclature over the past 50 years, and because several different floristic manuals were used, for example the floristic manuals of Harrington (1954) and Weber (1976). For the present study all plant nomenclature has been converted to follow Weber and Wittmann 1992. The identify of every plant species in all stands was checked by hand, and updated and synonymized using Weber and Wittmann 1992.

Table 1. Data sets used in the development of the classification. The basin or river system that each study inventoried, a short name used in the data set (not on graphs!) in the present study, the data source, and the number of stands used are presented.

Location/Basin	Name	Source	Number of Stands
White River	WH	Kittle et al. 1994	84
Rio Grande River	R	Kittle et al.	78
Gunnison River	GU	Kittel et al. 1995	163
San Miguel/Dolores Rivers	SM	Kittel and Lederer 1993	91
South Platte River	SPL	Kittel et al. 1996	104
Arkansas River	AK	Kittel et al. 1996	100
Colorado River	CO	Kittle et al. 1994	189
Yampa River	YA	Kittel and Lederer 1993	131
San Juan River	SJ	Richard et al. 1996	272
Cherry Creek	CH	Cooper and Cottrell 1989	332
Front Range	FR	Cooper and Cottrell 1990	195
Crested Butte	CB	Cooper 1993	157
Telluride Mt. Village	TE	Cooper 1995	84
Boulder valley	B, EBCP, BB, MR	Cooper 1988	142
Telluride region	T	Cooper and Gilbert 1990	143
E-470 beltway E of Denver	E	Cooper 1987	23
Bonny Reservoir area	BR	Cooper 1988	11
San Luis Valley	SV and VG	Cooper and Severn 1992	169
Rollinsville area	R	Cooper and Cottrell 1988	47
Yampa R., canyon	Y	Cooper 1995	106
Green R., Lodore Canyon	L	Cooper 1995	68
Green R., Allen Bottom,	AB	Merritt 1997	36
Yampa R., Deer Lodge Park	DL	Merritt 1997	36
Park Range	PR	Cooper and Merritt 1996	18
North Park	NP	Cooper and Merritt 1996	34
Larimer County plains	LA	Merritt 1996	51
South Park	SP	Cooper 1990	246
High Creek fen, South Park	HC	Cooper 1996	88
Green R., Whirlpool, Split	GR	Cooper 1995	109
Front Range alpine	K	Komarkova 1979	77
Antero Reservoir flats	U	Ungar 1979	5
San Luis Valley	Ra	Ramaley 1942	3
Eastern Plains	T	Tibbetts 1994	14
Animas and La Plata R.	A	McKee et al. 1995	197
Cross Creek valley	H	Cooper 1986	22

		TOTAL	3625

Data Formatting

The floristic data set for each stand was entered or modified to the Cornell compressed format (ter Braak 1887-1992). Each stand and each species were given a unique number. There are 3,625 stands and 1,168 species. The data set is in space delimited ASCII format. A title occupies the first line, a FORTRAN format statement describing the format of the data set is in line 2, and the number of data couplets per line of data on line 3. The data begin on line 4. Data consist of the stand number in the first column, followed by couplets of species number and species abundance in columns across the page. A maximum of five couplets occur per line. Each stand can occupy as many lines as necessary. The data set ends with a 0 in the first column. The 0 line is followed by a list of all 1,168 species used in the analysis, with species one occurring in the first column, and ten species occurring across each line. The species names are followed directly with the stand names. For example, stand number 1 is WH1.

Each data set was checked, species nomenclature revised, species cover values or classes converted, and the data set formatted. Data sets were then concatenated and their formats standardized using a re-written and expanded version of the FORTRAN language computer program COMPOSE (rewritten with permission from the program distributor, Microcomputer Power, Ithaca, New York). The two rewritten versions of this program, "COMPBIG" and "COMPHUGE", can concatenate and edit 5,000, and 10,000 stands, respectively. Once the entire data set was concatenated it was reviewed to catch additional species nomenclature problems, such as slightly different names for the same taxon. COMPBIG was used to combine synonymous species, update and revise species names, delete stands that were from aquatic and dryland ecosystems, and to perform a number of other utilities. The final data set contains 3,625 stands and 1,168 taxa.

The environmental data set was assembled in Cornell full format (ter Braak 1987-1992) using the spreadsheet program EXCELL©. The data set is formatted similarly to the vegetation data set, with the first three lines being title, format, and data points per line. The forth line begins the data, but data are not in couplets. Instead, each parameter occupies the same column(s) throughout the data set. Stands, in the identical order as the stand data set, are the rows. Environmental parameters are numerical using continuous, discrete, and binary (dummy) variables. Environmental data is missing for a number of Colorado Natural Heritage Inventory stands due to incomplete data forms.

Environmental parameters developed and used in this analysis were selected based on, (1) their potential importance for HGM classification, and (2) data sets available contained sufficient information to develop these parameters. In all 21 environmental variables were developed and are described below. Column 1 contains stand numbers.

Stand Location (columns 2-3)

Definition: Universal Transverse Mercator (UTM) projection x and y coordinates that provide the general or exact location of wetland stands.

Units: meters (continuous)

Method: Longitude and latitude geographic coordinates were transformed to UTM's using PC-Arc Info 3.5 with the PROJECT command, or UTM locations were determined directly from maps.

<u>Data Source</u>: Latitude and longitude coordinates were obtained from data sheets, or U.S. Geological Survey maps.

Elevation (column 4)

<u>Definition</u>: Height above sea level of the wetland stand.

<u>Units</u>: meters (continuous)

<u>Methods</u>: Elevation in feet was converted to meters.

<u>Data Source</u>: Elevation data was obtained from U.S. Geological Survey quadrangle maps.

Soil Texture and Organic Content (columns 5-8)

<u>Definition</u>: Soil textures were classified as mineral soils with coarse-textures (column 5), mineral soils with fine-textures (column 6), mineral soils with an organic surface horizon (column 7), or organic soils (column 8) as four dummy variable. A stand had one soil texture and a 1 was placed in that column with the other three columns receiving a 0. Course-texture soils have the majority (> 50%) of horizons consisting of sandy loam or coarser particle sizes (sand, gravel, cobble). Fine-textured soils have the majority (>50%) of horizons consisting of loam or finer particle sizes (silt and clay). Organic surface horizon soils have distinct soil horizons (typically O, A, B, C; in this order) with the upper horizon being highly organic but only a few inches in thickness. Organic soils have organic horizons at least 40 cm in thickness in the top 80 cm of soil.

<u>Units</u>: binary; dummy variables, 0 means soil not of this class, while 1 means of this class.

Methods: Soil textures were determined primarily from soil pit data and observations from the overall stand. Determination of soil texture classification relied heavily on professional judgment in many stands were the soil pit data did not fall into one definite category.

Data Source: Data sheet information was used. Stands without soil information do not have soil texture data.

Channel Gradient (column 9)

Definition: The slope of the channel reach that the stand is associated with, defined as the drop in elevation over the length of the stream segment. Slopes were categorized as low gradient (< 2.0%) receiving a 1, medium gradient (2.0 - 10.0%) receiving a 2, and high (> 10%) receiving a 3.

Units: discrete, categorical

Methods: Gradients were either measured directly in the field, or estimated from topographic quadrangle maps.

Data Source: Data sheets or U.S. Geological Survey maps.

Bedrock Type (columns 10-13)

Definition: The dominant bedrock type in the watershed. Typical formations that were classified as metamorphic/ basement igneous (column 10) are granite, gneiss, schist, and metamorphosed sedimentary. Surface igneous/volcanic (column 11) category included andesite, basalt, tuff, and breccia dominated formations. Marine sedimentary (column 12) category included shale, limestone, dolomite, and some siltstone dominated formations. Continental sedimentary (column 13) category included conglomerate, sandstone, and dominant alluvial deposit formations. Professional judgment was used to make a determination where several formations were present in a watershed.

Units: Binary, dummy variables

Methods: Field data sheets, or USGS Colorado lithologic map.

Data Source: Data sheets or USGS Colorado lithologic Maps

Surficial Geology (columns 14-17)

Definition: Dominant geomorphic processes shaping the site and contributing unconsolidated material (sediment) to the site. Glacial (column 14) landscapes were formed by erosion (i.e. cirque basin and U-shaped valleys) and deposition (moraines or pro-glacial lake fills) due to alpine glaciers. Alluvial landscapes (column 15) are formed by the energy of moving water along streams, and fluvial features are created by scour and sediment deposition. Colluvial landforms (column 16) are formed by material contributed from hill slopes via mass wasting and moved by gravity. Eolian landforms (column 17) are formed by wind transported material.

Units: Binary, dummy variables.

Methods: For each basin data set, information on parent material, landform (geomorphology), valley dimensions, elevation, and stream classification was used to group each stand into one of these four categories. Not all data sets had complete information listed above and information from maps was used to classify sites where necessary.

Data Source: Data sheets and maps.

Stream Order/Channel Association (column 18)

Definition: Stream reaches are classified according to the Strahler stream classification method. Categories are as follows: 0 = no association with lotic (riverine) environment, 1 = 1st order stream, 2 = 2ND order stream, 3 = 3-5th order stream, 4 = >5th order stream.

Units: discrete, categorical

Methods: Data sheet information or maps.

Data Source: Data sheets and USGS topographic quadrangle maps.

Inundation (column 19)

Definition: The periodicity of standing water on the stand. Categories are defined as follows: 0 = never inundated, 1 = occasionally (less than once a year), 2 = seasonal (more than once a year), and 3= permanent (constant standing water).

Units: discrete, categorical

Methods: Inundation was categorized using information and notes on data sheets. Typical information utilized were field notes and observations recorded, plan view and cross-sectional drawings, information on flood frequency, and elevation from bankfull stage.

Data Source: Data sheets.

Soil Moisture (column 20)

Definition: A qualitative description of the periodicity of moisture conditions in the upper 40cm of soil in each stand. Categories are defined as follows: 0 = dry (never moist), 1 = seasonal (moist or wet for only part of the year), 2 = permanent (always moist).

Units: discrete, categorical

Methods: Soil moisture was categorized using professional judgment primarily from information on soil profiles (soil pits) recorded on data sheets. Notes on the soil moisture conditions, season when the pit was dug, presence and depth of mottling, gley horizons, and depth of water table were all utilized to determine categorization.

Data Source: Data sheets.

Water Source (column 21)

Definition: The dominant source of water for the stand. Categories are as follows: 1 = predominantly groundwater, 2= both groundwater and stream flow, and 3 = predominantly stream flow.

Units: discrete, categorical

Methods: For most stands information was available on data sheets relevant to water source. When information was not recorded professional judgment was used by assessing notes taken and information on geomorphic/landscape stand location.

Data Source: Data sheets.

Hydrologic Disturbance (column 22)

Definition: The presence or absence of up-stream hydrologic alterations. Categories are as follows: 0 = no hydrologic disturbances, 1 = major water diversions or groundwater pumping (only when presumed to effect surface flows), and 2 = mainstream dam located above the stand and having significant hydrogeomorphic affects.

Units: discrete, categorical

Methods: Notes on data sheets or topographic quadrangle maps were adequate to identify disturbance.

Data Source: Data sheets and USGS topographic quadrangle maps.

Statistical Analyses

The vegetation and environment data sets were analyzed simultaneously with a rewritten and expanded version of the personal computer package CANOCO (with permission from Microcomputer Power, Ithaca, N.Y., the distributor of the program). The program was modified to accommodate 5,000 stands and 2,000 species, and recompiled using a FORTRAN compiler. The program performs a variety of multivariate statistical analyses, including indirect and direct gradient analyses. For the current project, direct gradient analyses using Canonical Correspondence Analysis (CCA) were performed. CCA uses both stand composition and environmental variable data sets to perform direct gradient analysis. Canonical ordination techniques are designed to detect the patterns of variation in the species data that can best be explained by the environmental variables (Jongman et al. 1995). The resulting ordination diagram expresses not only a pattern of variation in species composition, but also the main relations between the species and each of the environmental variables. One analysis performed by CCA is the selection of a linear combination of environmental variables that maximize the dispersion of the species scores along ordination axes. CCA constrains the ordination axes to be linear combinations of these environmental variables (ter Braak 1986). The species and stands are positioned as points in the CCA diagram, and sites with similar species composition and/or similar environmental values are positioned similarly in the diagram. Species centroids represent the weighted average of the species distribution in the ordination plot. Details about CCA are reported and discussed by ter Braak (1986), Jongman et al. (1995), Palmer (1993) and many others. Over the past ten years CCA has become one of the most widely used multivariate methods in community ecology.

In this report two types of analyses performed by CCA are utilized, Weighted Averages (WA), and Linear Combinations (LC). For both analyses, initial site scores are determine by a weighted averaging algorithm based upon species abundance values for stands. In LC, a multiple linear least-squares regression is performed with the site scores (determined from the WA analysis) as the dependent variables, and the environmental variables as the independent variables (Palmer 1993). New site scores are then assigned as the value predicted using the regression equation. This regression equation is a Linear Combination of variables. By contract the WA output is determined almost entirely by the weighted averaging algorithm (Palmer 1993). Both outputs are used by ecologists, and Palmer (1993) recommends the LC output for most applications, however other researchers suggest that the LC and WA outputs are both useful for different purposes (eg. Økland 1996).

There are many benefits and drawbacks of the LC approach. Since the site scores are constrained to be linear combinations of environmental variables, only variance in the stand data with a specified linear statistical relationship to at least one of the environmental variables will be extracted by the axes. All variation in the stand data set that is not related to the environmental variables supplied is discarded. If the perfect environmental data set is available and is used to analyze the variance in stand data then CCA using the LC option is an excellent approach. However, it is rare to know what environmental variables are best to analyze, and they are typically difficult to quantify. The LC option may be best used to test specific hypothesis about the relationship of the vegetation data to the environmental data set. Økland (1996) suggests the use of both weighted averaging (WA) methods ordination and constrained ordination (LC) methods as parallel applications in the analysis of data sets. In this report I use both the WA and LC outputs from CCA.

A number of statistics are presented to document the effectiveness of the ordination. The eigenvalue for each axis represents the variance in the community matrix that is attributed to a particular axis. These values range from 0 to 1, with higher numbers indicating a more important axis. The percentage of variance in the community matrix that is explained by each axis is also reported. For a particular axis, this value is calculated as 100 times the ratio of the eigenvalue to the total variance (total inertia in the data set) (McCune and Mefford 1997). The species-environment correlation is a standard correlation coefficient between sample scores for an axis derived from the species data (the WA scores) and the samples scores that are linear combinations of the environmental variables (the LC scores). Because the LC scores are determined using multiple regression, if a large number of environmental variables are used, a large correlation coefficient will result for this statistic. The interset correlations are the correlations of environmental variables with the environmental variables.

Results

Weighted Averaging Ordination

The Weighted Averaging (WA) output from CCA produced an excellent ordination of the entire data set. This ordination output is presented as three types of figures: (1) Figures 1, 2 and 3 include the stands plotted using WA scores for ordination axes 1 and 2, and illustrate the data set, and HGM classes, and HGM subclasses; (2) Figure 4 presents the same stand scores with stands identified by study area, and (3) Figures 5 and 6 are the species ordination plots constructed from the centroid of important plant species along axes 1 and 2. These two figures illustrate the HGM classes and subclasses, respectively.

Eigenvalues for all axes are strong indicating their importance for interpretation (Table 2). Axis one, interestingly, has a lower eigenvalue than axes 2 through 4, which I cannot yet explain.

TABLE 2. Statistics for the CCA ordination.

AXES	1	2	3	4	Total Inertia
Eigenvalue	.583	.872	.804	.763	73.549
Species-Environment Correlation	.830	1.000	1.000	1.000	
Cumulative % variation					
of species data	.8	2.0	3.1	4.1	
of species-environ. Correl	2.8	55.1	56.2	56.2	
Proportion of Variance Explained by Environmental Variables	.793	1.000			
Sum of all unconstrained Eigenvalues					73.549
Sum of all constrained Eigenvalues					2.428

Figure 1 provides an overview of stand data set structure. A large number of points are in a band extending from the upper left to the lower central portion of the ordination space. On both the far left and far right the band widens with stands more widely dispersed along axis 2. This ordination represents a complex of elevation, hydrologic regime, geomorphic process and salinity gradients. The highest elevation sites are on the left side, while the lowest elevation sites are on the right. Thus, the areas with the greatest amount of ecological, hydrologic and geomorphic variability are at the higher and lowest elevations. Between, -40 and +20 on axis 1, most points represent foothill and low elevation mountain regions are confined to the central band of points, indicating that at these elevations most wetlands occur along streams and stands are relatively similar with regard to their floristic composition. At higher elevations a wider range of wetland types and environments occur, most likely representing the variability created in glaciated terrain, including cirque basins, stream sides, ground water fed peatlands, and wet meadows all being common.

Peatlands occupy the far left side of the ordination from near +200 to -100 along axis 2, and include the topogenous and oligotrophic peatlands of kettles and other depressions that have limited ground water flow near +200, soligenous peatlands on non-calcareous substrates from +180 to +50, and the distinctive soligenous peatlands of calcareous substrates from +50 to -100.

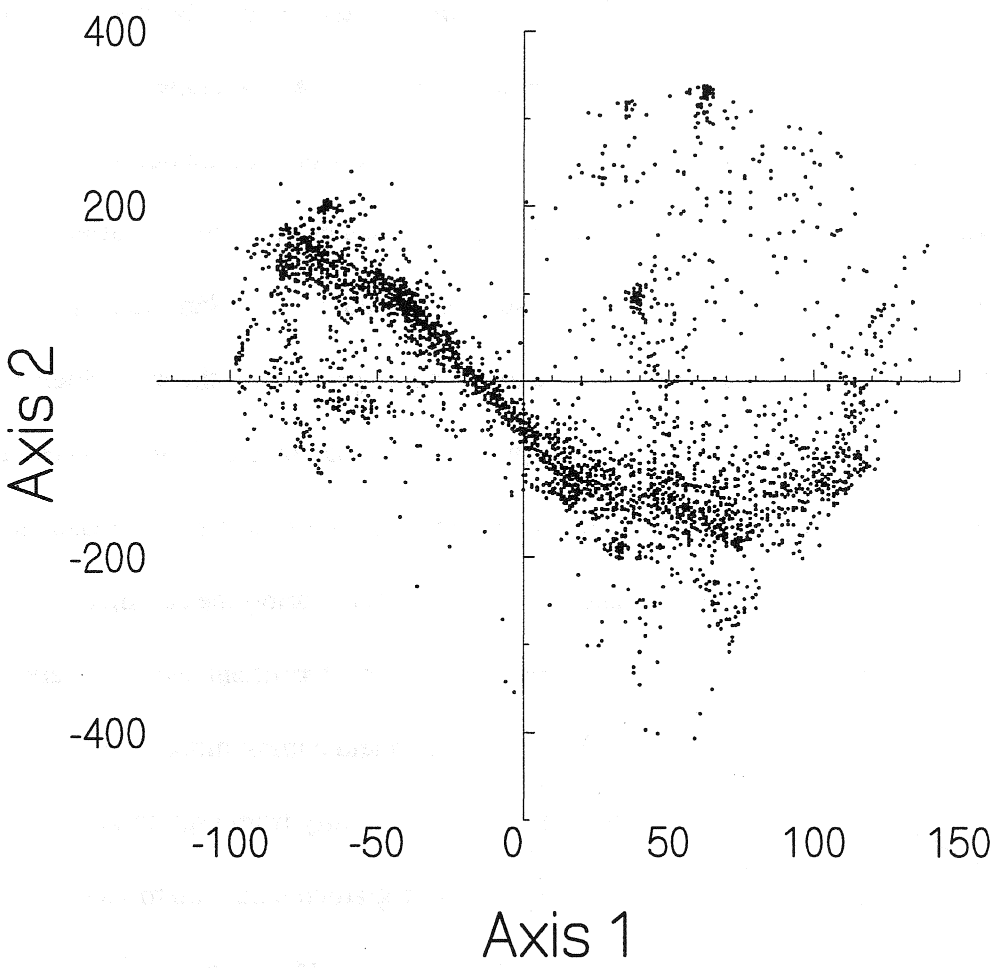

Figure 1. Weighted Averages output from CCA analysis of stand data set along axes 1 and 2. Each point represents one stand.

Moving right from the calcareous peatlands along axis 1 it can be seen that they are ecologically and floristically related to mineral soil slope and mineral soil flat wetlands, which are plotted from -50 to +80 along axis 1, and below the main band of riparian points. These range from highly productive wet meadows (mineral soil slopes) to unproductive mineral soil flats (salt flats) with limited plant cover. The gradient from calcareous peatland (organic soil slope), to wet meadow (mineral soil slope), to salt flat (mineral soil flats) is related to the landscape position of the wetland, the duration of saturated soil conditions resulting from the combined affects of the type of aquifer supplying the water source, site climate (eg. arid in South Park or the San Luis valley vs. relatively humid in subalpine cirques) and the topographic gradient of the site. Sites with the longest duration saturation, and without highly saline soils, have carbon balances that favors the long-term storage of carbon and the development of organic soils. Seasonally wet sites with moderate duration soil saturation (>30-60 days during the summer) are wet meadows with mineral soils. Sites with shorter duration or intermittent saturation are mineral soil flats supporting a wide of halophytic species and communities.

The main riparian band of points changes fundamentally from high to low elevation. All sites are on high to moderate topographic gradients but due to variation in elevation and growing season length, substrate texture, size or the stream and its disturbance regime, the composition of communities changes in a regular manner. At higher elevations herb and low shrub-dominated communities are abundant, while at mid- to low-elevations tree and shrub dominated-communities occur.

Clearly, the hydrogeomorphic and ecological variation in middle-elevation stands (the main band of points between -40 and +20 along axis 1) is limited. However, at lower elevation the variation between sites increases due to hydrogeomorphic complexity, a larger flora, a number of highly successful exotic plants that dominate communities, and human manipulations that have increased the diversity of sites.

The top right portion of the ordination includes stands of low elevation marshes and pond and lake margins (depressional and lacustrine fringe). This is a highly variable group of communities, ranging from permanently inundated marshes plotted in the top right, between +20 and +80 along axis 1, and +350 to +200 along axis 2. Seasonally or intermittently inundated systems are also clearly represented. For this group of stands, the water regime modifiers developed for the palustrine system in the Fish and Wildlife Service's wetland classification by Cowardin et al. (1979) are appropriate. Including permanently flooded, semi-permanently exposed, seasonally flooded, temporarily flooded, and intermittently flooded. The long-term patterns of water regime will control many ecological functions of these wetlands. The basins grade into peatlands that occupy kettles and other depressions at higher elevation which are plotted near +200 on axis 2 at -70 along axis 1 of the ordination space.

In general the ordination effectively helps identify the main HGM classes, illustrated in Figure 2. Depressions along the top, riverine in the broad band across the center, slopes on the far left and lower left, and mineral soil flats on the lower right. The ordination also indicates the relationships among these classes, how they vary and grade into each other, and their control by elevation, and hydrogeomorphic variables. In addition, subclasses can be subdivided based on clusters of stands as shown in Figure 3.

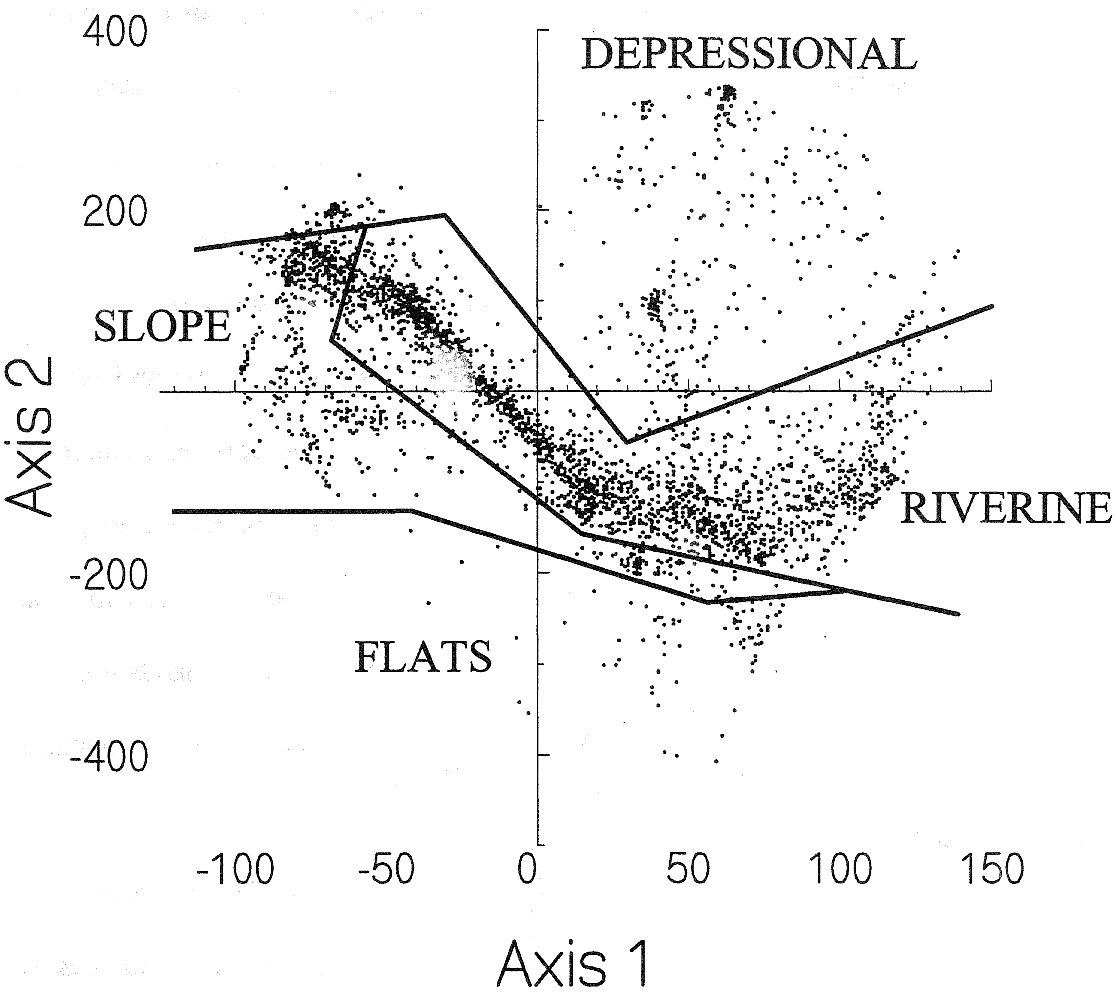

Figure 2. Weighted Averages output from CCA analysis of stand data set along axes 1 and 2. Each point represents one stand. The four HGM classes are identified.

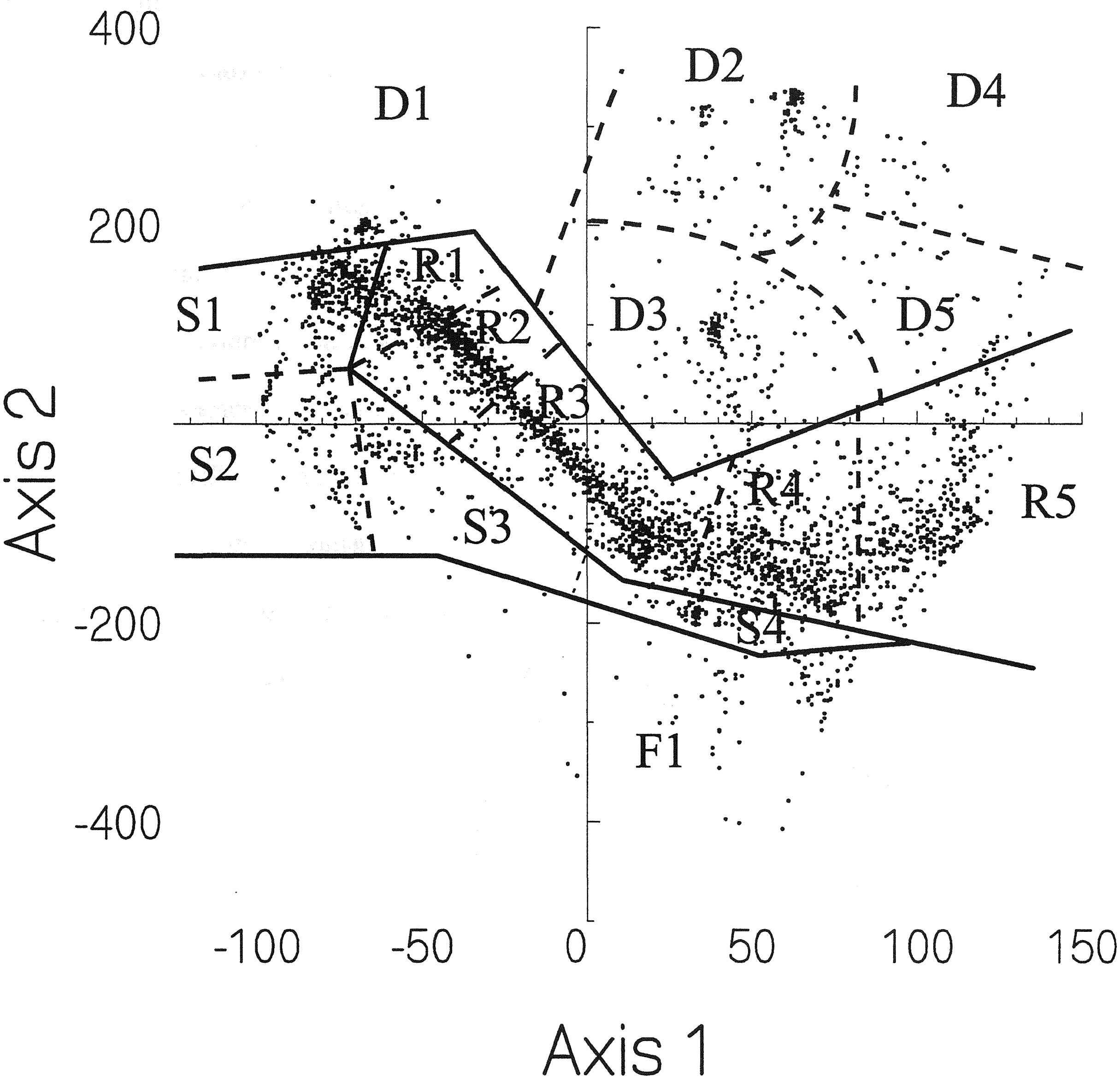

Figure 3. Weighted Averages output from CCA analysis of stand data set along axes 1 and 2. Each point represents one stand. The 15 proposed HGM subclasses are identified.

Figure 4 plots the WA ordination data set overlaid with the environmental vectors. It can be seen that the data is largely driven by two opposing environmental forces, high elevation, glaciated landscapes, and peat soils are on the left, while coarse-textured soil, alluvial landscapes, and high stream orders are on the right. These variables appear to create axis 1. Axis 2 is largely driven by duration of inundation with sites with the longest duration inundation at the top, and those rarely or never inundated at the bottom. The main body of riparian and peatland data also respond to this variable with the peatland end being tilted up, with the low elevation riparian end is tilted down. The salt flats are opposite the depressions. The variable soil moisture points in a direction between the peatlands and depressions, indicating that both types can have the highest soil moisture, while lower elevation riparian and flat sites have lower soil moisture.

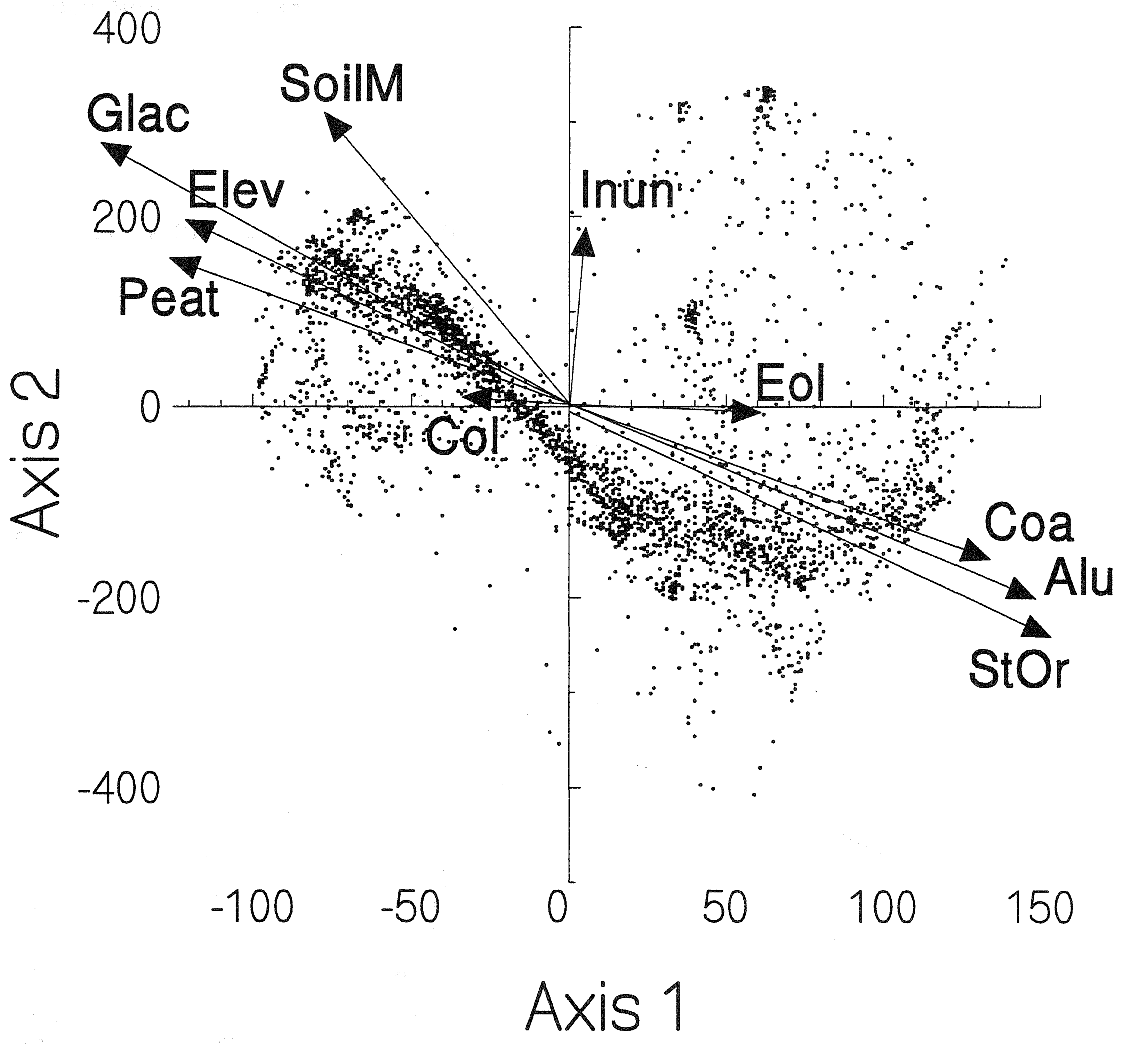

Figure 4. Weighted averages output from CCA analysis along axis 1 and 2. Each point represents one stand. The arrows represent the main direction of variation and strength of the environmental variables. The longer arrow indicate the strongest variables.

Interset correlations for all environmental variables and the four analyzed ordination axes are presented in Table 3.

TABLE 3. Interset correlations for environmental variables with CCA axes. Larger numbers indicate more significant correlations.

NAME	Axis 1	Axis 2	Axis 3	Axis 4
Elevation	333	241	134	18
Coarse	380	-187	-152	-68
Fine	24	-6	61	39
Organic	-162	114	-22	50
Peat	-363	224	323	61
Stream Gradient	96	-57	-298	-123
Igneous	-50	-24	-95	-46
Volcanic	-138	78	77	32
Marine	-273	190	158	54
Sedimentary	515	-213	-57	11
Glacial	-461	308	207	-28
Alluvial	422	-240	-172	2
Colluvial	-91	14	28	25
Eolian	166	-10	125	70
Stream Order	435	-284	-283	-56
Inundation	14	226	-21	145
Soil Moisture	-228	329	300	190
Water Source	311	-138	-223	-56
Hydrologic Mod.	527	-243	-32	40

Figure 5 plots the WA stand scores along CCA ordination axes 1 and 2 with each point labeled according to the study site location. The study sites group by geographic location indicating that the detailed investigations of several regions and several wetland types have provided the only data for understanding the full range of wetland types in Colorado. This is true for the calcareous peatlands of South Park, symbol H sampled by Cooper (1990 and 1996). The salt flats are represented primarily by data sets from the San Luis Valley, symbol S (Cooper and Severn 1993), North Park, symbol N (Cooper and Merritt 1997), and the Boulder valley, symbol B (Cooper 1989). Data on many depressional wetland types are from the Great Plains southeast of Denver in the Cherry Creek basin, symbol E, (Cooper and Cottrell 1991), Boulder valley, symbol B (Cooper 1989), Crested Butte region, symbol C (Cooper 1994), Animas and La Plata River basins, symbol A (McKee 1996), and North Park (Cooper and Merritt 1997).

The highest elevation slope wetlands, including peatlands and wet meadows are from the alpine research of Komárková, symbol K (Komárková 1979) and the Front Range, symbol F (Cooper and Cottrell 1990). Many riverine (riparian) stands are from studies by the Colorado Natural Heritage Inventory. While this body of data contains a significant amount of redundancy, it allows the similarities and differences between river basins and along elevation gradients to be identified. In addition, the diversity of riverine communities vs. other wetland types has not previously be assessed and clearly forms only a small percentage of the overall variability of Colorado wetland types. The lowest elevation riverine wetlands are represented best by stands from the lower Yampa and Green Rivers (symbol D) (Cooper 1995), and the lower Animas and La Plata Rivers (symbol A) and include stands of all ages and inundation duration.

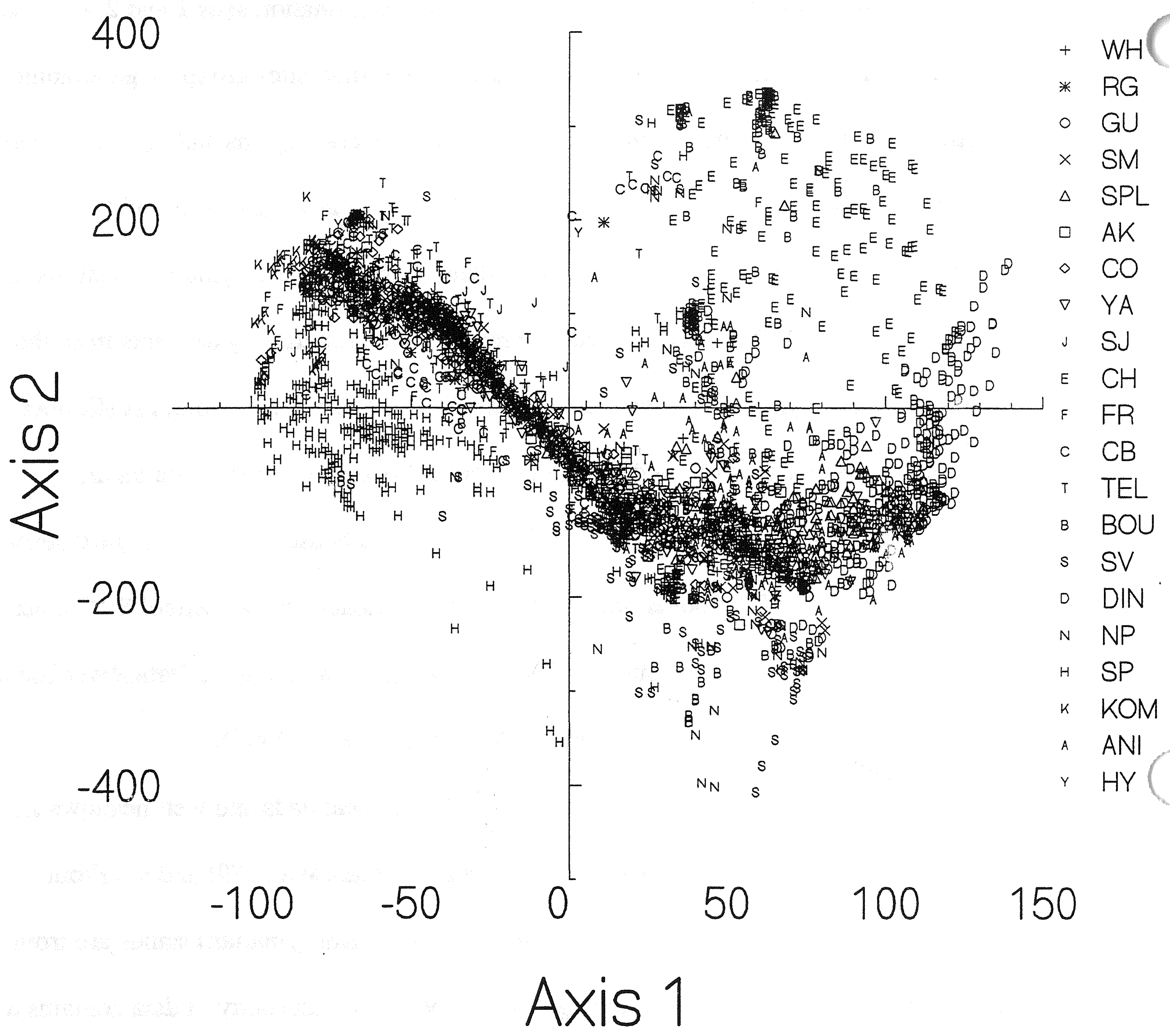

Figure 5. Weighted averages output from CCA analysis along axis 1 and 2. Each point represents one stand and are identified by the geographic location of the study. WH is White River, RG is Rio Grande, Gu is Gunnison R., SM is San Miguel R., SPL is South Platte R., AK is Arkansas R., CO is Colorado R., YA is Yampa R., SJ is San Juan Nat. For., CH is Cherry Creek basin, FR is Front Range, CB is Crested Butte, TEL is Telluride region, BOU is Boulder valley, SV is San Luis Valley, DIN is Dinosaur area, NP is North Park, H is South Park, KOM is Komarkova's work, ANI is Animas and La Plata R., HY are other miscellaneous areas.

The species ordination (Figure 6) is useful for understanding the plant species that drive the stand ordination patterns. Because stand scores are a weighted average of the species scores the location of species' centroids in the ordination are critical to understand. Most species are also highly sensitive to site hydrologic regime (eg. duration or frequency of saturation, inundation depth and frequency, soil redox potential), geomorphic processes (eg. erosion and deposition from flowing water vs. stability on the scale of centuries or millennia), and water-substrate chemistry, they integrate environmental heterogeneity on a scale that is critical to organisms, and that control wetland functions.

The species ordination indicates that the data set includes the full range of wetland communities that are know to occur in Colorado. These ordinations also indicate that a number of significant problems arise in defining the boundaries of HGM classes in Colorado. For example, the boundary between slope and mineral soil flats is unclear. Many of the same species (eg. *Glaux maritima* and *Triglochin maritimum*) and communities occur in highly calcareous peat soil slope wetlands, mineral soil slope wetlands, and mineral soil flats. This problems is overcome somewhat by the two environmental variables inundation and soil moisture. Flats are generally of limited inundation and soil moisture compared with calcareous peatlands and meadows.

Low and middle elevation floodplain landscapes may be irrigated for hay production, and slope and riverine wetlands blend together. Indeed, at low elevation, it is possible for wetland complexes to be a mix of depressional, riverine, slope and flats wetlands. All irrigated lands pose problems with regard to classification. Since most are not associated with stream sides they most likely should be classified as slope wetlands even where their principal water source is surface not ground water. Many irrigated wetlands are similar to mineral soil slope wetlands, particularly those dominated by *Juncus arcticus* and other herbaceous meadow plants.

Depressions are also problematical because in glaciated terrain water levels may be relatively stable and basins may fill with organic matter. In addition, the hydrologic regime of these sites is not basin like, with water flowing in from the sides, but many have a ground water flow through pattern. These sites are functionally more similar to slope class peatlands than with depressional or lacustrine fringe wetlands dominated by cattail.

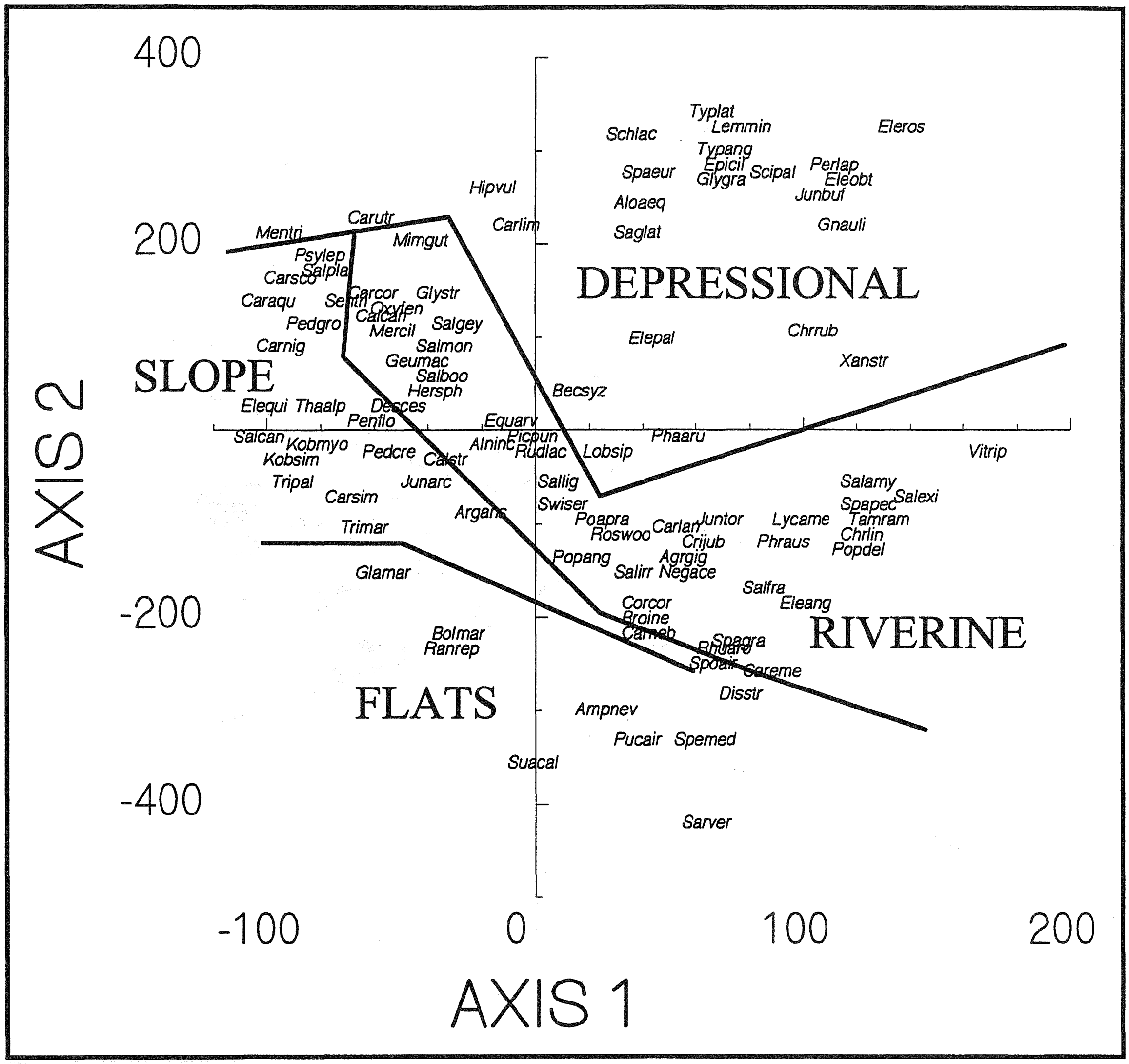

Figure 6. Species ordination from Weighted Averages output from CCA analysis along axes 1 and 2. Centroids of the 99 most common and diagnostic species are identified, and the four HGM classes are identified.

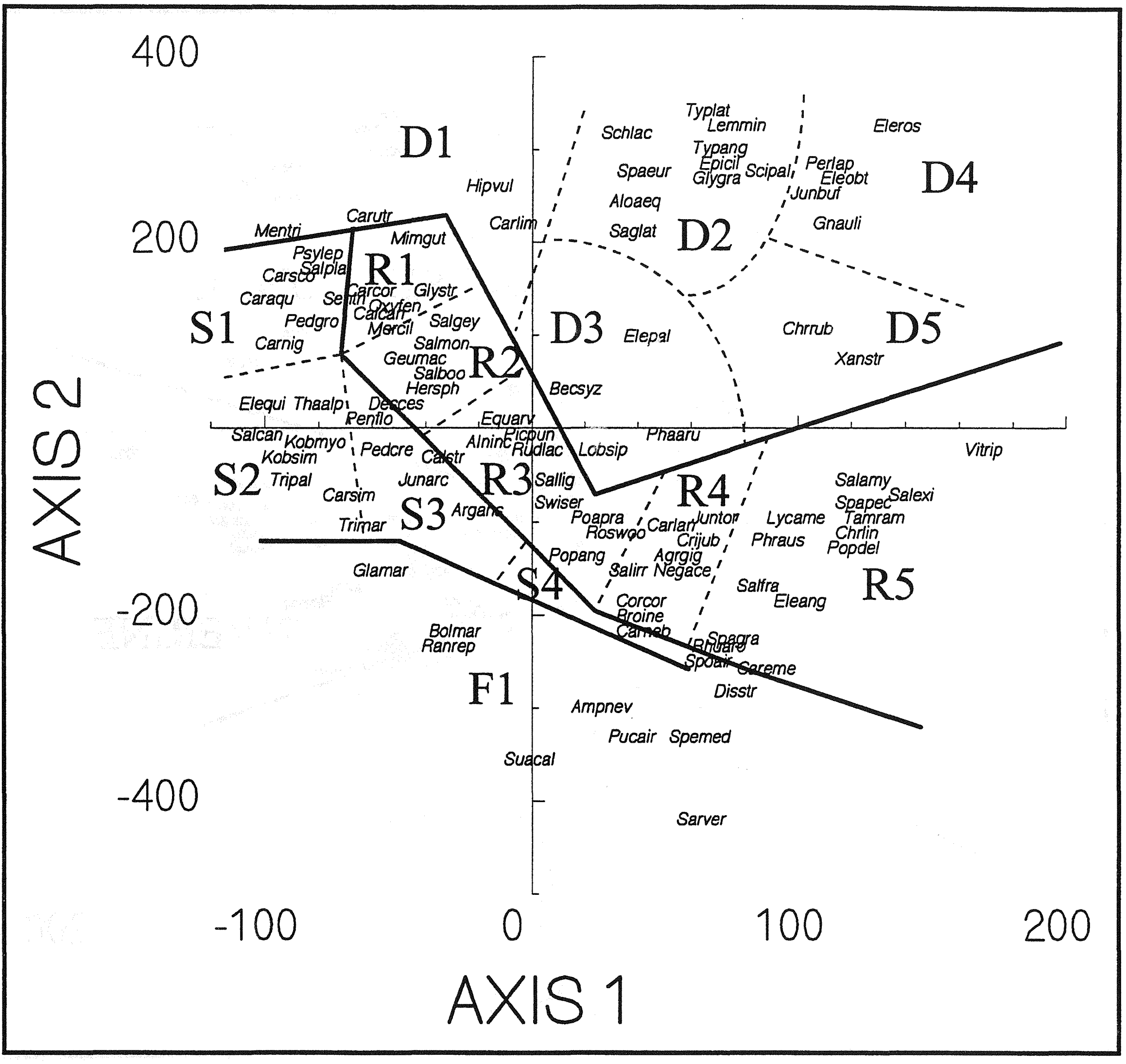

Figure 7. Species ordination from Weighted Averages output from CCA analysis along axes 1 and 2. Centroids of the 99 most common and diagnostic species are identified. The 15 HGM subclasses are identified.

Linear Combination Ordination

The ordination using the linear combination (LC) output from CCA was used to construct a joint plot of stands with environmental variables represented by arrows (Figure 8). The ordination axes are constrained to be linear combinations of environmental variables, and the points are the fitted values from multiple regression analysis. This ordination is similar to the WA ordination in that the main body of points is organized in a band from the top left to the bottom right, with peatlands and alpine meadows in the top left, and low elevation riverine systems on the lower right. In addition, depressions are on the top right, and flats on the bottom of the ordination. This figure indicates the continuity of the data set and the overall difficulty in identifying distinct groups of stands based upon the environmental variables.

Elevation, peat soils and glaciated terrain are positively correlated indicating that wetlands with peat soil occur at high elevations, many high elevation wetlands have peat soils, and many peat soil wetlands occur in glaciated terrain. Peat and elevation are negatively correlated with coarse-textured soils, high stream orders, alluvial landscapes, and hydrologically modified sites, indicating that a very strong complex environmental gradient driven by elevation, stream order (a surrogate for stream power), water source, and soil type controls many types of Colorado wetlands. The tangential inundation duration also contributes a significant range of variation from depressions to flats across all landforms, elevations, and wetland classes.

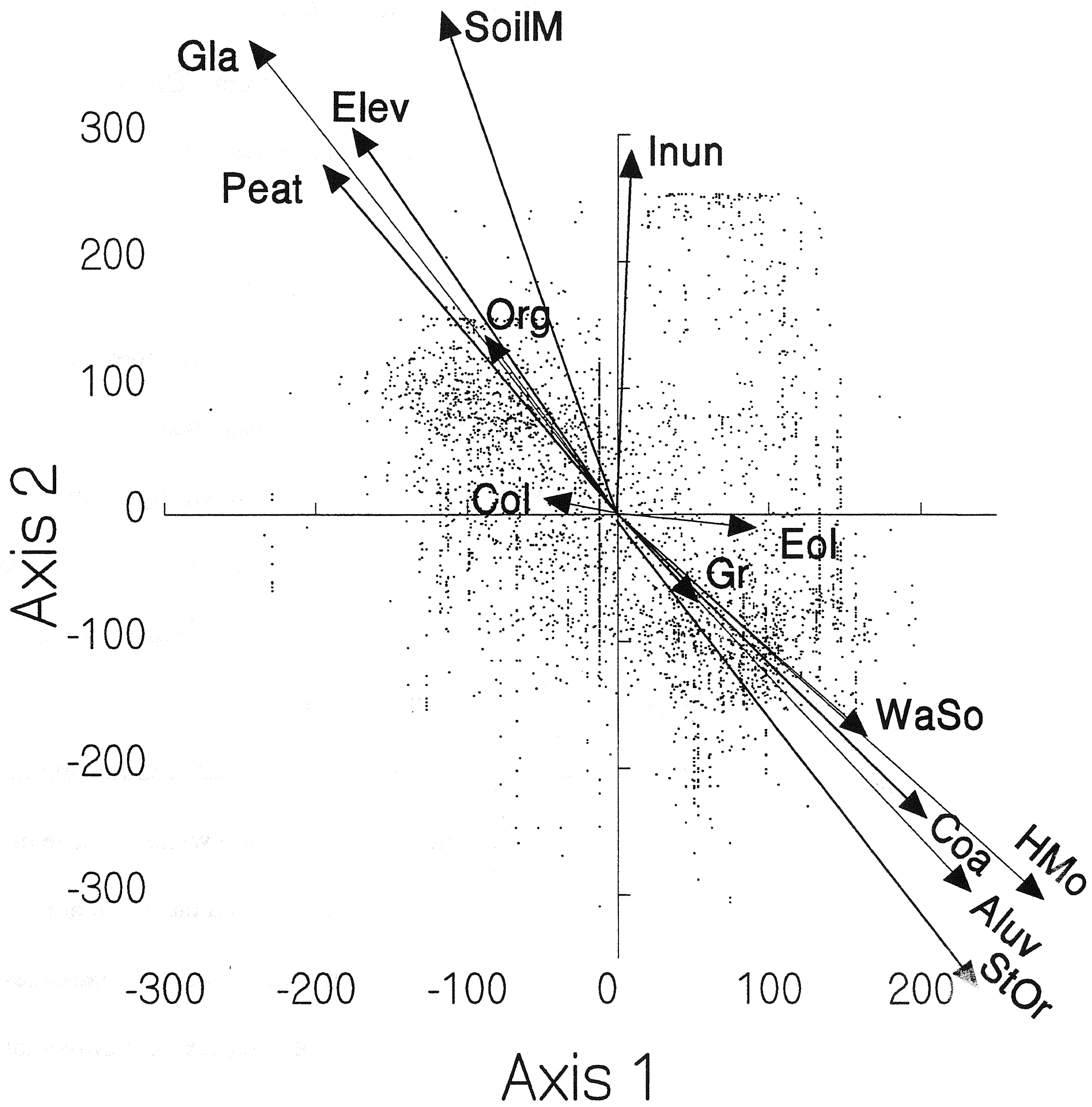

Figure 8. Linear combination output from CCA analysis of stand data set along axes 1 and 2. Each point represents one stand. The arrows represent the main directions of variation in the environmental variables.

HGM Classes and Subclasses for Colorado

CCA ordination was used to identify the major groups of stands representing relatively distinct hydrogeomorphic and floristic units. The divisions were identified with the aid of the environmental axes and vectors, but a certain amount of professional decision-making was necessary. In high elevation, glaciated landscapes many valley bottom sites are wet and many have organic soils. However, there are distinctive groups of species and communities in groundwater-supported vs. stream-supported ecosystems. This information was used to make the break between the slope and riverine class at high elevation. In addition, the break between slope and depressional at high elevation is also difficult because few floristic and few environmental differences exist, except for inundation duration which helps identify peatlands in depressions. I am not completely comfortable identifying high elevation basins with organic soils as depressional wetlands as they share most of the characteristics of slopes. The only distinction is that these basins have longer duration inundation, and deeper standing water than slope wetlands.

The strong complex environmental gradient from high to low elevation valley bottoms shows up in the distinctive linear band of stands on the WA ordination, and helps place most stands into riverine vs. slope and depressional wetland classes at mid to high elevations. However, at low elevation where the diversity increases substantially the divisions are more difficult to identify. The depressional systems are generally clear cut being separated by the duration of inundation and categorized by their water regime modifier and vegetation tolerance to both long duration inundation and drought. Many ephemeral depressions have similar characteristics to seasonally flooded and relatively bare low elevation river bars.

Fifteen HGM subclasses in the four HGM classes are identified and suggested for use. I have lumped depressional and lacustrine fringe classes for this report as data on lakes and reservoirs large enough to be distinct from depressions were not found.

CLASS DEPRESSIONAL

Subclass D1: Mid to high elevation basins with peat soils and lake fringes with or without peat soils. There is relatively little information on these types of depressions. I would suggest that peat depressions are functionally distinct from lake margins in their hydrologic regime, water sources, and geomorphic processes. However, data were not available to segregate these wetland types. One reference wetland would be Green Mountain Trail pond, in Rocky Mt. National Park where we have conducted investigations for the past 12 years (Cooper 1990). Other reference areas should be identified.

Subclass D2: Low elevation basins that are permanently or semi-permanently flooded. This subclass includes reservoir and pond margin wetlands as well as marshes. Many are terminal sump systems for water moving from the mountains, or from irrigation ditches to reservoirs. Water levels fluctuate, but may have perennial surface water. Reference wetlands could be a large natural marsh located just northeast of Head Lake in the San Luis Valley, and a reservoir margin, such as Cherry Creek or Boulder Reservoir. The vegetation may be dominated by bulrush and cattail species.

Subclass D3: Low elevation basins that are seasonally flooded. These depressions may be terminal sump systems for water moving from the mountains, or depressions in irrigated landscapes. A reference wetland would be Mishak Lakes in the San Luis Valley. This site is seasonally flooded, but dry for long periods of time. The vegetation may be dominated by *Eleocharis palustris*.

Subclass D4: Low elevation basins that are temporarily flooded. These basins are flooded for short periods of time in the spring and early summer. Perennial vegetation is poorly developed, and the depression bottom may be mud or dry cracked soil. These sites may include abandoned beaver ponds, small irrigation ponds, and other ephemeral systems. Common plants include smartweed (*Persicaria lapathifolia*), toadflax (*Juncus bufonis*), and *Alopecurus aequalis.*

Subclass D5: Low elevation basins that are intermittently flooded. This subclass is closely related to Subclass D4, and includes sites that are not flooded annually, or that are largely barren.

CLASS RIVERINE

Subclass R1: Steep gradient low order streams and springs on coarse-textured substrate. Wetlands of this subclass occur at all elevations, and are very common in the subalpine zone, but also occur on the plains. Common plants in these stands include chiming bells (*Mertensia ciliata*), butterwort (*Senecio triangularis*), Manna grass (*Glyceria striata*), monkey flower (*Mimulus guttatus*).

Subclass R2: Moderate gradient, low to middle order streams on coarse and fine-textured substrates. These sites are typically dominated by willow thickets and may contain complexes of beaver ponds. The reference reaches selected include the upper Colorado River valley in Rocky Mt. National Park, particularly the reach between the Never Summer Ranch and the Colorado River trailhead, although others should be chosen.

Subclass R3: Middle elevation moderate gradient reaches along small and mid-order streams. The vegetation is dominated by tall shrubs (alder) and trees (narrow-leaf cottonwood, blue spruce). One reference reach should be the Carpenter Ranch along the Yampa River near Hayden, Colorado.

Subclass R4: Low elevation canyons in the mountain foothills and plateaus along larger rivers. Generally with steep gradients and woody vegetation predominating. These sites have coarse soils and steeper gradients than Subclass R5. Plants dominating are box elder (*Negundo negundo*), tamarisk (*Tamarisk ramosissima*) One reference reach should be the Yampa River canyon within Dinosaur National Monument, and an impacted reference could be Glenwood Canyon along the Colorado River.

Subclass R5: Low elevation floodplains along mid- to high-order streams with fine-textured substrate. Most sites have perennial flow, but a few may be intermittent. Plains and Fremont cottonwood (*Populus deltoides*) is the historic dominant plant, but this species no longer occupies all of its former habitat due to physical manipulations of these sites. These are among the most manipulated wetland systems in Colorado, particularly from a hydrologic and geomorphic perspective. However, an excellent reference site is Deer Lodge Park below the confluence of the Yampa and Little Snake Rivers. Other reference reaches could be along the Arikaree in far eastern Colorado, and Bijou Creek east of Denver.

CLASS SLOPE

Subclass S1: Alpine and subalpine fens and wet meadows on non-calcareous substrates. These sites may be dominated by herbaceous or woody vegetation and may have organic or non-organic soils. Reference wetlands could include Big Meadows (Cooper 1990) and Spring Fen (Johnson 1995) in Rocky Mountain National Park.

Subclass S2: Subalpine and montane fens and wet meadows on calcareous substrates. Calcareous peatlands and wet meadows are distinct from those on crystalline and other non-calcareous rocks. These sites may be dominated by herbaceous or woody vegetation and may have organic or non-organic soils but are typically saturated for long-duration each growing season. The best reference wetland is High Creek fen in South Park.

Subclass S3: Wet meadows are abundant at middle elevations in the mountains and have a seasonally high water table. These sites are dominated by herbaceous plants such as *Juncus arcticus*. These sites may or may not be supported by irrigation. Reference sites could be chosen in the northern portion of South Park, and should include natural and irrigated sites.

Subclass S4: Low elevation meadows with a seasonal high water table. These sites may or may not be supported by irrigation. This is a problematical group, related to subclass S3, but also distinct. This subclass may occur on floodplains, or at springs. Typical dominants include Nebraska sedge (C*arex nebraskensis*).

CLASS MINERAL SOIL FLATS

Subclass F1: Middle to low elevation sites with a seasonal high water table, and occasionally with shallow standing water. These sites may or may not be in basins. Saline soils have developed due to the evaporation of water containing appreciable solutes. This subclass should be subdivided when more data are available. A reference site on the southern side of Antero Reservoir in South Park is suggested.

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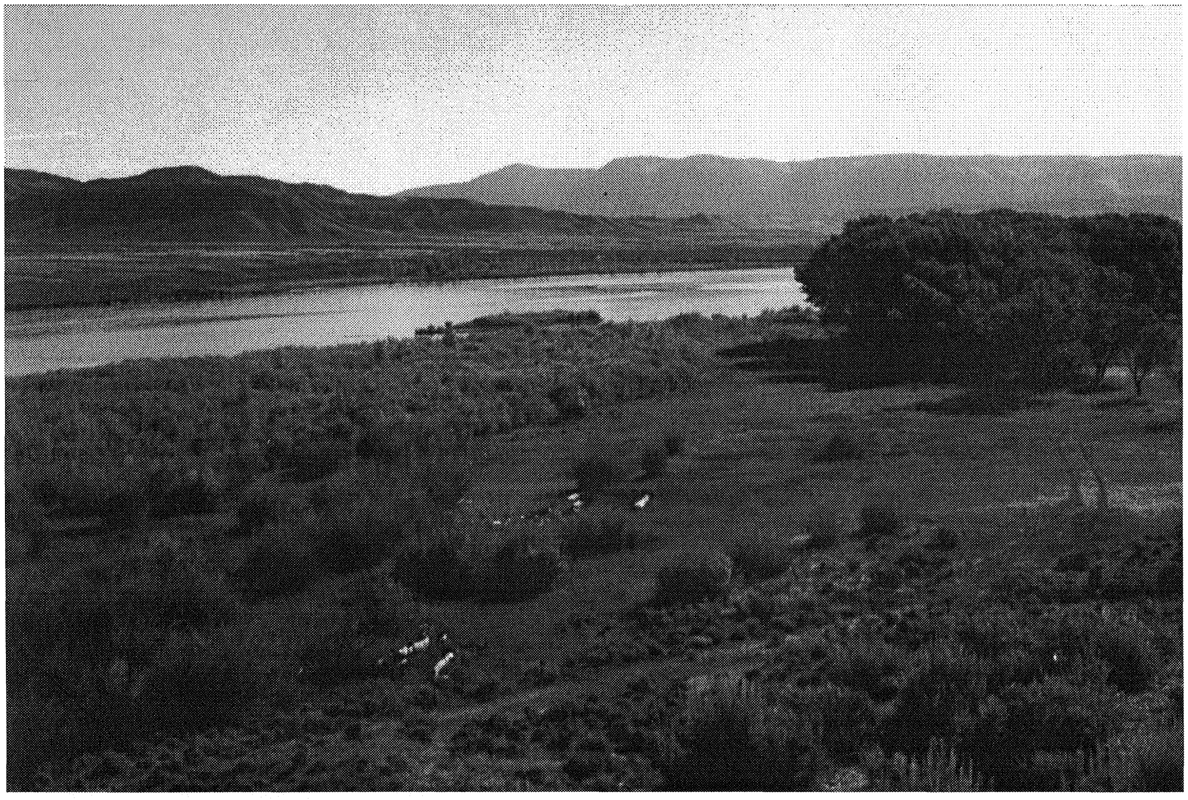
CHARACTERIZATION AND FUNCTIONAL ASSESSMENT OF REFERENCE WETLANDS IN COLORADO

A PRELIMINARY INVESTIGATION OF HYDROGEMORPHIC (HGM) CLASSIFICATION AND FUNCTIONS FOR COLORADO'S WETLANDS



Section 4

HGM Hydrological and Geochemical Functions

A STEPWISE, INTEGRATED HYDROGEOMORPHIC APPROACH FOR THE CLASSIFICATION OF WETLANDS AND ASSESSMENT OF WETLAND HYDROLOGICAL AND GEOCHEMICAL FUNCTION IN THE SOUTHERN ROCKY MOUNTAINS OF COLORADO

Final Report

by

Kenneth E. Kolm, Principal Investigator and Associate Professor
Div. of Environmental Science and Engineering

Ruth M. Harper-Arabie, Ph. D. Graduate Student
Div. of Environmental Science and Engineering

John C. Emerick, Co-Principal Investigator and Associate Professor
Div. of Environmental Science and Engineering

Colorado School of Mines
Golden, Colorado 80401

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EXECUTIVE SUMMARY

A step-wise, integrated hydrogeomorphic approach (HGM) for the classification of wetlands in the southern Rocky Mountains, Colorado, was developed. This approach is used to classify the main wetland types, and to provide a framework for determining wetland hydrologic function. The conceptualization and characterization of ground-water flow systems approach and logic developed by Kolm (1993), Kolm et al. (1996), and Kolm and van der Heijde (1996) was incorporated with the hydrogeomorphic approach (HGM) as developed by Brinson (1993) to develop this classification and to determine wetland function.

Five reference sites representing southern Rocky Mountain wetlands were selected and accompanying field studies were conducted. Four of the reference wetlands were used to study site-specific hydrogeomorphic characteristics, such as ground-water and surface water, soils, and geomorphology, using the procedures developed as part of the new approach, and to determine wetland hydrologic functions. In addition, the geochemistry of these reference wetlands was characterized, and the variables that should be measured to determine geochemical functions of Colorado wetlands were identified. The result was an enhanced understanding of the surface water, ground-water, and geochemical functions observed in the reference wetland sites in the southern Rocky Mountains.

The approach to wetlands characterization and HGM classification included the following analyses: surface features, including hydrophytes, peat and mineral soils, surface water, topography, beaver activity; subsurface features, including geomorphologic deposits, geology, and hydrogeology; and ground-water system features, including water levels, recharge, and discharge. These analyses resulted in identifying the critical hydrologic functions in the southern Rocky Mountain wetlands, the critical variables that could be assessed for determining wetland function, and the two classes: slope and riverine, that are observed. Four reference sites, including two slope wetland sites: Peru Creek Wetland and Big Meadows Wetland; and two riverine wetland sites: Browns Park Wetland and Deerlodge Wetland, were characterized by variables and function, and classified using this new HGM approach and classification.

As a result of the reference site analysis and HGM method development, 15 hydrologic function equations are proposed for the southern Rocky Mountain wetlands. 2 of the functions pertain to the atmospheric processes (ATMin and ET); 7 of the functions pertain to the surface water processes (SWin-riverine, SWin-slope, SWout-riverine, SWout-slope, SWstore-dynamic, SWstore-long term, and ED); and 6 of the functions pertain to the ground-water processes (GWinterception, GWmovement, GWout-river, GWout-springs and seeps, GWstorage-dynamic, and GWstorage-long term). 24 variables were defined in order to complete the hydrologic function assessment process. Each of the variables was assigned a ranking between 0.0 and 1.0 with respect to the reference site.

The results of the geochemical analysis conducted at the four reference sites were analyzed using ANOVA, linear regression, correlation, and spatial analysis. The results showed that the geochemistry of wetland sites is spatially affected by the hydrology, and is influenced by other biogeochemical cycles, including the iron, sulfur and nitrogen cycles. Retention, transport, and chemical reactions of metals and other nutrients were observed to be directly and indirectly influenced by hydrology, soils, and biological activity of the wetland.

As a result of the reference site analyses, eight geochemical function equations are proposed for the southern Rocky Mountain wetlands. Two of the functions pertain to cations (Mstore and Mtrans); two of the functions pertain to anions (Nstore and Ntrans); one of the functions pertains to both the metals and nutrients (MNmove), and three of the functions are proposed as alternative functions (Mstore (riverine), MNstore (slope), and Nstore (riverine)). Fourteen variables and five hydrologic functions were defined in order to complete the biogeochemical function assessment process. Each of the variables was assigned a ranking between 0.0 and 1.0 with respect to the reference site.

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FORWARD

This report has been prepared for the Colorado Geologic Survey, Colorado Department of Natural Resources, Denver, Colorado, as a deliverable under Memorandum of Understanding Grant # CD9980004-0397 (CSM contracts # 4 - 41737 and # 4 - 41712) with the Colorado School of Mines (CSM). The project has been carried out under the responsibility of Dr. Kenneth E. Kolm, Associate Professor, Div. of Environmental Science and Engineering, Principal Investigator. Dr. John Emerick, Associate Professor, Div. of Environmental Science and Engineering advised on the geochemical sampling, field and laboratory analysis, and statistical analysis and interpretation of the geochemical data. Much of the field work, and laboratory and data analysis and interpretation was performed by Ruth Harper-Arabie, Ph.D. Graduate Student, Environmental Science and Engineering, who will be extending this study as part of her Doctoral Dissertation.

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Kenneth E. Kolm
Golden, Colorado
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A STEPWISE, INTEGRATED HYDROGEOMORPHIC APPROACH FOR THE CLASSIFICATION OF WETLANDS AND ASSESSMENT OF WETLAND HYDROLOGICAL AND GEOCHEMICAL FUNCTION IN THE SOUTHERN ROCKY MOUNTAINS OF COLORADO

1.0 INTRODUCTION

1.1 Purpose and Scope

The first objective of this study was to develop a step-wise, integrated hydrogeomorphic approach for the classification of wetlands in the southern Rocky Mountains, Colorado, that could be used to classify the main wetland types, and to provide a framework for determining wetland hydrologic function. The conceptualization and characterization of ground-water flow systems approach and logic developed by Kolm (1993), Kolm et al. (1996), and Kolm and van der Heijde (1996) was incorporated with the Hydrogeomorphic Approach (HGM) as developed by Brinson (1993) to achieve this objective.

The second objective of this study was to characterize the geochemistry of reference wetlands and to identify the variables that should be measured to determine geochemical functions of Colorado wetlands. Five reference sites were selected and accompanying field studies were conducted. The reference wetlands were also used to study site-specific hydrogeomorphic characteristics using the procedures developed as part of the first objective, and to determine wetland hydrologic functions . The result is an enhanced understanding of the surface water, ground-water, and geochemical functions observed in the reference wetland sites in the southern Rocky Mountains.

1.2 General Background

HGM was developed by Brinson (1993) for the purpose of classifying functionally similar wetlands based on 1) geomorphic setting; 2) water source and transport; and 3) hydrodynamics. The HGM approach assumes that the maintenance of the wetland and related ecosystem is primarily a function of a combination of physical and chemical factors. The measurement of these physical and chemical factors, therefore, provides an avenue for the investigator and the regulator to understand the nature and function of wetlands, and to evaluate the relative values of each wetland.

The logic and conceptualization and characterization methodology described by Kolm (1993), Kolm et al. (1996), and Kolm and van der Heijde (1996), was employed in combination with the Brinson (1993) approach for the development of wetlands classification and determination of wetlands function. The values of incorporating the Kolm (1993) approach are 1) the approach is non-invasive; and 2) in using the approach, the subsurface framework and ground-water flow system can be estimated with minimal time being spent on-site. An understanding of the ground-water system is imperative. Without this understanding, it is possible that wetlands will be grouped into classes based simply upon their position in the landscape without a thorough consideration of water source and dynamics. Kolm et al. (1996), supported by the American Society for Testing and Materials Standard Guide D 5797, addresses the general procedure, types of data needed, and references that enable the investigator or regulator to complete the process of analysis and interpretation of each data type with respect to geomorphic and geohydrologic processes and framework, and the surface water and ground-water system regimes. This approach has been used to solve several water supply and water quality problems (San Juan and Kolm 1996; Talbot and Kolm 1996). In addition, the hydrochemical aspects of the hydrologic system may be determined and analyzed during the conceptualization and characterization process (Kolm and van der Heijde 1996).

The geochemical role of wetlands can be significant, particularly with respect to trace element retention. This function of natural wetlands has served as a model for the design and construction of constructed wetland systems for treatment of acid mine discharge in the Rocky Mountains (Howard et al. 1989), and has spawned investigations into the use of natural wetlands for on-site control of mine discharge and mine waste leachate (Emerick et al. 1988). Retention of metals by wetland soils and metal uptake by vegetation has been studied in slope wetlands (Cooper and Emerick 1987; Emerick, 1988). Results have shown that metal concentrations in soils and plants of wetland systems receiving mine discharge or natural waters with high metal loadings are often several orders of magnitude higher than pristine sites. Processes controlling the release or "leakage" of such concentrated metals from wetlands to downstream waters are poorly understood and the degree to which such releases occur is not well known.

It is understood that wetlands can influence the fate and transport of elements in associated surface and pore waters in several ways. These may include: 1) entrapment of flocculants containing precipitated elements, suspended particles onto which elements have been adsorbed, or mineral particles which contain trace elements; 2) adsorption of elements (chiefly cations) by the organic matter present in wetland soils; 3) creating favorable geochemical environments for the precipitation of certain elements (often microbially mediated); and 4) by direct uptake by plants and incorporation in organic matter. The degree to which various elements remain trapped in wetland systems varies according to such factors as the seasonal hydrologic regime, seasonal growth and decomposition cycles of vegetation, the structure and organic composition of the soils, and the degree and time period of element loading. Some trace elements such as cadmium and zinc may be retained during late spring and summer when the soils are saturated and plant growth is at its maximum, and then released during the early spring following a period of drying soils, geochemical weathering, and organic matter decomposition. A change of management practices (such as grazing or ditching) may influence the degree to which a given wetland is primarily a sink for trace elements or a source of these elements to downstream surface waters. A detailed study of all of these factors is beyond the scope of this study, however, a general approach for assessing geochemical function consistent with HGM methods would be particularly valuable in the southern Rocky Mountains and in other regions where elevated trace element concentrations, as a result of extensive mineralization and mining activity, are an important water quality issue.

1.3 General Approach

1.3.1 Wetland Classification and Characterization

The integrated approach for a wetlands classification scheme is based on conceptualizing and characterizing wetland classes and subclasses. This approach includes: 1) Problem Definition and Data Base Development; 2) Preliminary Conceptualization; 3) Surface Characterization; 4) Subsurface Characterization (Geomorphic, Geologic, and Hydrogeologic; 5) Ground-Water System Characterization and Quantification; and 6) Wetlands System Characterization and Classification based on function including water supply, and water quality. This approach is an iterative process beginning with a theoretical understanding of the wetlands system followed by data collection and refinement of the understanding. Additional data collection and analysis, and the refinement of the wetlands system classification and function occurs during the entire process of wetlands characterization. This project developed and refined this procedure for wetlands classification as outlined in Steps 1 - 6.

The methodology developed using this procedure was integrated with the geochemical part of the study. The "reference wetlands" sites representative of each main type were identified during the development of this classification. The characterization of the geochemical functions was correlated with each wetland type using hydrogeomorphic data collected in field studies to verify and refine the classification.

The existing data were gathered and reviewed according to the logic of Kolm (1993) and Kolm and others (1996) to develop the appropriate "Common Data Topics and Types" and "Interpreted Data Bases" tables as related to wetlands classification and function assessment. Preliminary classification of wetlands systems were conceptualized using these data bases. This resulted in the development of several conceptual models of wetland classes and systems analysis that were used for refinement of the classification scheme and function determination.

The existing data, including both the natural and anthropogenic features of the reference sites, were analyzed. Field reconnaissance was conducted, as necessary, to relate the preliminary analysis of the information collected to reference study site conditions. In areas where field data were sparse, basic photointerpretation and terrain analysis techniques were applied to remote sensing data, aerial photography, and topographic maps to acquire information, and were used to quantify and distribute wetland system parameters.

The surface characterization procedures described by Kolm (1993) that are important to wetlands classification and functional assessment were combined with those identified in hydrogeomorphic classification studies by Brinson (1993 and 1995), Brinson and others

(1995), Smith and others (1995), and Hauer and Cook (1996a and b), and a critical list with procedures were developed. The appropriate procedures for evaluating geomorphic process, deposits, and landforms, based on surface characterization, were determined for application to wetland systems.

The appropriate structure, and physical and chemical characteristics, distribution, and continuity of stratigraphic and lithologic units (soil and rock) were determined for each wetland classification and function assessment. The type, properties, and distribution of geomorphic materials, landforms, slope; and other geomorphic processes and characteristics with respect to the surface water and ground-water hydrology were interpreted to understand wetland class and function. In addition, the important chemical constituents, both natural and anthropogenic, that pertain to the surface-water and ground-water systems were determined. This data and analysis was integrated into the assessment of geochemical function conducted as a later part of the study.

The importance of hydrogeology and ground-water systems were determined for each wetland class. Each type of wetland system was then characterized and classified using the surface and geomorphological characterization, subsurface characterization, and hydrogeologic and ground-water system characterization and quantification, as appropriate. The wetlands system characterization and classification included the boundary conditions (predominantly hydrogeomorphic) and the general functions (hydrologic, biologic, and chemical).

1.3.2 Hydrochemical Characterization

The development of methods to evaluate the geochemical functions of wetlands primarily relied on field studies at a small number of selected reference sites that represented a range of trace element loads in two types of wetlands: slope and riverine. A review of published literature regarding previous studies that assessed geochemical functions in wetland ecosystems was conducted. Reference sites were then selected with consideration to the needs of developing the hydrological approach and classification, and on-site conceptualization.

The characterization of the wetland sites consisted of: 1) Establishing the hydrologic and geologic setting for each wetland using the approach discussed; 2) Assessing and sampling the plant community on each site as required; 3) Collecting and analyzing soil samples for geochemical analysis, and conducting soil coring to describe depth, composition, and other characteristics of soils; and 4) Collecting water samples from the wells during spring runoff, midsummer, and fall, and analyzing for dissolved Fe, Zn, Cl, and NO_3 ions using atomic absorption spectrophotometry methods for the metals and ion chromatography methods for nitrate. These data were analyzed and the geochemical functions were hypothesized based on the results.

1.4 Location of Reference Study Sites

Five wetlands located in Colorado were chosen as reference sites based upon professional judgment, accessibility, and previous installation of wells needed for sampling. The wetlands represent two slope wetlands, two riverine wetlands, and one mixed wetland (slope and riverine components). All of the wetlands chosen are located on the western side of the Continental Divide.

The **Pennsylvania Mine Wetland** (which, for purposes of this report, will be referred to in the text as the **Peru Creek Wetland**) is a slope wetland located at an elevation of 10,660 feet on the south side of Peru Creek near Dillon, Colorado The wetland is located at 39°36'00"N latitude and 105°48'30"W longitude. The second slope wetland, referred to as the **Big Meadows Wetland**, is located in Rocky Mountain National Park at an approximate elevation of 9,405 feet. The southern section of the wetland has latitudinal and longitudinal coordinates of 40°18'30"N and 105°48'30"W, respectively.

The riverine wetlands selected include the **Allen Bottom Wetland** and the **Deerlodge Wetland**. Allen Bottom, the wetland studied in Browns Park, is located on the Green River near the Browns Park Wildlife Refuge in northwestern Colorado. For purposes of this report, this wetland will be referred to in the text as the **Browns Park Wetland**. The elevation of this wetland is approximately 5,350 feet and the latitude and longitude coordinates of the most eastern boundary are 40°46'10"N and 108°53'30"W. The Deerlodge wetland is in Dinosaur National Monument at an elevation of 5,620 feet. This wetland is adjacent to the Yampa River and has latitude and longitude coordinates on the northern boundary of 40°26'50"N and 108°29'10"W.

A wetland in the Kawuneeche Valley was chosen to represent a mixed wetland (slope and riverine aspects). Although a chemical database is included in Appendix A.5, an analysis of this data was not conducted because of a lack of available well survey data.

1.5 Field Sampling Methods

The objectives of the field sampling were to determine water levels and to obtain samples of water, soils, and plants that were representative of the wetland. The samples were collected over a seven-month period to track changes in chemical constituents over time and hydrologic regime.

1.5.1 Water Source and General Well Construction

The water samples were obtained from two sources: flowing or ponded surface water, and ground-water from wells. The construction of wells varies between sites, but is assumed to be consistent within sites. New wells were installed with a hand auger. PVC pipe, with diameters ranging from 0.5 to 2.5 inches, was used as casing. Screening on the wells, in most cases, was placed from the base of the well to above the surface of the ground-water. The auger hole surrounding the casing was back filled and capped with either low permeability material or with an aluminum plate to prevent surface water from flowing into the wells. All of the wells were constructed in shallow ground-water and typically did not exceed ten feet. In the three wetlands where peat was present, wells were nested in pairs with one of the wells screened in only the peat and the second screened in both the peat and the underlying materials.

For the purpose of this report, wells in the Peru Creek wetland and the Big Meadows wetland are classified as being completed in either peat or unconsolidated materials. The new wells installed during the 1997 field season at Peru Creek were screened in only the peat layer. Wells installed prior to 1997 are described by Huskie (1987); these wells were installed into unconsolidated cobbles underlying the peat. Although these wells were screened in the peat and the cobbles, it is assumed that the hydraulic conductivities in the cobbles are so much greater than in the peat, that recharge from the peat is negligible. In Big Meadows, wells installed during the 1997 field season were known to be screened in the peat only, therefore, these are termed peat wells. The construction of the wells installed prior to 1997 is described by Cooper (1990) and Shuter (1988). No well logs for these wells are known to exist, however, Cooper (1990) does state that the wells were installed through the entire peat column down to the underlying alluvium and glacial outwash or till. Recharge rates in these wells tend to support that the wells are either partially screened in high hydraulic conductivity layers or surface water is able to recharge the wells. Although no surface water visibly entered the wells from the surface, it is possible that surface water entered the voids which were present around the wells and recharged from a lower level. The wells installed in Big Meadows prior to 1997 are termed the unconsolidated wells.

1.5.2 Water Samples

1.5.2.1 Collection Procedures

Three casing volumes were purged from each well with a PVC bailer to insure the sample collected was representative of the pore water. A casing volume is determined by multiplying the height of the water column within the casing with the cross-sectional area of the casing (Fenn et al. 1977). A liter of water was collected from the well following the removal of the third well volume with the same bailer used to purge the well, placed in an acid-washed Nalgene HDPE bottle, and capped immediately.

Peat wells were bailed dry and allowed to refill before a sample was collected. This was necessary, given the low permeability of peat, for enough water to be present in the well for sampling. The amount of time needed for the wells to recharge ranged from approximately 6 hours to 24 hours (overnight). A bailer, which had been rinsed three times with de-ionized (DI) water, was used to collect each sample from the peat wells. The samples were placed in a one-liter acid-washed Nalgene HDPE bottle and capped immediately.

Surface water was collected by partially submerging an acid-washed, one-liter Nalgene HDPE bottle in the water. Water was allowed to flow into the bottle with the mouth facing upstream. The bottle was rinsed with this sample and emptied. This action was repeated two times. The third sample collected was capped immediately and used for chemical analysis.

1.5.2.2 Chemical Analysis: Field Methods

Approximately 400 ml of the water sample was poured into a 500 ml acid-washed plastic beaker. Dissolved oxygen (D.O.), conductivity, pH, Eh, and temperature were measured for this sample. D.O. was measured using a field probe and meter that was calibrated based upon the site elevation. A two-point calibration was used for the pH meter. Eh of prepared Light's solution was measured with a platinum redox electrode; this value was used to standardize redox values of water samples to an H_2 redox electrode (Light 1972). For comparison purposes, Eh measurements were also calculated in the laboratory. All probes were rinsed with DI water between samples.

Following these measurements, the beaker was emptied, rinsed with DI water, and filled with a measured 100 ml water sample. Alkalinity was measured on this sample with a sulfuric acid titration to an endpoint of $pH = 4.8$. A portion of the sample remaining was placed in a 250 ml Nalgene HDPE bottle and acidified to $pH < 2.0$ with 1:1 HNO_3. Another portion of the sample was filtered through a 0.45 µm pore size filter into a 250 ml Nalgene HDPE bottle and acidified to $pH < 2.0$ with 1:1 HNO_3. The remaining sample was left in the one liter bottle, capped, and placed on ice (in an ice chest).

1.5.2.3 Chemical Analysis: Laboratory Methods

The samples, which were kept on ice in the field, were stored in a freezer until anion analysis on a Dionex Ion Chromatograph (IC) could be completed. Prior to IC analysis, the samples were thawed over night, filtered through a 0.45µm pore size filter, and analyzed according to the Dionex protocols. A five-point calibration was used for fluoride, chloride, phosphate, nitrate, and sulfate. Samples that had concentrations greater than the standards were diluted and re-run.

The two samples that were acidified in the field were analyzed on a Perkin Elmer Inductively Coupled Plasma- Atomic Emission Spectrometer (ICP-AES) according to instrument protocol. An internal spike of scandium (1:100) was used to standardize the samples; the average of three analyses per sample is reported. The samples that were not filtered in the field are reported as total cations, the filtered samples are reported as dissolved cations.

Eh measurements were also determined in the laboratory. These measurements were calculated with the Nernst equation (Pankow 1991). The sulfate concentrations measured with the IC were interpreted to be the oxidized species and sulfide the reduced species. The difference between the total sulfur measured on the ICP and the sulfate was assumed to be the concentration of sulfides in the samples. At pH > 6.0, sulfide was assumed to be in the form of HS^-; at pH < 6.0, sulfide was assumed to be in the form of H_2S. The calculated Eh values were used for statistical purposes; both calculated and field measured Eh values are presented in Appendix A.

1.5.3 Soil Samples

1.5.3.1 Collection Procedures

Soil samples were collected one time on the last sampling date for each site. Four samples per well were collected. A five-meter radius was marked around each well, and samples were collected at approximately 90° intervals around that radius. The first sample collected was used to determine bulk density. The remaining samples were composited for use in chemical analysis and particle size analysis.

Peat samples were collected by digging a core with a "sharp shooter" shovel. The core collected represented peat from ten to twenty centimeters below the surface. The dimensions of the core were measured and recorded. The samples were stored in plastic bags, with composite samples stored on ice.

At sites where no peat formation had occurred, the soils were primarily of mineral composition. Soil samples from the reference sites were collected using procedures described by Stout (1994). After the sample was collected, the holes were lined with plastic and a measured volume of water was used to back-fill the holes. This volume was recorded as the volume of soil removed. The samples were stored in the same manner as the peat samples.

1.5.3.2 Chemical and Physical Analysis: Laboratory Methods

Soil samples that were kept on ice in the field were kept frozen in the laboratory until analysis could be completed. The bulk density samples were weighed while wet and then air dried to a constant weight. Bulk density was calculated based upon dry weights divided by field-measured volumes of the samples.

The frozen samples were thawed overnight and hand mixed so that the three composite samples were well mixed. A subsample was removed and oven dried for 24 hours. These samples were ground with a mortar and pestal to pass through a US #10 (1mm size) sieve.

Subsamples of the ground soils were tested for carbonate presence with HCl (Craft et al. 1991). When carbonates were present, a minimum of 2 ml of 5M HCl was added to the soils to remove the carbonates; if needed, more than 2 ml HCl was added to remove all of the carbonates. Loss on ignition was used to determine percent organic matter (%OM) in each of the soils (Carter 1993; Goldin 1987). When carbonates were present, loss on ignition was determined for two samples. Carbonates were removed from one sample but not the second. The percent loss by weight of the first sample represented %OM present. The percent loss by weight of the second sample represented the total percent of carbon present. The difference between the two was percent carbonate present. Soil samples with %OM less than 25% are considered to be mineral soils, and samples with %OM greater than 25% are considered to be organic soils (Mitsch and Gosselink 1993).

Total pore space for each sample was estimated as described by Carter (1993). For mineral soils, a particle density of quartz, 2.65 Mg m^{-3} was assumed. For peat (high organic) samples, a particle density of 1.55 Mg m^{-3} was assumed (Carter 1993; Verdonck et al. 1978).

Chemical analyses were performed on the composited soil samples, which were ground to pass through a 1mm sieve. Mineral soils were digested according to USEPA method 3050B (1996). Peat samples were digested with a dry ash method as described by Ali et al. (1988). These samples were filtered through a 0.45μm pore size filter. The filtrate was spiked with scandium and analyzed on the ICP-AES for cation content.

For particle size analysis, a hydrometer method (Carter 1993; Day 1965) was used on a subsample of the composited soils. Results are reported as percentage sand, percentage silt, and percentage clay, and by soil texture classification, as determined by a soil textural triangle.

1.5.4 Plant Samples

1.5.4.1 Collection Procedures

Plant samples were collected one time on the last sampling date for each site. Two samples per well were collected. Samples were randomly collected within a two-to-five meter radius surrounding each well. A 10 cm^2 sample of above ground herbaceous plant material was clipped to the ground and stored in a brown paper bag. Dead material was removed.

1.5.4.2 Chemical Analysis: Laboratory Methods

Plant samples were oven dried at 95° F for 24 hours and weighed. Plant biomass for each well was averaged and is recorded as dry plant material in grams per square meter. The dried samples were ground in a Wiley Mill to pass a 2 mm screen. The ground plant material was digested with a dilute acid digestion. These samples were filtered through a 0.45 μm pore size filter. The filtrate was spiked with scandium and analyzed on the ICP-AES for cation content. Values reported are an average of the two samples collected per well.

1.5.5 Data Analysis

1.5.5.1 Hydrologic Analysis

Data for hydrologic characterization of each site were collected as described by Kolm et al. (1996). These data were used to hypothesize ground-water flow direction in each of the reference wetlands. Field measurements were used to verify and refine the conceptualization and characterization conclusions. Ground-water levels were measured throughout the field season. These measurements were used to hand contour potentiometric maps. For presentation purposes, Surfer® for Windows, Version 6 (Golden Software, Inc. 1995) was used to contour the same maps. Kriging was the statistical method used by Surfer. Boundary conditions were controlled so that Surfer would best represent the hand-contoured maps.

The river stages of the riverine wetlands were estimated. An upstream well located near the river was assumed to be representative of the river level at that point. The gradient of the river was determined by measuring the distance between topographic lines which cross the river on the appropriate USGS 7.5' topographic map. This change in elevation was divided by the measured distance. This change in elevation per unit length was applied to the wetland with the river stage in the upstream well as the starting point.

1.5.5.2 Geochemical Analysis

Statistical analyses of the chemical data collected were used to determine basic effects of soil properties, plant properties, and chemical environment on geochemical functions. Interactions between chemicals were also determined based upon these statistical results. These statistical analyses included linear regressions, correlations, percent ion composition, and two-way analysis of variance (ANOVA).

Linear regressions were used to test for trends of geochemical parameters along the flow path. By using the hydrologic data for each wetland, wells were classified as upstream, midstream and downstream along ground-water flow paths. The average of the shortest and longest distances between groups of wells in the upstream, midstream and downstream areas was calculated. The chemical values measured in each of the wells were then plotted on the Y-axis against average distance and a straight line was fit though the plotted observations using the least squares method.

Pair-wise correlations were determined by comparing the average of measured parameters in upstream, midstream, and downstream wells. The purpose of the correlation analysis was to determine how strongly correlated various chemical parameters were to each other and to help elucidate key chemical processes affecting the wetland sites. A positive correlation exists when large values of one variable are associated with large values of the second variable. A negative correlation exists when small values of one variable are associated with large values of the second variable.

Average cumulative percentage in mg/l of major ions in water samples were plotted so differences between types of water are visible (Hem 1985). The two-way ANOVA without replication was performed on all of the measured parameters to determine whether the means of samples varied significantly by sampling location within a wetland site or by sampling date.

The mean value of cation concentrations in soil, plants and water were determined based on a weight/weight ratio, and based on a weight/soil volume ratio. For the soil and water calculations of the weight/volume ratio, the volume was a 1m X 1m X 0.01m block of soil and the weight was the weight of the media in that volume of soil. The same volume of soil was used for the plant weight/volume ratio, but the weight of the above ground biomass on the surface of the 1m X 1m X .01m block of soil was used.

2.0 STEP-WISE, INTEGRATED HYDROGEOMORPHIC APPROACH FOR WETLAND CLASSIFICATION

The development of the southern Rocky Mountains wetland classification scheme, which incorporates both the HGM methods of Brinson (1993), and the Conceptualization and Characterization of Kolm (1993); Kolm and others (1996); and Kolm and van der Heijde (1996) is described in a step-wise, integrated approach involving both surface and subsurface characterization and analysis. This approach is designed hierarchically for wetland identification, wetland function delineation, and, ultimately, wetland type.

In the following approach and classification scheme, the ground- and surface-water flow systems and dynamics are to be determined. This information, in conjunction with geomorphic settings, can be used to determine the wetland process, and wetland class and subclass. In addition, this classification scheme provides the framework or structure for wetland functional analysis (Tables 2.1 and 2.2). It is recommended that this step-wise, integrated approach be followed by the Assessment Procedure Development Team in defining the wetland function, and in determining the variable indices for each function.

2.1 Step 1: Surface Characterization

The purpose of the surface characterization step is to determine or reaffirm if, by definition, the area being assessed is a **wetland**. In addition, the wetland **functions** pertaining to hydrologic sinks and sources within the system are identified. Surface characterization consists of evaluating the appropriate vegetation, soils, surface water, climate, topography, and animals associated with the wetland being evaluated. The anthropogenic aspects of the evaluation are to be incorporated into these categories.

2.1.1 Step 1a: Vegetation Characterization

Vegetation observed on-site and in the surrounding area is used to determine the presence of a near-surface water table (in some cases, depth to water table may be approximated) and can indicate water quality (for example, low versus high salinity). Where

System Unit	Indicator/Characterization Parameter			Hydrologic Function	PM	BM	DL	AB	KW
Surface	A. Vegetation	1.	Hydrophyte	ET, GWmove	X	X	X	X	X
		2.	Non-hydrophyte				X	X	
	B. Soil	1.	Peat	GWmove, GWinter, SWstoredyn, SWstorelt	X	X			X
		2.	Mineral	GWstoredyn, ED			X	X	X
	C. Surface Water	1.	Springs/seeps	SWin, GWoutss	X	X			X
		2.	Overland flow		▨	▨	▨	▨	▨
		2a.	Source = springs/seeps	SWout	X	X			X
		2b.	Source = flooding	SWstoredyn, ED, SWin, GWstoredyn		X	X	X	X
		3.	Channel flow		▨	▨	▨	▨	▨
		3a.	Channel Enters Wetland	SWin		X	X		
		3b.	Gaining Stream in or on the Boundary of Wetland	GWoutr	X	X	X	X	X
		3c.	Losing Stream in or on the Boundary of Wetland	GWstorelt, ED, GWmove		X	X	X	X
		3d.	Channel Exits Wetland	SWout		X			
		4.	Still water	GWoutss, SWstorelt	X	X			X
	D. Climate	1.	Evaporation	ET	X	X	X	X	X
		2.	Annual Precipitation		▨	▨	▨	▨	▨
		2a.	Snowpack	ATMin	X	X	X	X	X
		2b.	Rain	ATMin	X	X	X	X	X
	E. Topography	1.	Locally (on site)		▨	▨	▨	▨	▨
		1a.	Low Gradient (<2%)	GWmove, GWstoredyn, SWstorelt, SWstoredyn, ED	X	X	X	X	X
		1b.	High Gradient (>2%)	GWmove					
		1c.	Slope Direction		▨	▨	▨	▨	▨
		1d.	Microtopography (hummocky)	SWstoredyn, SWstorelt, ED, GWstoredyn	X	X	X	X	X
		2.	Locally (boundary conditions)		▨	▨	▨	▨	▨
		2a.	Low Gradient (less than or equal to on-site gradient)	GWmove, GWoutr					
		2b.	High Gradient (greater then on-site gradient)	GWinter, GWmove	X	X	X	X	X
		2c.	Slope Direction Into Wetland	GWinter	X	X	X	X	X
		2d.	Slope Direction Away From Wetland	GWoutr	X		X	X	X
	F. Animals	1.	Beaver Activity	SWstorelt, ED					X

Table 2.1 Checklist and Identification of HGM Hydrologic Functions and Indicators for southern Rocky Mountain Wetlands.

System Unit	Indicator		Characterization Parameter	Hydrologic Function	PM	BM	DL	AB	KW
Subsurface	Geomorphic Deposits/ Hydrogeomorphology		3-D Structure of System, Hydraulic Conductivity, Storativity, Saturated Thickness, Transmissivity	GWstorlt, GWstordyn, GWmove, GWinter, SWstorlt, SWstordyn, ED	▨	▨	▨	▨	▨
		1. Periglacial			▨	▨	▨	▨	▨
		1a. Stone Nets, Stone Stripes, Patterned Ground							
		1b. Lakes- "depressional"				X			
		2. Glacial			▨	▨	▨	▨	▨
		2a. Morraine (lateral, terminal and recessional)			X				X
		2b. Morraine Lacustrine Deposits				X			
		2c. Till				X			
		2d. Erosional lakes (tarns)							
		3. Mass Wasting			▨	▨	▨	▨	▨
		3a. Colluvium			X				X
		3b. Lacustrine deposits within colluvium							
		4. Fluvial			▨	▨	▨	▨	▨
		4a. Terraces, Abandoned Floodplains, Outwash Plains					X	X	X
		4b. Modern floodplain					X	X	X
		4d. Lacustrine (oxbow lakes)							
	Geology/ Hydrogeology		3-D Structure of System, Hydraulic Conductivity, Storativity, Saturated Thickness, Transmissivity,	GWstorlt, GWstordyn, GWmove, GWinter, SWstorlt, SWstordyn, ED	▨	▨	▨	▨	▨
		1. Fracture Flow			▨	▨	▨	▨	▨
		1a. Stratified Igneous Extrusive Rocks							
		1b. Metamorphic and Igneous Intrusive Rocks			X	X		X	X
		1c. Crystalline Limestone Rocks (With or Without Karst)							
		2. Matrix Flow			▨	▨	▨	▨	▨
		2a. Stratified Sandstones (With Fracture Flow)							
		2b. Fault Gauge							
		3. Confining Units			▨	▨	▨	▨	▨
		3a. Shales					X		
		3b. VolcanicAshes							

Table 2.1cont. Checklist and Identification of HGM Hydrologic Functions and Indicators for southern Rocky Mountain Wetlands.

System Unit	Indicator		Characterization Parameter	Hydrologic Function	PM	BM	DL	AB	KW
Subsurface	Hydrostructure		3-D Structure of System, Hydraulic Conductivity, Storativity, Saturated Thickness, Transmissivity	GWstorlt, GWstordyn, GWmove, GWinter, SWstorlt, SWstordyn, ED					
		1. Fracture Zones			X	X	X	X	X
		2. Faults (Normal and Reverse)			X				
		3. Folds							
		4. Igneous Contact Zones			X				
Ground Water System	GW Movement (Direction) And Boundary Conditions		Head or Potentiometric Surface	GWstorlt, GWstordyn, GWmove, GWinter, SWstorlt, SWstordyn, ED					
		1. Horizontal							
		1a. To River or Channel			X				
		1b. From River or Channel							
		1c. To and From River (seasonally)					X	X	X
		1d. To and From River (spatially)				X	X	X	X
		1e. From Bedrock Source			X	X	X		
		2. Vertical							
		2a. Up			X				
		2b. Down							
		2c. Up and Down (seasonally)			X				X
		2d. Up and Down (spatially)				X	X	X	X

PM= Pennsylvania Mine Wetland
BM= Big Meadows Wetland
DL= Deerlodge Wetland
AB= Allens Bottom Wetland
KW= Kawuneeche Valley Wetland

Table 2.1cont. Checklist and Identification of HGM Hydrologic Functions and Indicators for southern Rocky Mountain Wetlands.

Function Abbreviation	Function Name	Function definition
ET	Evapotranspiration	The removal of water from the terrestrial environment to the atmosphere.
GWinter	GW interception	The interception of ground-water, typically by a low K layer.
GWoutss	GW out springs/seeps	The removal of water from the ground-water system to the surface water system via springs and seeps. May result in water remaining on site.
GWoutr	GW out river	The removal of water from the ground-water system to the surface water system (results in a gaining stretch of river or stream). Results in movement of water off site.
GWstorelt	GW storage-long term	Storage of water into regional system, or in subsurface of wetland.
GWstoredyn	GW storage-dynamic	Storage of water in subsurface of wetland during flooding events.
GWmove	GW movement (moderation of)	A change in the direction and velocity of ground-water.
SWstoredyn	SW storage-dynamic	Short term storage of surface water. e.g. during flooding events.
SWstorelt	SW storage-long term	Storage of surface water for long periods of time. Water is stored because recharge to a ground-water system is retarded by a low hydraulic conductivity layer, or is retained by microtopography or dam like structures.
SWin	SW in	Surface water enters wetland as a channel.
SWout	SW out	Surface water exits wetland as a channel.
ATMin	Atmosphere in	Input to wetland from atmosphere.
ED	Energy Dissipation	Degree to which wetland can dissipate energy.

Table 2.2 Definition of Proposed Hydrologic Functions in Southern Rocky Mountain Wetlands.

hydrophytes are present, wetlands may be present, and the wetland **functions** of **evapotranspiration** of water from the water table is observed (Table 2.1). ET is a ground-water system loss or sink. In addition, when a plant is respiring during the growing season, the plant functions as a pumping well and draws water toward it in a radial-like manner. In this respect, the hydrophytes are part of the wetland function of **ground-water movement.**

The type and spatial distribution of hydrophytes (facultative and obligate wetland plant species) and non-hydrophytes should be mapped for the wetland. In the southern Rocky Mountains, hydrophytes consist of aspens, cottonwoods, willows, sedges etc. This map will provide the areas within the wetland where the evapotranspiration and ground-water movement functions occur with respect to the ground-water saturated zone.

2.1.2 Step 1b: Soils Characterization

Soils observed on-site and in the surrounding area are used, in conjunction with the vegetation analysis, to determine the presence and horizontal distribution of organic or mineral soils. Vertical peat distribution, if required, is determined by other direct (cores, etc.) or indirect (geophysics) measurements. Where **hydric** soils are present a **wetland** may be identified, and the wetland **functions** of **ground-water movement, ground-water interception, surface-water storage long term,** and **surface water storage dynamic** are observed (Table 2.1). These functions represent ground-water system source, transport, and storage. Mineral soils, by comparison, are more representative of the ground-water system processes of infiltration and recharge, and are considered as part of the wetland functions of **ground-water storage dynamic** and **energy dissipation.** In addition, the characterization of soil properties is useful for assessing the wetland function of **atmosphere in.**

The type and spatial distribution of organic and mineral soils should be mapped for the wetland. In the southern Rocky Mountains, peat may be associated with specific phreatophytes such as *Carex, Eleocharis,* and various mosses. The depth of peat will be variable due to various processes and time of formation. This soils map will provide the areas within the wetland where the ground-water movement, ground-water interception, and ground-water storage long term functions occur with respect to the ground-water saturated zone.

2.1.3 Step 1c: Surface Water Characterization

Surface water observed on-site and in the surrounding area is used, in conjunction with the vegetation map, to determine the location of springs and seeps, types of overland flow, type and distribution of channeled flow, and the presence of still water. Surface water flow, inundation, velocity, and other parameters may be determined by direct measurements, if required. Where **surface water** occurs, the area may be classified as a **wetland**, and the wetland **functions** of **ground-water out springs/seeps, ground-water out river, ground-water storage dynamic, ground-water storage long term, ground-**

water movement, surface water in, surface water storage-long term, surface water storage dynamic, surface water out springs and seeps, surface water our river and **energy dissipation** may be observed (Table 2.1). These functions represent ground-water system source and sink, and surface water source, transport, and sink.

The type and spatial distribution of springs and seeps, overland flow due to ground-water discharge as springs and seeps, overland flow due to inundation or flooding by streams, channels entering the wetland area, channels flowing through the wetland (classified as either gaining, losing, or neither gaining nor losing of surface water), channels leaving the wetland, and areas of still or ponded water should be mapped for the wetland. In the southern Rocky Mountains, this surface water type and distribution map will provide the areas within the wetland where the ground-water interception, and ground-water out functions occur with respect to the ground-water saturated zone system. In addition, most of the surface water system functions of the wetlands can be analyzed during this step.

2.1.4 Step 1d: Climate Characterization

Climate data observed on-site and in the surrounding area is used, in conjunction with the vegetation and surface water data and analysis, to determine the type and distribution of precipitation and evaporation. Precipitation, such as daily or annual rainfall and snowpack, and evaporation may be measured directly, if required. Where evaporation occurs, the wetland **function** of **evapotranspiration** may be observed (Table 2.1). Where precipitation occurs, the wetland **function** of **atmosphere in** may be observed. These functions represent surface-water system sink and ground-water system source, respectively.

The amount of evaporation at the wetland site should be estimated, and the type, spatial, and temporal distribution of precipitation should be mapped for the wetland. In the southern Rocky Mountains, the precipitation type should include both the temporal aspects and amounts of rain and snow received by the wetland. This information will provide the areas within the wetland where the atmosphere-in functions occur with respect to the ground-water saturated zone system (infiltration and recharge).

2.1.5 Step 1e: Topographic Characterization

The topography observed on-site and in the surrounding area is used to determine the microtopography of the site, the topographic slope gradient and slope direction of the site, and the topographic slope gradient and slope direction of the areas surrounding the wetland. Topographic slope gradients, slope directions, and microtopography may be determined by direct measurements, if required, or by using topographic maps. Where topographic slope gradient is either low or high within the wetland, and the slope direction is determined, the wetland **functions** of **ground-water out river, ground-water movement,** and **ground-water storage dynamic** can be interpreted. In addition, slope gradient can be used as a variable to evaluate **surface water storage dynamic** and **long-term**, and **energy dissipation**. Where topographic slope gradient and slope direction are determined around the boundary of the wetland, **ground-water interception, ground-water out river,** and **ground-water movement functions** are interpreted. Where microtopography is observed and mapped **ground-water storage dynamic, surface water storage-long term, surface water storage-dynamic,** and **energy dissipation functions** may be observed (Table 2.1). These functions represent ground-water system source, transport and sink, and surface water source, transport, and sink.

The microtopography of the site, the topographic slope gradient and slope direction of the site, and the topographic slope gradient and slope direction of the areas surrounding the wetland should be mapped and analyzed for the wetland. In the southern Rocky Mountains, microtopography will most likely be geomorphologically and/or anthropogenically derived (for example, meander scrolls in a fluvial environment; hummocky terrain in moraine or mass wasting topography; excavations where anthropogenic activity has occurred). Typically, the wetland topography is of low slope gradient resulting in low-gradient ground-water movement. The topographic slope is variable, but usually reflects a river or mass wasting process. The topography of the area surrounding the wetland is typically high slope gradient and the slope gradient is usually towards the wetland. This indicates that ground-water, if available, will be moving into the wetland from a high gradient system, and that the surrounding area may be a source for long-term ground-water input into the wetland system. However, most of the Southern Rocky Mountain wetlands have moderate to low slope gradients where the wetlands connect to nearby streams or topographically low areas. This indicates that ground-water, if available, will be moving from the wetland to the river or surrounding areas. The maps generated in this step will provide the areas within the wetland where the ground-water movement, ground-water interception, and ground-water out functions occur with respect to the ground-water saturated zone system. In addition, the surface water system wetland functions of energy dissipation and surface water storage - both long-term and dynamic, can be analyzed during this step.

2.1.6 Step 1f: Animal Activity Characterization

Animal, specifically beaver, activity observed on-site and in the surrounding area is used to determine the hydrologic changes in either the ground-water flow or chemistry (for example, water table changes), or surface water flow or chemistry. Where beaver dams have been constructed, the wetland **functions** of **surface water storage long-term** and **energy dissipation** are observed (Table 2.1). These functions represent surface water system storage.

The type and spatial distribution of beaver activity that alters surface water systems should be mapped for the wetland. In the southern Rocky Mountains, beaver activity is profound, and significantly alters classes and subclasses of wetlands. This map will provide the areas within the wetland where the surface water storage functions occur, and may be interpreted for areas of recharge to the ground-water saturated zone.

2.2 Step 2: Subsurface Characterization

The purpose of the subsurface characterization step is to further understand the spatial and temporal nature of the three-dimensional structure of the wetland system, and to understand the material properties with regards to fluid flow and chemical transport in the ground-water system that supports the wetland. In addition, the wetland **functions** pertaining to **ground-water storage long term, ground-water storage dynamic,** and **ground-water movement** are determined, and **functions** pertaining to **ground-water interception, surface water storage-long term, surface water storage dynamic,** and **energy dissipation** are refined. Subsurface characterization consists of evaluating the appropriate geomorphic deposits, geology, and hydrogeology associated with the wetland being evaluated. The anthropogenic aspects of the evaluation are included in these categories.

2.2.1 Step 2a: Geomorphologic Characterization

The type and distribution (three-dimensional nature) of geomorphologic deposits and landform features observed on-site and in the surrounding area of the wetland are determined in conjunction with the vegetation, soils, and topography. The stratigraphic nature of these deposits, if required, is determined by other direct (cores, etc.) or indirect (for example, geophysics) measurements. Where these geomorphologic deposits and landform features occur, and if the appropriate **hydric** soils, **hydrophytes**, and/or **surface water** is present (a **wetland** has been identified in the surface characterization step), then the wetland **functions** of **ground-water movement, ground-water storage-long term,** and **ground-water storage-dynamic** are observed (Table 2.1). These functions represent ground-water system transport and storage. In addition, the distribution of these geomorphologic deposits and landforms can be interpreted for microtopography, and be part of the wetland **functions** of **ground-water interception, surface water storage-long term, surface water storage dynamic,** and **energy dissipation.**

The type and spatial distribution of geomorphic deposits and landform features should be mapped and characterized for the wetland and surrounding area. The physical and chemical characteristics of the geomorphologic deposits, such as sorting or gradation, texture, and mineralogical composition, can be used to interpret hydrogeological and hydrochemical properties and the three-dimensional structure of the wetland. The depth or thickness of geomorphologic deposits will be variable due to the various processes and time of formation. In the southern Rocky Mountains, these deposits and landforms may be periglacial (stone nets, stone stripes, patterned ground, "depressional" water bodies), glacial (lateral, recessional, terminal, and medial moraines, till, moraine lacustrine material, tarns), fluvial (modern floodplains, terraces or outwash plains, lacustrine (oxbow lakes), or mass wasting (colluvium in various geometries, lacustrine deposits within colluvial hummocky topography). The geomorphologic deposits and landforms map can be interpreted to show the areas within the wetland where the ground-water movement, ground-water interception, ground-water out, and ground-water storage functions occur with respect to the ground-water saturated zone, and to show information regarding the microtopography and surface water system storage.

2.2.2 Step 2b: Geologic Characterization

The three-dimensional geologic framework observed on-site and in the surrounding area of the wetland is determined in conjunction with the surface and geomorphologic analysis. The stratigraphic and lithologic nature of these rocks, and the geologic structure can be determined by direct (mapping, cores, etc.) or indirect (for example, geophysics) measurements. If the appropriate **hydric** soils, **hydrophytes**, and/or **surface water** is present (a **wetland** has been identified in the surface characterization step), then the geologic bedrock and structure can be interpreted to derive the hydrogeology necessary for the wetland **functions** of **ground-water movement, ground-water interception, ground-water storage-long term,** and **ground-water storage-dynamic** (Table 2.1). These functions represent ground-water system transport and storage. In addition, the distribution of geologic lithology and structure can be interpreted for microtopography, and be part of the wetland **functions** of **surface water storage-long term, surface water storage dynamic,** and **energy dissipation.**

The three-dimensional geologic framework should be mapped and characterized for the wetland and surrounding area. The physical and chemical characteristics of the bedrock materials, such as sorting or gradation, texture, and mineralogical composition, can be used to interpret hydrogeological and hydrochemical properties and the three-dimensional structure of the wetland. The depth or thickness of geologic units will be variable due to the various processes and time of formation. In the southern Rocky Mountains, most types of lithologic materials exist, including crystalline metamorphic and intrusive igneous rocks, and stratified sedimentary (including karst) and volcanic rocks. In addition, faults and fracture zones (derived by direct mapping or indirectly by a lineament analysis) are commonly observed. The bedrock geology and geologic structure map will be interpreted in the next step to show the areas within and around the wetland where the ground-water movement, ground-water interception, ground-water out, and ground-water storage functions occur with respect to the ground-water saturated zone, and to show information regarding the microtopography and surface water system storage.

2.2.3 Step 2c: Hydrogeologic Characterization

Hydrogeologic characterization is then performed to assess the important ground-water system features of the geologic and geomorphologic framework including aquifer permeability, type, homogeneity and heterogeneity, and isotropy and anisotropy. Hydrostratigraphic and hydrostructural units are determined and attributes, such as saturated thickness, hydraulic conductivity, storativity or specific yield, mode of flow (matrix or fracture flow), and geologic and topographic continuity, are evaluated. The hydrogeologic properties of the bedrock and unconsolidated deposits can be determined by direct (aquifer and slug tests, etc.) or indirect (for example, gravel texture, sorting, etc.) measurements. If the appropriate **hydric** soils, **hydrophytes**, and/or **surface water** are present (a **wetland** has been identified in the surface characterization step), then the hydrogeology can be used in the ground-water system analysis to derive wetland **functions** of **ground-water interception**, **ground-water movement, ground-water storage-long term,** and **ground-water storage-dynamic** (Table 2.1). Other functions, such as ground-water interception and ground-water out river or spring/seeps can be confirmed. These functions represent ground-water system transport and storage. In addition, the hydrogeology can be interpreted for the wetland **functions** of **surface water storage-long term, surface water storage dynamic,** and **energy dissipation**.

The three-dimensional hydrogeologic framework should be mapped and characterized for the wetland and surrounding area. The physical characteristics of the hydrogeologic units, such as hydraulic conductivity, specific yield or storage, and saturated thickness, can be used to interpret the overall ground-water flow system with regards to the three-dimensional structure of the wetland. In the southern Rocky Mountains, most types of hydrogeologic units and characteristic flow properties exist, including crystalline metamorphic and intrusive igneous rocks with fracture flow properties, crystalline limestone rock with or without karst properties, stratified sedimentary units such as sandstones that may have both matrix and fracture flow properties, stratified volcanic rocks such as tuffs and breccias, that may have fracture flow properties, and stratified shales or volcanic ashes that have very low permeability and porosity and function as ground-water system confining units. In addition, most types of hydrostructural units and characteristic flow properties exist, including normal and reverse faults, regional and local-scale fracture zones, folding, and igneous contact zones. Ground-water movement will be influenced by these features, for example by enhanced flow regimes seen in fracture zones, or by restricted flow when two hydrologically disparate units are moved together. The hydrogeologic units will be interpreted in the next step to show the areas within and around the wetland where the ground-water movement, ground-water interception, and ground-water storage functions occur with respect to the ground-water saturated zone, and to show information regarding the surface water system storage.

2.3. Step 3: Ground -Water System Characterization

The ground-water system of the wetland is now characterized using the hydrogeologic framework and attributes, and the surface characterization. This procedure involves the determination of type, amount, and distribution of recharge; type, amount, and distribution of discharge; flow path vectors; type and distribution of wetland boundary conditions; and potentiometric surfaces of the wetland aquifer units. The type, amount, and distribution of recharge to and discharge from a wetland ground-water unit can be determined by direct (rain gages, lysimeters, spring measurements, evapotranspiration, wells, etc.) or indirect (for example, vegetation analysis, soil textures, etc.) measurements. Flow path vectors, wetland boundary conditions, and potentiometric surface are determined by the interpretation of the recharge, discharge, and hydrogeologic data, and the interpretation of data gathered by direct measurements (such as head in a water well). If the appropriate **hydric** soils, **hydrophytes**, and/or **surface water** are present (a **wetland** has been identified in the surface characterization step), then the ground-water system analysis is used to derive wetland **functions** of **ground-water interception, ground-water movement, ground-water storage-long term,** and **ground-water storage-dynamic** (Table 2.1). These functions represent ground-water system transport and storage. In addition, the ground-water system can be interpreted for the wetland **functions** of **surface water storage-long term, surface water storage dynamic,** and **energy dissipation**.

The three-dimensional ground-water system should be mapped and characterized for the wetland units and surrounding area. The recharge, discharge, flow paths, boundary conditions, and potentiometric surface of each wetland aquifer unit can be used to interpret the overall ground-water flow system with regards to the three-dimensional structure of the wetland. In the southern Rocky Mountains, two types of ground-water flow paths are observed: predominantly horizontal and predominantly vertical. The critical horizontal flow paths are from the wetland to a river, from a river to the wetland, both to and from a river (spatially separated) with respect to the wetland, and from a bedrock source to the wetland. A fifth category of horizontal flow includes those wetlands that have flow paths to and from a river that vary seasonally with the river elevations and inundation cycles. The critical vertical flow paths are from deeper parts of the wetland through low K material (usually peat) to the surface, from the surface of the wetland through low K material to deeper parts of the wetland, or both up and down through the low K material depending on head distribution. A fourth category of vertical flow includes those wetlands that have both up and down flow paths through low K material based on seasonal variation. These flow path categories have significant implications regarding both hydrological and geochemical functions.

2.4 Step 4: Determine Class of Wetland System Based on Ground-Water System Assessment

In the southern Rocky Mountains, the two HGM classes of wetland systems observed, **based on this ground-water system assessment**, are **slope** and **riverine.**

2.4.1 Slope Wetland Systems

Slope wetland systems are defined as wetlands with return flow from groundwater being the dominant water source, and dominant hydrodynamics being horizontally unidirectional (Brinson et al. 1995). The primary **functions** of slope wetland systems, as derived from the ground-water system assessment, are **ground-water out river, ground-water springs/seeps, ground-water movement, ground-water interception,** and **ground-water storage-long term**. There are two subclasses of **slope** wetland systems that are observed in the southern Rocky Mountains: **peat-dominated** and **mineral-soil/geomorphic deposits/bedrock-dominated.**

2.4.1.1 Peat-dominated slope wetland subclass

The peat-dominated wetland is typically in a multi-layer system structure where the peat is the top hydrogeologic unit, and is underlain by either unconsolidated geomorphic deposits and/or bedrock. The geomorphic deposits, if present, usually form a second hydrogeologic unit, and the underlying bedrock may or may not form the third hydrogeologic unit in the stack. In some peat-dominated wetlands, the geomorphic deposit is the peat, and the bedrock is the underlying hydrogeologic unit in the stack. In rare cases, the peat is the only hydrogeologic unit developed on impermeable bedrock.

The significance of this wetland framework is in the hydrogeologic characteristics of peat. Peat is typically a low permeability unit, and has a great ability to store water for long periods of time. Surface water flowing on top of the peat tends to infiltrate very little, if the peat is saturated, and the water tends to leave the wetland downgradient. Ground-water flow within the peat tends to be vertical, and water will move slowly on an upward or downward flow path based on ground-water head. Ground-water in the underlying unconsolidated deposits and bedrock aquifers will tend to flow horizontally out of the wetland. However, small amounts of this water will flow into the peat if the ground-water head is favorable (head in lower units is higher than head in the peat). The important **functions** of this system are **ground-water interception, ground-water storage-long term, ground-water out springs/seeps,** and **ground-water movement** (specifically direction and velocity) as controlled by the peat.

The temporal nature of this wetland subclass is for subtle changes of ground-water head to exist based on the seasonal extent of surface water inundation by ground-water discharge. In the spring and summer months, surface water inundates the wetland causing the entire hydrogeologic stack to be saturated and connected. The net result is that small amounts of ground-water are moving downward through the peat to the underlying aquifers. From the fall through early spring, the surface water is greatly reduced, and the head gradients indicate upward flow from the underlying aquifers through the peat to the surface. This has implications with regards to chemical functions within the wetland.

2.4.1.2 Mineral-soil/geomorphic deposits/bedrock-dominated slope wetland subclass

The mineral-soil/geomorphic deposits/bedrock-dominated slope wetland is typically in a multi-layer wetland structure where peat is absent, discontinuous, or insignificant. The unconsolidated geomorphologic deposits are the top hydrogeologic unit, and are underlain by bedrock. The bedrock may be a second hydrogeologic unit in the stack, or may be a confining layer (two different types of systems). In some cases, the bedrock is the only hydrogeologic unit in which the wetland is developed.

The significance of this wetland subclass framework is in the hydrogeologic characteristics of the unconsolidated deposits and bedrock. Unconsolidated geomorphological deposits typically have high permeability and porosity, and have a great ability to store water for short periods of time. Surface water flowing on top of these deposits tend to infiltrate greatly, if the deposits are saturated, and the water tends to flow through the wetland downgradient. Ground-water flow within these deposits tends to be horizontal, and water will move rapidly on a more horizontal flow path based on ground-water head and nearby topography. Ground-water in the underlying bedrock aquifers will tend to flow horizontally with topography out of the wetland, as well. However, small amounts of this water will flow into the overlying unconsolidated aquifer if the ground-water head is favorable (head in lower units is higher than head in the geomorphologic deposits). A system with only bedrock will tend to behave similarly to a system with unconsolidated geomorphologic deposits except that ground-water velocities and storage will vary based on hydrogeologic unit. The important **functions** of this system are **ground-water interception, ground-water storage-long term, ground-water out springs/seeps and rivers,** and **ground-water movement** (specifically direction and velocity) as controlled by the unconsolidated geomorphologic deposits or bedrock. However, the ground-water interception function is greatly reduced due to the high hydraulic conductivity of the material.

The temporal nature of this wetland subclass is for subtle changes of ground-water head to exist based on the seasonal extent of surface water inundation by ground-water discharge. Most of these wetlands have very little surface water inundation, and the head gradients usually indicate upward flow from the underlying aquifers through the unconsolidated deposits to the surface. This has implications with regards to chemical functions within the wetland.

2.4.2 Riverine Wetland Systems

Riverine wetland systems are defined as wetlands with overbank flow from a channel being the dominant water source and dominant hydrodynamics being horizontally unidirectional (Brinson et al. 1993). The primary **functions** of riverine wetland systems, as derived from the ground-water system assessment, are **ground-water out river, ground-water movement, ground-water storage-dynamic**, and **ground-water storage-long term**. In addition, the ground-water system assessment is helpful for determining the **functions** of **surface water storage dynamic, surface water in,** and **energy dissipation**. There may be subclasses of **riverine** wetland systems in the southern Rocky Mountains based on wetland structure and hydrology. For example, most riverine wetlands are associated with modern alluvium deposited on bedrock. If the bedrock has a large hydraulic conductivity, such as a fractured sandstone, the function of the wetland is to further enhance ground-water storage-long term, ground-water movement, and ground-water out If the bedrock has a small hydraulic conductivity, or if the bedrock system has an upward gradient, these same functions are diminished. However, the reference sites necessary to delineate these subclasses have not been studied.

The riverine wetland is typically in a multi-layer system structure where the alluvium is the top hydrogeologic unit, and is underlain by either transmissive (underlying hydrogeologic unit) or non-transmissive (confining layer) bedrock. The significance of this wetland framework is in the hydrogeologic characteristics of alluvium and the proximity of the alluvium to the river. Alluvium is typically a high permeability unit, and has a great ability to store water for long periods of time. Surface water flowing on top of the alluvium, particularly during times of inundation by flooding, tends to infiltrate considerably and the water tends to move through the wetland aquifer down gradient to discharge back into the river or to recharge a deeper aquifer. Ground-water flow within the alluvium tends to be vertical near the surface (recharge), and water will move slowly on a downward flow path based on ground-water head. Ground-water in the underlying deeper alluvium will tend to flow horizontally out of the wetland back to the river. However, small amounts of this water will flow into deeper bedrock aquifers if the ground-water head is favorable (head in lower units is lower than head in the alluvium). The important **functions** of this system are **ground-water out river, ground-water movement, ground-water storage-dynamic**, and **ground-water storage-long term**. Ground-water movement (specifically direction and velocity) as controlled by the alluvium, and by the seasonal river levels.

The temporal nature of riverine wetlands is for substantial changes of ground-water head to exist based on the seasonal extent of surface water inundation by flooding or rising river levels. In the spring and summer months, surface water inundates parts of the wetland causing the entire hydrogeologic stack to be recharged. The net result is that ground-water will move downward through the near surface alluvium to deeper alluvium or to the underlying aquifers. From the fall through early spring, the surface water volume and levels are greatly reduced, and the head gradients may indicate upward flow from the underlying aquifers, or flow from aquifers connected laterally to the wetland. This has implications with regards to chemical functions within the wetland.

3.0 HYDROLOGIC CASE STUDIES

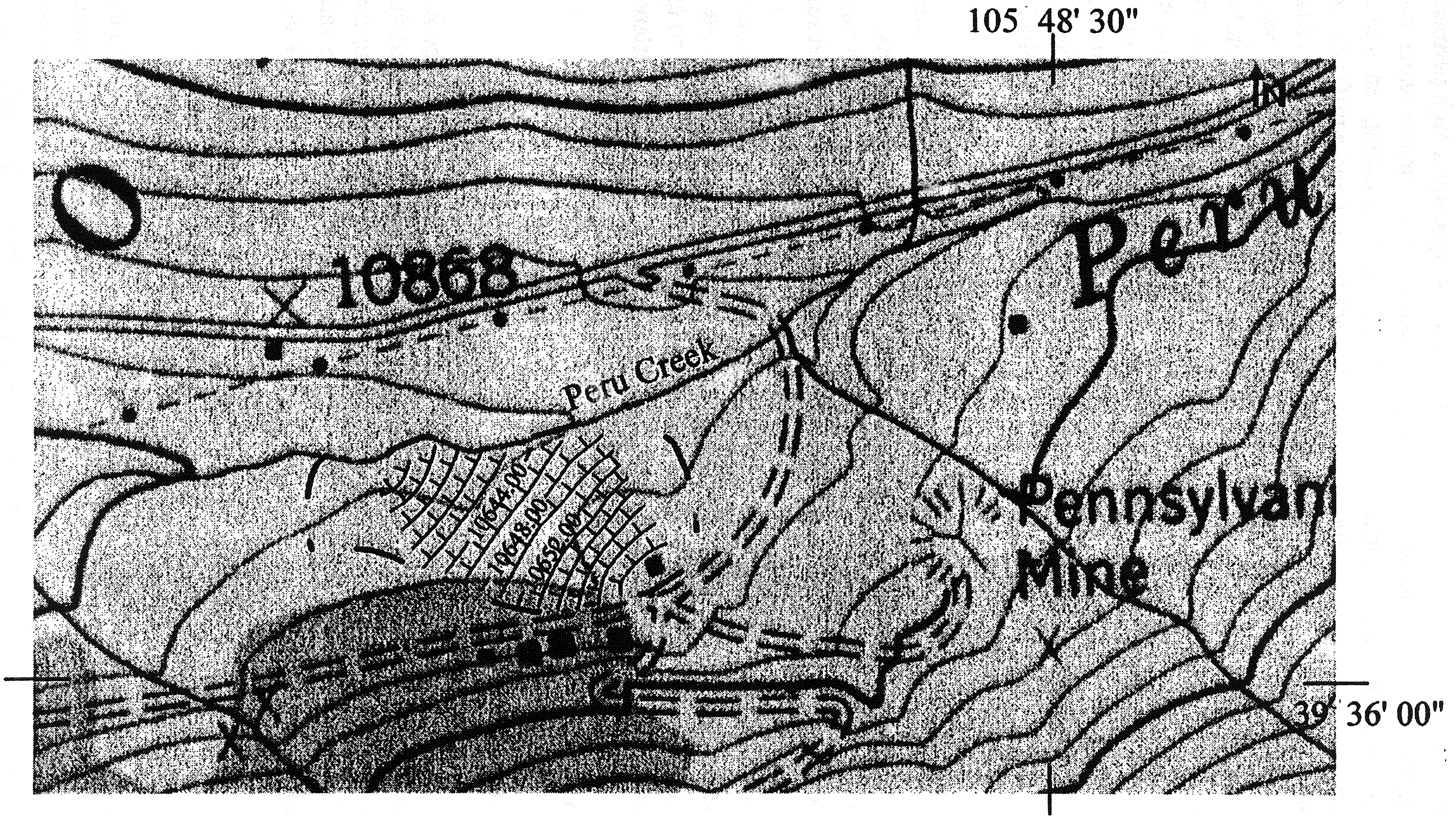
3.1 Peru Creek Wetland

The Peru Creek wetland system (T. 5 S., R. 76 W.) that was investigated in this study is located in the Peru Creek drainage basin, approximately 20 miles east of the town of Dillon, CO. The Pennsylvania Mine is near the base of Decatur Mountain at an elevation of 11,000 ft, and the wetland investigated in this study is located on the valley floor adjacent to the Pennsylvania Mine, and the southern edge of Peru Creek at 10,860 feet (Figure 3.1).

3.1.1 Vegetation Characterization

Vegetation data was obtained from Huskie (1987) and was field checked during on-site visits. The data and field work revealed that hydrophytes were observed to be continuous along the south side of Peru creek and intermittent along the north and west side. *Salix spp.* are the dominant species along the creek. The continuous presence of hydrophytes indicates that there is some continuity of ground-water levels along the

Figure 3.1 Location of Pennsylvania Mine Wetland. Potentiometric Surface in Colluvium on 8-04-97.



Contours Indicate 2.0 Foot Change. Hack Marks Indicate Downhill Direction.

creek. Hydrophytes are located south of Peru Creek and north of the site access road. Included in these wetland plants are *Decshampsia cespitosa* (tufted hairgrass), *Carex aquatilis* (sedge), and *Betula glandulosa* (bog birch). According to Huskie (1987), *D. cespitosa* is indicative of poorly drained soils and occurs where winter snow depths are greater than 2.5 feet. It grows on disturbed sites and is generally considered a pioneer species. In addition, tufted hairgrass has been determined by several researchers to be tolerant of heavy metals (Coulaud and NcNeilly 1992; Von Frenckell-Insam and Hutchinson 1993a; Von Frenckell-Insam and Hutchinson 1993b). The roots of *D. cespitosa* grow only in aerobic conditions, but their root mat contributes to anoxic conditions in deeper soil profiles. *D. cespitosa* are a successional species to *C. aquatilis* and generally found on deep accumulations of peat. Soil saturation has been found to range from standing water to deep water table conditions when *C. aquatilis* is present (Huskie 1987). The soils on which *B. glandulosa* are generally found have large accumulations of organic matter. When *B. glandulosa* is present, standing water in the spring and water tables near the soil surface throughout the summer are common (Fire Effects Information System 1998). These observations indicate that the wetland hydrologic function of **evapotranspiration** occurs, and that **ground-water movement** is governed locally by the vegetation (Table 2.1).

3.1.2 Soils Characterization

Peat is observed in the Peru Creek wetland. Initially, the vegetation species of *C. aquatilis* indicated that peat would be present. The spatial distribution (lateral and vertical extent) of the peat was estimated from the wells hand-augered in, and from published data (Huskie 1987). The presence and thickness of the peat, and the saturated nature of the peat, indicates that the wetland functions of **surface water storage dynamic, surface water storage long term, ground-water movement** (in this case, vertical movement), and **ground-water interception** are occurring (Table 2.1).

3.1.3 Surface Water Characterization

Peru Creek is a perennial stream topographically located on the downward side of the wetland. According to the data presented by Huskie (1987), the stretch of the Creek bordering the wetland site is gaining. This indicates that ground-water enters the surface water system at the wetland boundaries, and that the wetland function of **ground-water out river** occurs.

The second body of surface water present throughout the summer season was the surface water inundation of the wetland. Still water and overland flow across the eastern section of the wetland was noted. This surface water was stagnant in places due to the microtopography of the wetland, but was, in general, flowing towards Peru Creek. The source of the overland flow and still water was ground-water springs and seeps. The presence of these springs and seeps indicated the wetland functions of **surface water in and ground-water out-springs/seepss**. The presence of still water indicated the wetland functions of **ground-water out-springs/seeps and surface water storage long term,** and the presence of overland flow exiting the wetland indicates the function of **surface water out.**

Anthropogenic surface water features include settling ponds associated with the mine, and channeled trenches along the side of the wetland. Water is present year round in both of these features. An inspection of these ponds and trenches indicated that they leak and, therefore, contribute to surface water inputs into the wetland. Ground-water was noted to daylight near the entrance to the ponds. These anthropogenic features contribute to the wetland functions of **ground-water storage long term** and **ground-water movement**. In addition, these features may be sources for metals and other chemicals (for example, sulfates) into the wetland.

3.1.4 Climate

Precipitation and evaporation data was collected from the Dillon 1E weather station (elevation: 9,080 ft.) and was accessed through the National Weather Service Western region home page at http://wrcc.sage.dri.edu. It is expected that the values for precipitation will be higher and temperature will be lower at the Peru Creek site due to the differences in elevation.

The average annual precipitation over a 90 year period is 16.36"/yr as rain and 131.3"/yr as snowfall at Dillon 1E. According to Fetter (1988), total precipitation (snow and rain) can be estimated to be 29.49"/yr. In order to correct for the differences in elevation between the wetland site and the weather station, total precipitation was estimated to be approximately 40"/yr at the Peru Creek wetland.

On the average, snowfall occurs every month of the year except July and August. The majority of precipitation is in the form of snow from November to April at Dillon 1E. The average maximum and minimum temperature at Dillon 1E are 51.8°F and 16.36°F respectively (Appendix C.1b). During the 1997 sampling season, precipitation at Dillon 1E was greatest during late May and early June. A second peak is present from August through September (Appendix C.1c).

The precipitation indicates that a net amount of atmospheric water may be available for infiltration and recharge into the aquifers associated with the Peru Creek wetland. This indicates that the wetland functions of **atmosphere in** and **evapotranspiration** occurs.

3.1.5 Topographic Characterization

A 1:24:000 topographic map of the Montezuma, CO quadrangle (USGS 1958) was used, in conjunction with field observations, to determine slope gradient, slope elevation, microtopography, and drainage locations, patterns, and density. The site elevation ranged from approximately 10,880 ft on the southeast portion of the wetland to approximately 10,025 ft at Peru Creek at the northwest corner of the site. The mountains immediately adjacent to the wetland reach up to 12,890 ft in elevation. The site is divided into two topographic regions. Along the valley floor, where the wetland is located, the slope gradient is 0-2% generally toward the stream indicating that water is recharged and that soil (including peat) formation is a dominant geomorphic process. There is also microtopography that stores water on the wetland surface. Together, this indicates that the wetland functions of **ground-water movement, ground-water storage long term, ground-water storage dynamic, ground-water out river, surface water storage dynamic, surface water storage long term,** and **energy dissipation** occur.

The mountainous terrain surrounding the site slopes towards the wetland and river, and the slope gradients are greater than 2%. If this terrain has a ground-water system associated with it, the water will move towards and into the wetland system. Therefore, the wetland functions of **ground-water interception, ground-water movement,** and **ground-water out river** occur.

3.1.6 Animals Characterization

There was no apparent recent activity by beaver at the Peru Creek site. The main alteration of surface water activity was due to human activity (primarily mining related).

3.1.7 Geomorphologic and Geologic Characterization

The geomorphic deposits observed on-site include glacial moraines, colluvium, and weathering/pedogenic materials (primarily mineral soil and peat). Currently, the glacial materials are moving down slope under mass wasting processes to form modern colluvial deposits. The wetland is actually formed in a topographically flat area on top of colluvial deposits. The geomorphic material of peat is observed to be lying on top of the colluvium (Figure 3.2).

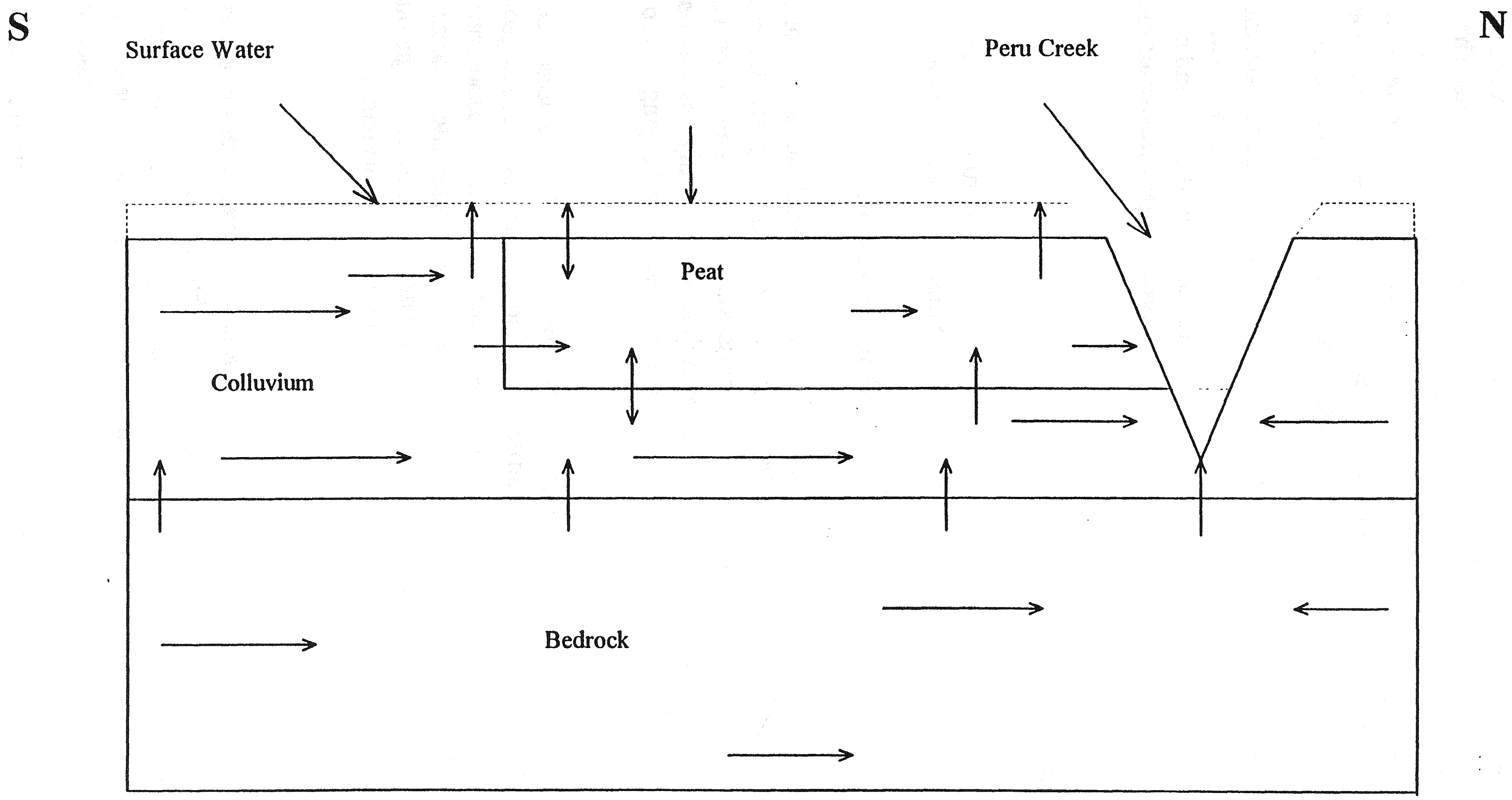
A 1:31,680 Geologic map (Neuerburg and Botinelly 1972) was used, in conjunction with field observations, to determine structural geologic features, bedrock geology, and mineralization locations and type. The hydrothermally altered Idaho Springs formation is the dominant bedrock geology lying underneath the wetland site. The zone of alteration is located along the southeastern corner of the site. In addition, an igneous contact zone forms the western boundary in the bedrock underneath the wetland.

3.1.8 Hydrogeologic Characterization

The three dimensional structure of the wetland is believed to be composed of three hydrogeologic layers that are all water-bearing (Figure 3.2). The Idaho Springs Formation bedrock, with fracture flow predominating, is the bottom layer of the wetland. A thin colluvial layer, composed primarily of cobbles, overlies the crystalline bedrock. Peat overlies the colluvial hydrogeologic unit, and is the visible surface layer.

Estimates of hydraulic conductivity range from 10^{-3} to 10^{-5} cm/sec in the peat layer, 10^{2} to 10^{-2} cm/sec in the unconsolidated colluvial layer, and from 10^{-2} to 10^{-6} cm/sec in the

Figure 3.2 Hydrogeologic Model of Pennsylvania Mine Wetland. Arrows Indicate Direction of Ground-Water Inputs, Outputs and Flow.



bedrock layer (Huskie 1987; Domenico and Schwartz 1990). The colluvial deposits have the greatest hydraulic conductivity, and are expected to allow water to easily enter (porosity range from 2-36%), and to easily pass horizontally through via matrix flow.

Storativity was estimated for the colluvial gravels to be from 23 to 28 percent, and for the bedrock to be 10 percent. By comparison, the peat layer will have relatively high storativity and is estimated at 44 percent. Peat is water bearing, but the water is retained by the unit, and movement is slow. The majority of water movement through peat is expected to be vertical and water is removed from the system by evapotranspiration or/and replaced by ground-water from below or/and precipitation infiltrating from above.

The hydrothermally altered Idaho Springs formation is chiefly composed of clays. The storativity of this formation is expected to be significantly lower and porosity higher than the colluvial deposits. This geologic unit, where present, will be water bearing, but the yield is estimated to be low. However, the chemistry associated with this unit may significantly affect the chemistry observed in the wetland.

A final hydrogeologic unit, and a source of chemical contamination to the wetland, are mine tailings piles which are found on site. A portion of these tailings are unsaturated with respect to ground-water. However, infiltration of atmospheric water through these piles will alter both ground- and surface water quality. In addition, it is thought that some of these tailings are buried on-site, which will be affected by ground-water infiltration.

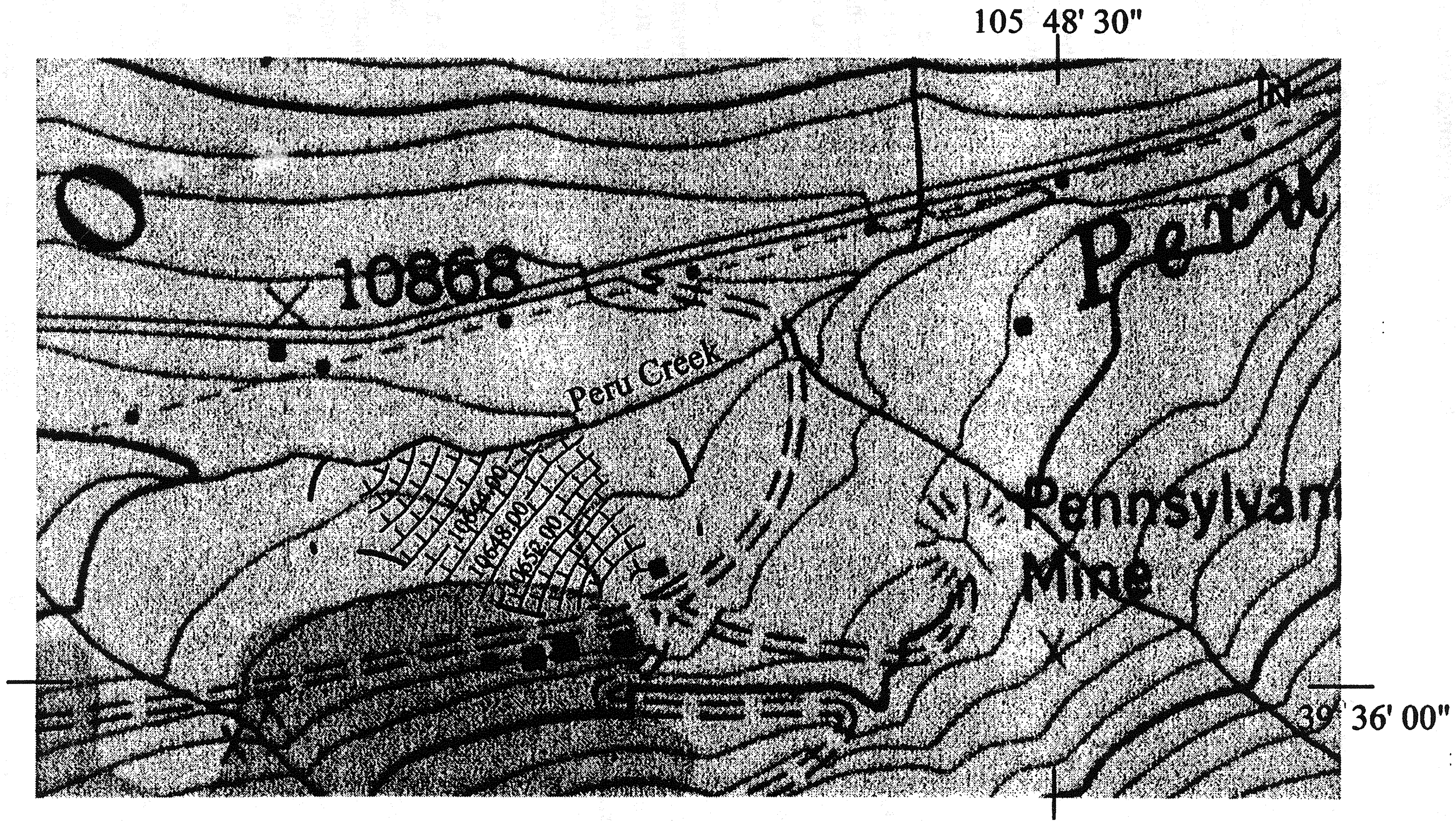
The hydrogeologic framework of the Peru Creek wetland directly affects the wetland functions of **ground-water movement, ground-water interception, ground-water storage long term, ground-water storage dynamic,** and **surface water storage dynamic.** The three-layered hydrogeologic system represents complex dynamics that are not easily assessed on a brief site visit.

3.1.9 Ground-Water System

Water levels were measured from shallow wells (including wells located in both colluvium and peat) on 6/12/97, 6/19/97, 8/4/97, 9/13/97, and 10/18/97. These water levels were analyzed for potentiometric surfaces for each separate hydrogeologic unit: colluvium (Figure 3.1) and peat (Figure 3.3), and seasonal and spatial comparisons were made (Figures 3.4 and 3.5). This analysis is used to confirm the proposed hydrologic functions.

Using the approach of Kolm (1993) and Kolm and van der Heijde (1996), combined with this paper, the ground-water system of the Peru Creek wetland was conceptualized to be in three components: the bedrock system, the colluvial system, and the peat system (Figure 3.2). Regional ground-water support for this wetland is derived from the crystalline bedrock system (Figure 3.2). The recharge to this system is from infiltration of precipitation in the upland mountain ridges and valley sides. The ground-water flow paths in this system are from topographically high areas to the valley bottoms and streams

Figure 3.3 Potentiometric Surface in Pennsylvania Mine Wetland in Peat on 8-04-97.



Contours Indicate 2.0 Foot Change. Hack Marks Indicate Downhill Direction.

Figure 3.4 Cross Section of Pennsylvania Mine Wetland on 6-19-97. Comparison of Heads in Peat and Colluvium During Spring Season.

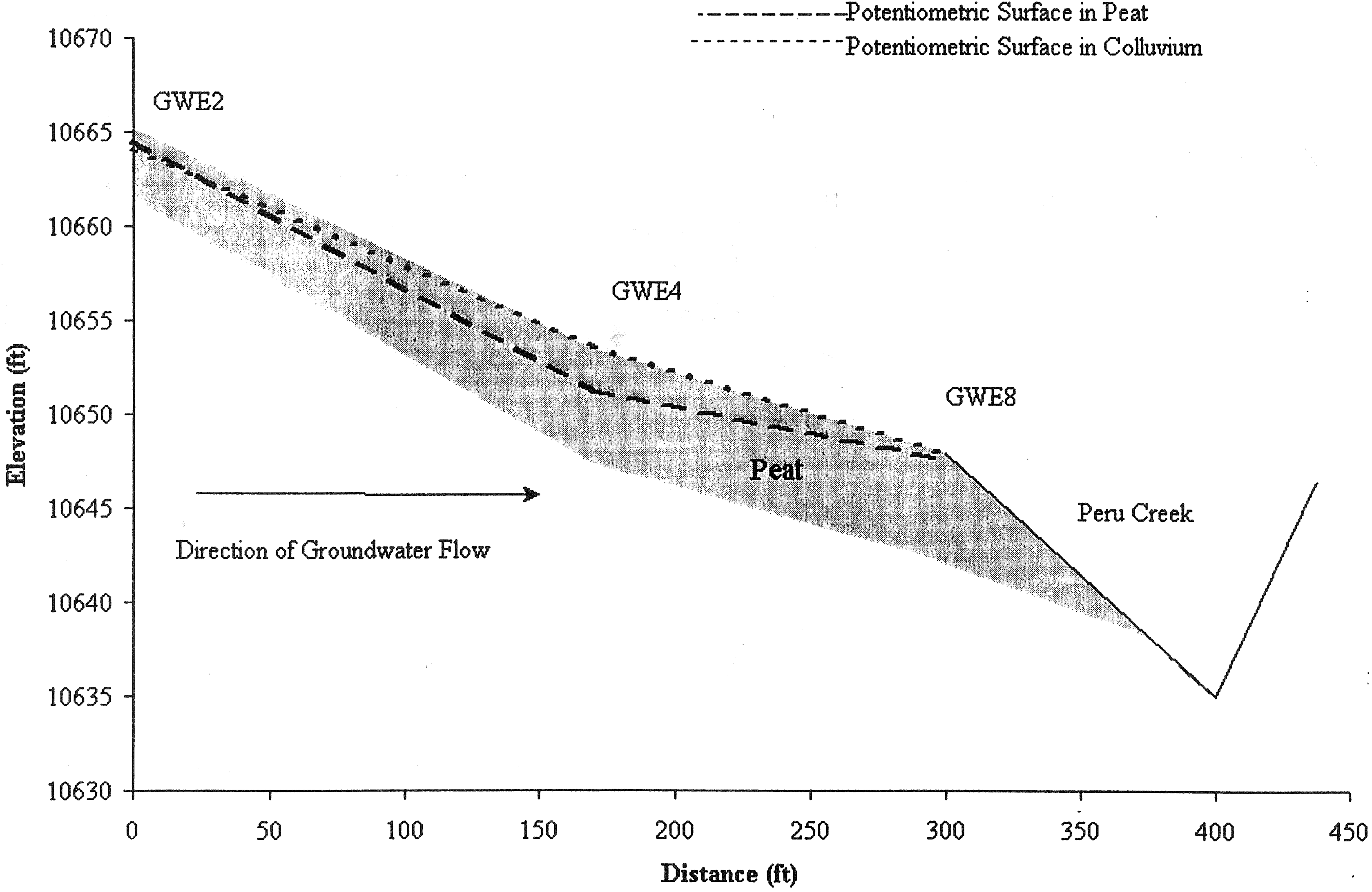
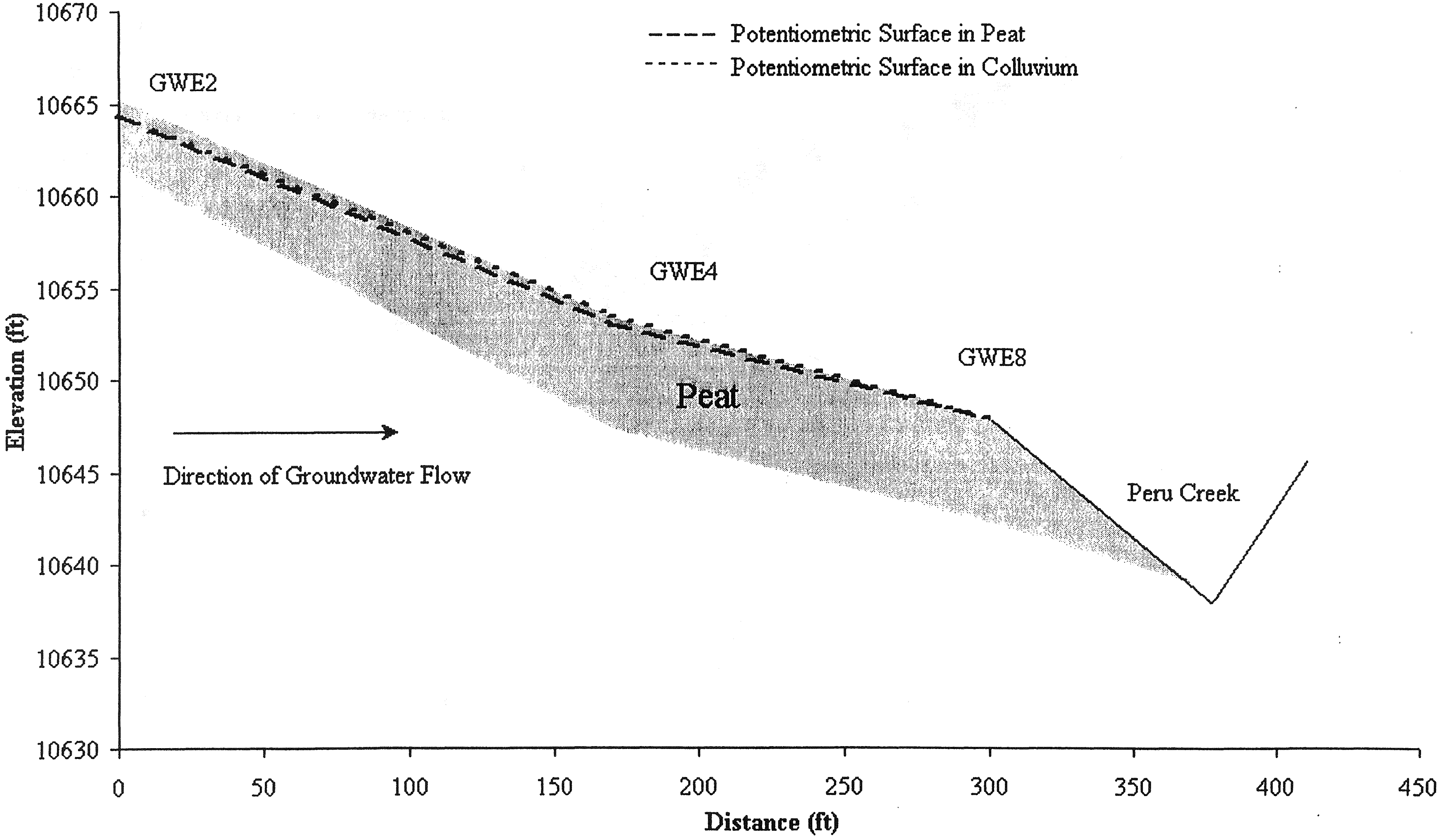


Figure 3.5 Cross Section of Pennsylvania Mine Wetland on 8-04-97. Comparison of Heads in Peat and Colluvium During Summer Season.



in the topographically low areas. The Peru Creek wetland is located between the regional recharge and discharge zones. Therefore, the bedrock ground-water system will discharge water on a long term basis into the colluvial system supporting the wetland.

The colluvial ground-water system is recharged by infiltration of precipitation and/or surface water inundation on the wetland surface, and by discharge from the bedrock system into the colluvial system (Figure 3.2). In general, the potentiometric surface interpreted from the heads observed in the colluvium show that the general flow direction is nearly horizontal from the topographically upgradient area to Peru Creek (Figure 3.1). In addition, the heads in the colluvium are generally greater that those in the peat indicating that the colluvial system discharges water vertically into the peat system (Figure 3.4). However, an analysis of seasonal effects show that during times of surface water inundation (6/19/97), the reverse is true in part of the upgradient area of the wetland (Figure 3.5). This indicates that ground-water from the peat system can vertically recharge the colluvial system during that time period in those parts of the wetland where the head in the peat system is greater than the head of the colluvial system.

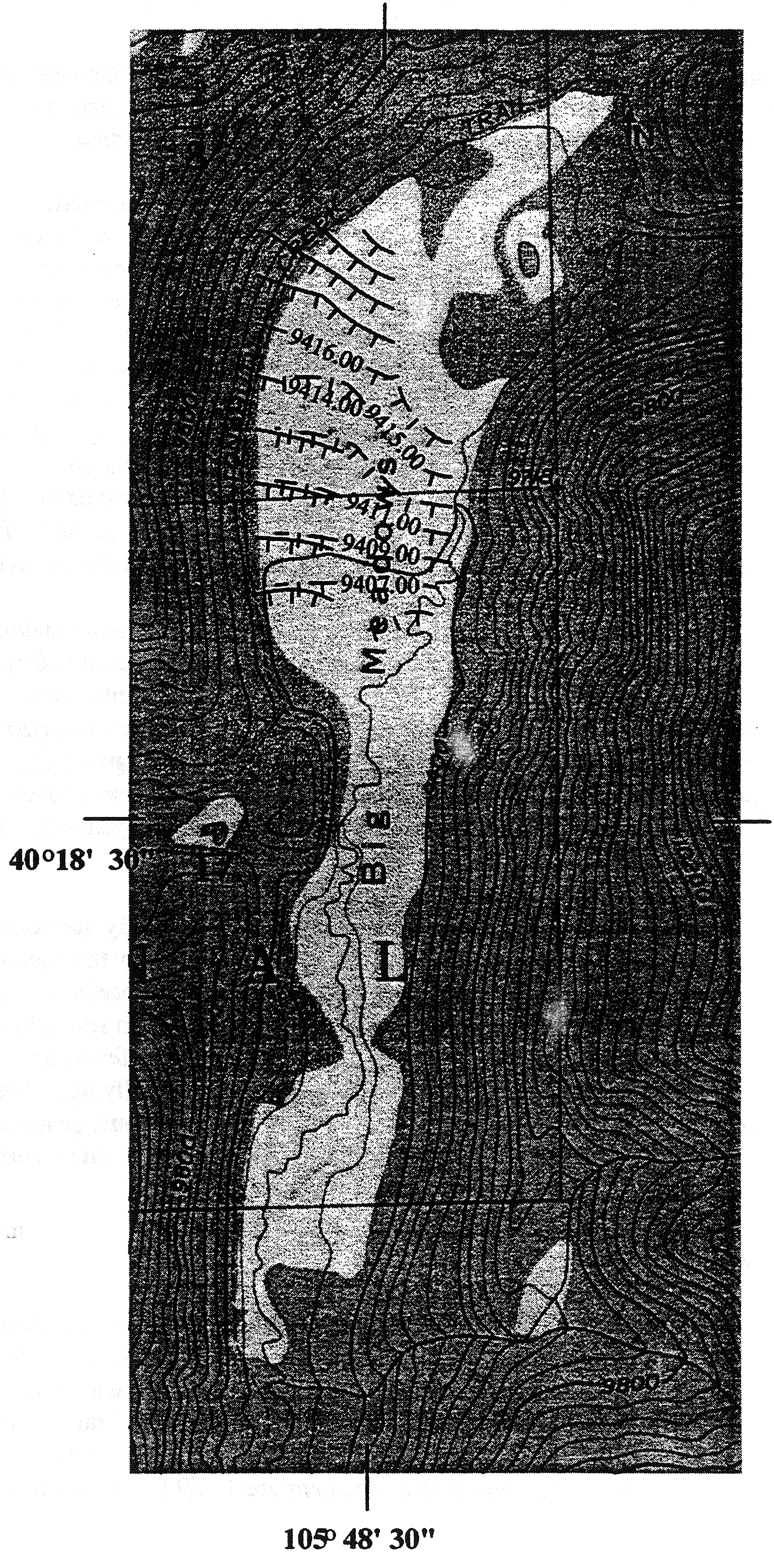
The peat ground-water system is recharged by infiltration of precipitation and/or surface water inundation on the wetland surface, and by discharge from the colluvial system into the peat system (Figure 3.2). In general, the potentiometric surface interpreted from the heads observed in the peat show that the general flow direction is nearly horizontal from the topographically upgradient area of the wetland to Peru Creek (Figure 3.3). However, the low hydraulic conductivity of the peat, and the agreement of the peat heads with the surface water elevations indicate that vertical flow upward from the peat system into the surface water is the dominant process.

In summary, ground-water movement was determined to move mostly horizontally through the colluvium from the bedrock source to the river, vertically through the peat from the colluvium to the surface water inundating the wetland surface, and seasonally to and from the peat to the colluvium based on surface water inundation levels in the upgradient part of the wetland. Ground-water from the bedrock aquifer recharges the surficial units regardless of season (ground-water movement vertically up). The analysis confirms that the ground-water functions of **ground-water movement, ground-water storage long term, ground-water storage dynamic, ground-water interception** and **surface water storage dynamic** occur in this wetland.

3.2 Big Meadows Wetland

The Big Meadows wetland, located in Rocky Mountain National Park, Colorado, is the second slope reference site chosen for this study (S. 8 and 17, T. 4 N., R. 75 W.) (Figure 3.6). The wetland is part of the Tonahutu Creek basin. Tonahutu Creek flows along the eastern edge of Big Meadows and into Grand Lake near the town of Grand Lake, CO. The elevation of the wetland is approximately 9,400 feet. A survey conducted by Shuter (1988) indicated that the dimensions of Big Meadows are 1,759 feet wide (east to west)

Figure 3.6 Location of Big Meadows Wetland.
Potentiometric Surface on 8-12-97.



Contours Indicate 2.0 Foot Change.
Hach Marks Indicate Downhill Direction.
- — Potentiometric Surface in Unconsolidated Layer
—— Potentiometric Surface in Peat

by 2,999 feet long (north to south). The wetland is surrounded by mountains ranging from 9,803 feet at the northeast to 11,424 feet at Mount Patterson to the east.

3.2.1 Vegetation Characterization

Vegetation data was obtained from an ecological study presented in Cooper (1990) and Bierly (1972), and was field checked. Cooper sampled vegetation stands at 60 stations which corresponded to some of the ground-water wells used in this study. Stand tables were created to demonstrate the floristic relations between vegetation stands.

In general, coniferous forests are observed on the topographic slopes surrounding the Big Meadows wetland. These forests consist of *Abies lasiocarpa* (Subalpine fir), *Picea engelmannii* (Engelmann spruce), *Pinus contorta* (Lodgepole pine), and minor amounts of *Populus tremuloides* (Quaking aspen) (Shuter 1988).

Species indicative of dry conditions are present on the tops of hummocks located near Tonahutu Creek. *D. cespitosa* and *A. corymbosa* communities were identified on the most mesic portions of the Big Meadows wetland.

On the valley floor, hydrophytic vegetation prevails. Along the western boundary of the wetland, *Salix planifolia* (planeleaf willow) and *Carex aquatilus* (water sedge) are most abundant. A small area of *Deschampsia cespitosa* (tufted hairgrass) and *Antennaria corymbosa* (pussytoes) was identified in the northwestern section of the wetland. The center of the wetland, west of the Horsetrail ditch, is dominated by *C. aquatilis and Psychrophila leptosepala* (marsh -marigold). The *S. planifolia* and *C. aquatilis* communities were characterizd by Cooper (1990) as being located where mineral-rich water from seeps keeps the ground-water table near the soil surface during early summer. This is supported by researchers who have described water tables where *S. planifolia* is present near the surface in the spring, and dropping to more than 39 inches below the surface by midsummer. In addition, the best water regime for *C. aquatilis* has been described as one where the water table is above ground in early June (Fire Effects Information System 1998). These observations indicate that the wetland hydrologic function of **evapotranspiration** occurs, and that **ground-water movement** is governed locally by the vegetation (Table 2.1).

3.2.2 Soils Characterization

Both mineral soils and peat exists in Big Meadows. The mineral soils were found to be adjacent to Tonahutu Creek. High organic soils are found west of the Horse Trail ditch and are most shallow along the western wetland boundary. The depth of peat generally increases to the south and to the east (Cooper 1990). The presence and thickness of the peat, and the saturated nature of the peat, indicates that the wetland functions of **ground-water movement** (in this case, vertical movement), **ground-water interception, ground-water storage long term and surface water storage dynamic** are occurring (Table 2.1).

3.2.3 Surface Water Characterization

Seeps and springs are observed along the north and west boundary of the Big Meadows wetland. The presence of these springs and seeps indicate the wetland function of **surface water in and ground-water out-springs/seeps**.

Overland flow is observed in the Big Meadows wetland. There are two sources of overland flow: seasonal flooding by a small channel that enters the wetland from the north, and springs and seeps that discharge to the surface along the north and west boundary of the wetland. Overland flow caused by seasonal flooding indicates the wetland functions of **surface water in, surface water storage dynamic, ground-water storage dynamic** and **energy dissipation.** Overland flow caused by springs and seeps indicate the wetland functions of **surface water out** and **ground-water out-springs/seeps** (Table 2.1).

Tonahutu Creek is a losing (northeast segment) and gaining (southeast segment) stream on the boundary of the Big Meadows wetland. The losing segment indicates the wetland functions of **ground-water storage long term, ground-water movement,** and **energy dissipation.** The gaining segment indicates that ground-water enters the surface water system at the wetland boundaries, and that the wetland function of **ground-water out-river** occurs.

Anthropogenic influences on the site include a ditch generally oriented from north to south through the middle of the wetland. This ditch, the Horse Trail Ditch, varies in depth from 15.2 to 61.0+ cm and in width from 20.3 to 91.4 cm (Shuter 1988) and is believed to intercept both ground and surface water and to act to channel the water out of the wetland. Specifically, the northern part of the ditch is losing, indicating the wetland functions of **ground-water storage long term** and **ground-water movement;** and the southern part of the ditch is gaining and exiting the wetland, indicating the wetland functions of **ground-water out-river** and **surface water out.**

Part of the wetland has still water due to microtopography. The presence of still water indicates the wetland functions of **ground-water out-springs/seeps** and **surface water storage long term**.

3.2.4 Climate Characterization

Precipitation data was recorded at the Grand Lake 1NW weather station and was accessed through the National Weather Service Western region home page at http://wrcc.sage.dri.edu. The historical climatic data for Grand Lake 1NW, station number 053496 is included as Appendix C.2. Grand Lake 1NW is located at latitude 40°16'N and longitude 105°50'W at an elevation of 8,681 feet. Cooper (1990) states that precipitation measured in Big Meadows during the summer of 1988 yielded similar results as those recorded at Grand Lake 1NW.

The highest mean precipitation over a 48 (1948 to 1996) year period is in August and July with 2.20 and 2.09 inches respectively. This peak corresponds with the predicted monsoon season. The lowest mean precipitation is in October and November with 1.30 and 1.37 inches respectively. Precipitation is predominantly in the form of snow from November through March, is approximately equal amounts of snow and rain in April, is predominately in the form of rain in May, June, September, and October, and is all rain in July and August (Appendix C.2b). In the summer of 1997, snow pack completely melted from the wetland edges between the dates of 6/10/97 and 6/24/97.

Precipitation and evaporation is observed for all 12 months of the year. This indicates that the wetland functions of **atmosphere in** and **evapotranspiration** occur at any time.

3.2.5 Topographic Characterization

1:24 000 topographic maps of the Fall River Pass, CO (USGS 1977) and the Grand Lake, CO quadrangles (USGS 1978) were used to determine elevations, and hydrography. The Big Meadows wetland is poorly dissected by surface water channels indicating that a continuous ground-water system is present in the subsurface.

According to Shuter (1988), the lateral topographic slope across Big Meadows from west to east is less than 0.1%. As a result, the wetland is an area of ground-water recharge or discharge, and soil/peat formation is the dominant physical process. The on-site wetland slope gradient indicates the wetland functions of **ground-water movement, ground-water storage dynamic, ground-water out-river, surface water storage dynamic, surface water storage long term, and energy dissipation.** The direction of the slope, from north to south, indicates the wetland function of **ground-water movement.** The gentle hummocky topography observed in the wetland indicates the wetland functions of **ground-water storage dynamic, surface water storage dynamic, surface water storage long term,** and **energy dissipation.**

The gradients of the slopes surrounding Big Meadows range from 2% to greater than 8%. Where the gradient is greater than 2%, the predicted path of surface water is sheetflow along the direction of the gradient. This water may act as a recharge to the wetland where gradients decrease. The predicted path of ground-water in the surrounding area is towards the wetland from all sides, or towards Tonahutu Creek. The steep boundary condition slope gradient indicates the wetlands functions of **ground-water interception, ground-water movement,** and **ground-water out-river.** The boundary slope direction into the wetland indicates the wetland functions of **ground-water interception, ground-water movement,** and **ground-water out-river.** The boundary slope direction into Tonahutu Creek indicates the wetland function of **ground-water out-river.**

3.2.6 Animals Characterization

There is no beaver activity observed at this site. Therefore, there is no wetland function associated with beaver activity occurring.

3.2.7 Geomorphologic and Geologic Characterization

A 1:50,000 Geologic map (Braddock and Cole 1990) was used to determine structural geology and geologic bedrock at the Big Meadows wetland site. A 1:500,000 Colorado map (USGS 1980) was used to determine large scale anomalous linear drainages. The reported depth to bedrock in Big Meadows ranges from 46 m in the southern section of the wetland (Shuter 1988) to 53 m (Braddock and Cole 1990).

The three dimensional shape of this wetland has been greatly affected by geomorphic processes. The glaciated valley provides a scoured bedrock surface. A dam at the valley outlet is believed to have been caused by terminal moraines. This created a lake which was eventually able to fill with lacustrine and fluvial sediments. Bierly (1972) states that the valley profile of Tonahutu Creek is typical of glacial valleys; the profile starts at the head of Tonahutu Creek at an elevation of 11,401 feet, flattens through Big Meadows and then drops rapidly again to Grand Lake. Meierding (1977) has described exposed lake sediments composed of gray-blue clay interlayed with peat in stream cuts in Big Meadows. Lateral moraine material of Pinedale age surrounds the wetland on the valley sides. The modern valley floor of Big Meadows is covered with Holocene-aged alluvium.

The bedrock underlying and surrounding the wetland area is Silver Plume Granite. The mineral composition of this formation is predominantly quartz, oligoclase, and microcline. Inclined schistosity occurs along the eastern and northeastern border of Big Meadows (Braddock and Cole 1990).

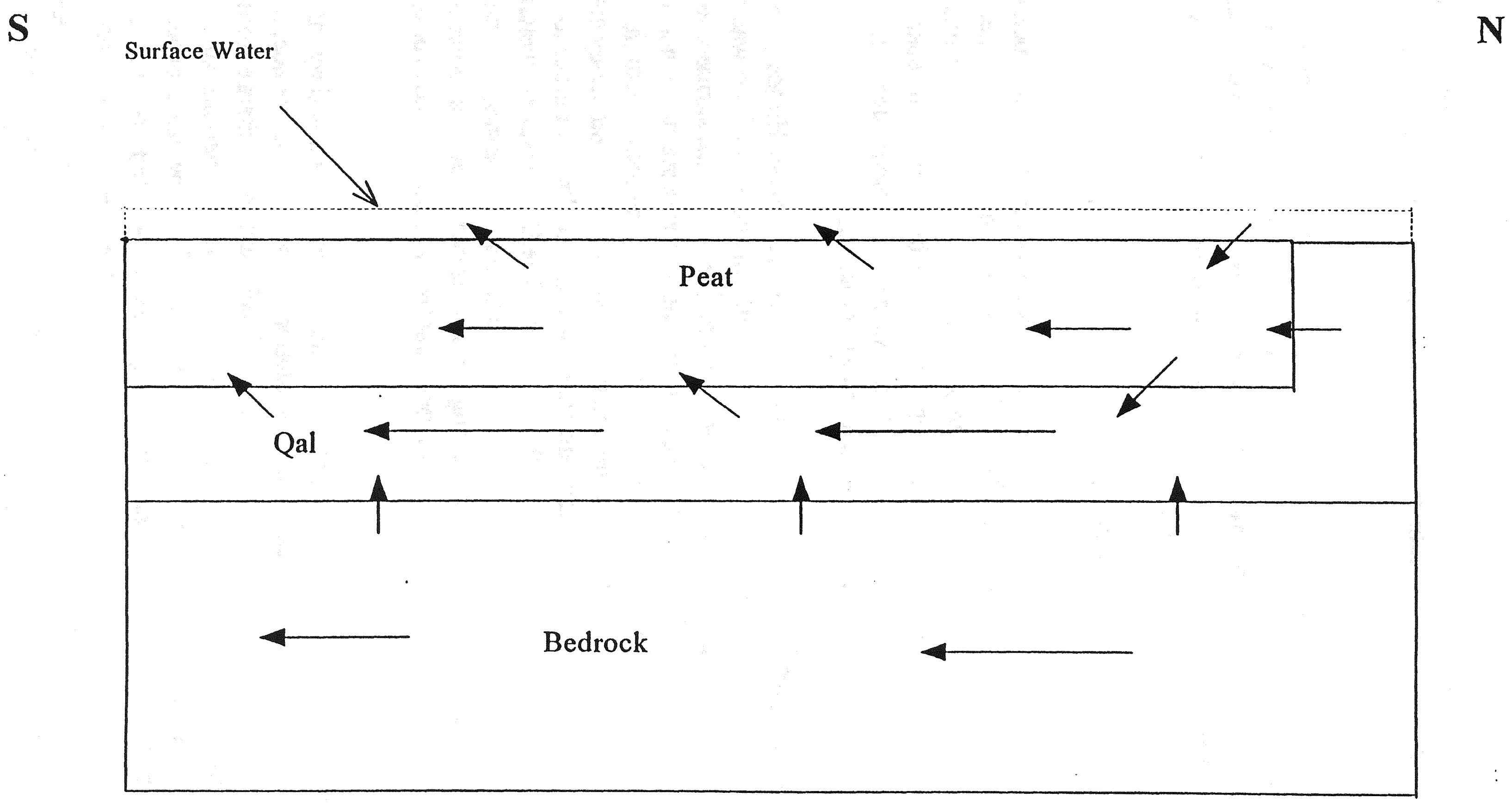
Two anomalous linear drainages were identified on the regional scale. A north to south one includes Tonahutu Creek in Big Meadows, the Arkansas River near Brown's Canyon, and St. Louis Creek, a tributary of the Frasier River near Tabernash, CO. The second anomalous linear drainage, an east to west one, includes the northern portion of Tonahutu Creek, the Yampa River, the Little Thompson River west of Bourthoud, CO, and the Republican River near Wray, CO.

3.2.8 Hydrogeologic Characterization

The three dimensional structure of the wetland is believed to be composed of at least three hydrogeologic layers that are all water-bearing (Figure 3.7). The Silver Plume Granite bedrock, with fracture flow predominating, is the bottom layer of the wetland. A thick glacial lacustrine/alluvial layer, composed primarily of unconsolidated cobbles, sands, silts, and clays, overlies the crystalline bedrock. Peat overlies most of the unconsolidated hydrogeologic unit, and is the visible surface layer.

The estimated hydraulic conductivity of this peat layer ranges from 10^{-3} to 10^{-5} cm/ sec and estimated Sy is 44 percent (Kolm 1993; Johnson 1967). Alluvium and glacial lacustrine material was found to underlie the peat and has an estimated hydraulic

Figure 3.7 Hydrogeologic Model of Big Meadows Wetland. Arrows Indicate Direction of Ground-Water Inputs, Outputs and Flow.



conductivity of 10^{-11} to 10^{2} and Sy of 3 to 23 percent (Kolm 1993). Clay lenses were also noted during the 1997 well installation activities.

In the crystalline bedrock, fracture flow would be the predicted mode of water flow. The estimated hydraulic conductivity of this bedrock layer ranges from 10^{-2} to 10^{-6} cm/sec (Kolm 1993).

The hydrogeologic framework of the Big Meadows wetland directly affects the wetland functions of **ground-water interception, ground-water movement, ground-water storage long term, ground-water storage dynamic,** and **surface water storage dynamic.** The three-layered hydrogeologic system represents complex dynamics that are not easily assessed on a brief site visit.

3.2.9 Ground-Water System

Water levels were measured from shallow wells (including wells located in both colluvium and peat) on 6/10/97, 6/25/97, 8/12/97, and 9/27/97. Other sources of Big Meadows ground-water system data include Cooper (1990) and Shuter (1988). These water levels were analyzed for potentiometric surfaces for each separate hydrogeologic unit (colluvium and peat), and seasonal and spatial comparisons were made. This analysis is used to confirm the proposed hydrologic functions.

Using the approach of Kolm (1993) and Kolm and van der Heijde (1996), combined with this paper, the ground-water system of the Big Meadows wetland was conceptualized to be in three components: the bedrock system, the glacial lacustrine/alluvial system, and the peat system (Figure 3.7). Regional ground-water support for this wetland is derived from the crystalline bedrock system (Figure 3.7). The recharge to this system is from infiltration of precipitation in the upland mountain ridges and valley sides. The ground-water flow paths in this system are from topographically high areas to the valley bottoms and streams in the topographically low areas. The Big Meadows wetland is located between the regional recharge and discharge zones. Therefore, the bedrock ground-water system will discharge water on a long term basis horizontally and vertically into the glacial lacustrine/alluvial system supporting the wetland, and horizontally into Tonahutu Creek.

The glacial lacustrine/alluvial ground-water system is recharged by infiltration of precipitation and/or surface water inundation on the wetland surface, by stream losses along the northern segments of Tonahutu Creek, and by discharge from the bedrock system horizontally and vertically into the glacial lacustrine/alluvial system (Figure 3.7). In general, the potentiometric surface interpreted from the heads observed in the glacial lacustrine/alluvial system show that the general flow direction is nearly horizontal from the topographically upgradient area near the northern end of the wetland, to the southern segments of Horse Trail Ditch and Tonahutu Creek (Figure 3.6). In addition, the heads in the glacial lacustrine/alluvial system are generally greater that those observed in the peat in the central and southern part of the system indicating that the glacial lacustrine/alluvial system discharges water vertically into the peat system at these locations. However, in the northern part of the wetland, the reverse is hypothesized to be true indicating that ground-water from the peat system can vertically recharge the glacial lacustrine/alluvial system in those parts of the wetland where the head in the peat system is greater than the head of the glacial lacustrine/alluvial system (Figure 3.6).

The peat ground-water system is recharged by infiltration of precipitation and/or surface water inundation on the wetland surface, by stream losses along the northern segments of the Horse Trail ditch, and by discharge from the glacial lacustrine/alluvial system into the peat system (Figure 3.7). In general, the potentiometric surface interpreted from the heads observed in the peat show that the general flow direction is nearly horizontal from the topographically upgradient area of the wetland to both the Horse Trail Ditch and Tonahutu Creek (Figure 3.6). However, the low hydraulic conductivity of the peat, and the comparison of the heads in the peat wells with the surface water elevations (heads in peat wells are greater than surface water elevations) indicate that vertical flow upward from the peat system into the surface water is the dominant process.

In summary, ground-water movement was determined to move mostly horizontally through the glacial lacustrine/alluvial material from both the bedrock and peat sources to Horse Trail Ditch and Tonahutu Creek, vertically through the peat from the glacial lacustrine/alluvial material to the surface water inundating the wetland surface in the central and southern part of the wetland, and vertically through the peat from the surface water to the glacial lacustrine/alluvial system in the northern part of the wetland. Ground-water from the bedrock aquifer recharges the surficial units regardless of season. The ground-water movement is vertically up and /or horizontally into the glacial lacustrine/alluvial system. The analysis confirms that the ground-water functions of **ground-water movement, ground-water storage long term, ground-water storage dynamic, ground-water interception** and **surface water storage dynamic** occur in this wetland.

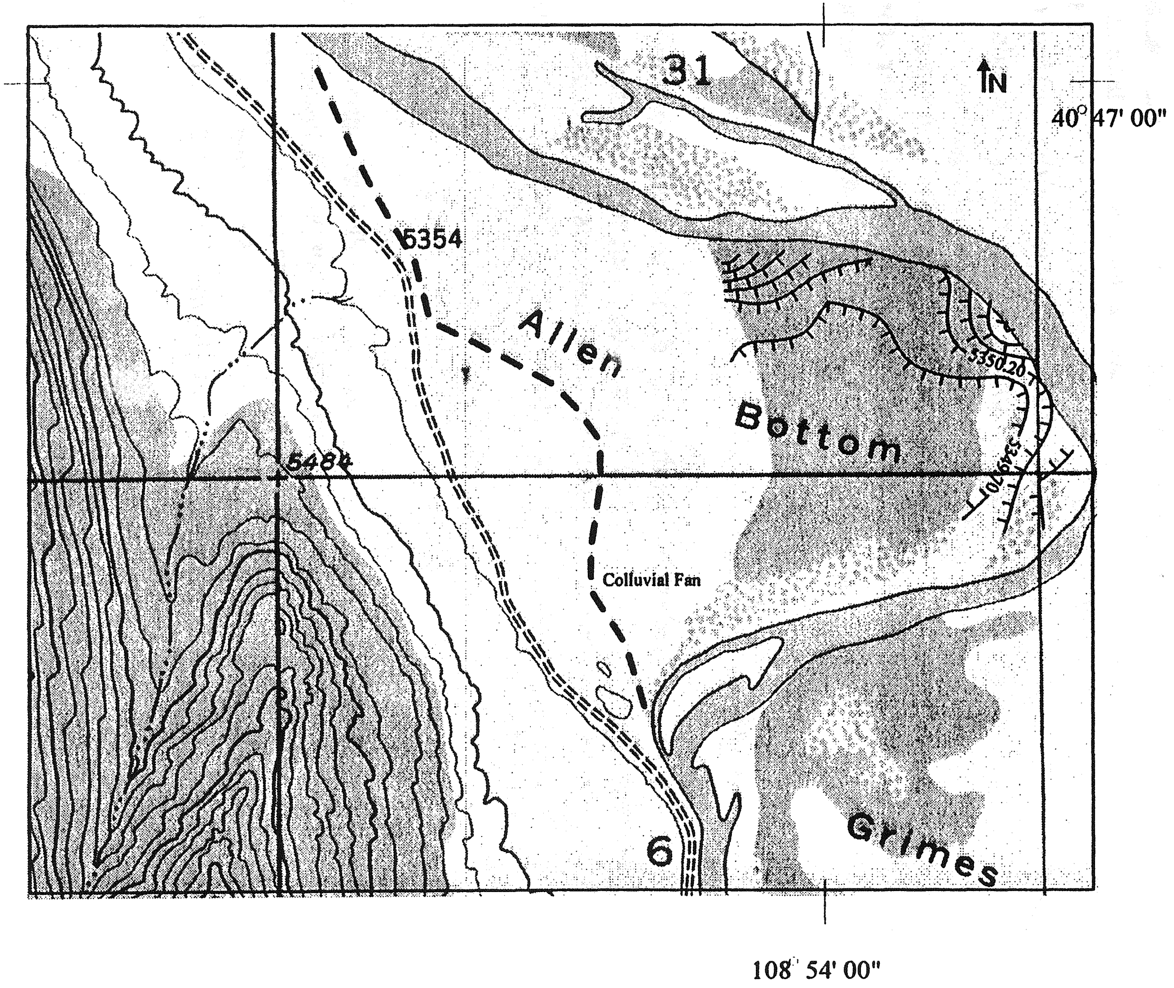
3.3 Browns Park Wetland

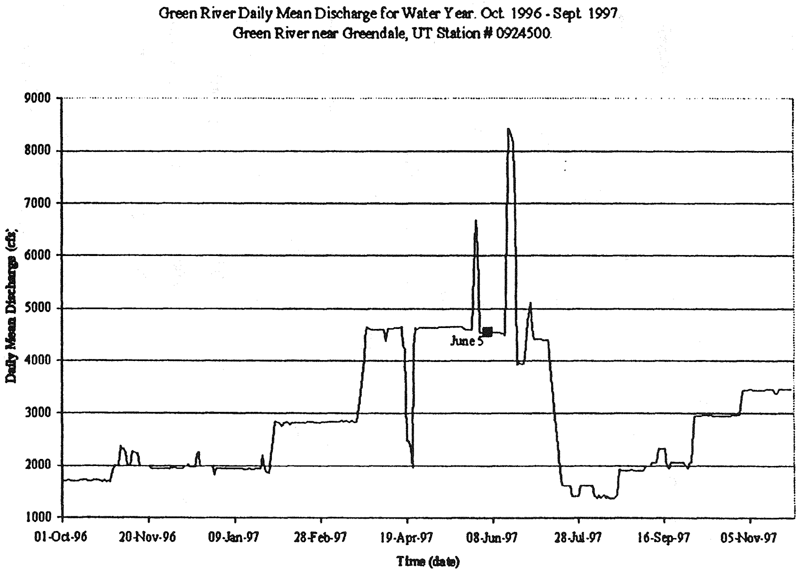
The Browns Park wetland, located on the south west side of the Green River near the Browns Park National Wildlife Refuge, northwestern Colorado, was chosen as a riverine reference site (Figure 3.8). The elevation of the wetland ranges is approximately 5,345 feet above sea level. The exact location of the wetland is S. 31 and 6, T. 10 N. and 9 N., R. 102 N.

3.3.1 Vegetation Characterization

Vegetation data was obtained from on-site visits and using NAPP aerial photography. The vegetation on-site is composed of *Populus deltoides* (cottonwood) and grasses. *P. angustifolia* is commonly found on alluvial benches adjacent to rivers which are periodically flooded, and grows well on gentle slopes within 1.5 to 6 feet of the permanent water table on thin, poorly developed sandy loam. Periodic flooding is

Figure 3.8 Location of Allen Bottom Wetland. Potentiometric Surface on 6-05-97 and Hydrograph of the Green River.




Green River Daily Mean Discharge for Water Year. Oct. 1996 - Sept. 1997.
Green River near Greendale, UT Station # 0924500.

Contours Indicate 0.5 Foot Change. Hach Marks Indicate Downhill Direction.

necessary to maintain the cottonwood communities (Fire Effects Information System 1998). In areas where overbank flooding still occurs, *Equisetum* arvense, which is indicative of wet conditions, was present (Weber and Wittman 1996). The channel which was inundated throughout the season was dominated by reeds and rushes. *Tamarix pentandra* (salt cedar) was common on the current floodplain. *Crysothamnus nauseosus* (rubber rabbitbrush) was present in thick stands on the northern edge of the wetland and was intermittently located throughout the middle of the wetland. These observations indicate that the wetland hydrologic function of **evapotranspiration** occurs, and that **ground-water movement** is governed locally by the vegetation (Table 2.1).

The areas surrounding the wetland grade from grasses, characterized by *Anisantha tectorum* (cheat grass) *and Hesperostipa comata* (needle and thread grass), to S*abina osteosperma* (Utah juniper) and *Pinus edulis* (pinyon pine). *A. tectorum* generally grows in the 6 to 22 inch precipitation zone and outcompetes native vegetation by utilizing most of the available upper soil moisture. *S. comata* grows well on dry, soils with low water-holding capacities. Average annual precipitation of *Sabina spp.* ranges from 10 to 13 inches (Fire Effects Information System 1998).

3.3.2 Soils Characterization

The soils observed on most of the wetland site are aerobic and are located in an unsaturated zone. Specifically, no peat or hydric soils are observed to be forming at this wetland. The soils may be serving as a conduit for infiltration and eventual recharge to the aquifer in the subsurface. Therefore, the mineral soils indicate the wetland functions of **ground-water storage dynamic** and **energy dissipation** are present.

3.3.3 Surface Water Characterization

There are no springs or seeps observed at the Browns Park wetland. There are springs observed in the uplands nearby. There are also no permanent bodies of still water to be observed.

The Green River is the only perennial surface water located along the northern, eastern, and southern boundary of the Browns Park wetland. The elevational change of the river along the wetland was estimated to be 2.0 feet per mile. The segment of river adjacent to the northern and eastern boundary of the wetland is predicted to be losing indicating the wetland functions of **ground-water storage long term, ground-water movement,** and **energy dissipation.** The segment of river adjacent to the northeastern boundary of the wetland is predicted to be gaining indicating the wetland function of **ground-water out-river.**

The Green River is controlled by the Flaming Gorge Dam approximately 41 miles north of Vernal, Utah. Water stage data was obtained for the 1997 water year. This hydrograph of the Green River is included as part of Figure 3.8. The peak present in late May was the result of a bypass release at Flaming Gorge followed by the possibility of unpredicted flooding downstream at Jensen, Utah. As a result of the possible flooding, the releases were suspended until mid June, visible as the second peak on the hydrograph (Ryan 1997).

A small part of the wetland was inundated throughout the sampling season. This abandoned channel was noted to be connected to the river with surface water. Signs of inundation during the two peak discharges on the Green river were noted on the newest floodplain on the southeastern portion of the wetland. The overland flow as the result of flooding indicates the wetland functions of **surface water in, surface water storage dynamic, ground-water storage dynamic,** and **energy dissipation.**

3.3.4 Climate Characterization

Historical precipitation data was collected from the Browns Park Refuge weather station (#051017) and was accessed through the National Weather Service Western region home page at http://wrcc.sage.dri.edu. Provisional precipitation data for 1997 was obtained from the Colorado State University, Department of Atmospheric Science.

The average annual precipitation over a 31 year period is 8.41"/yr as rain and 18.0"/yr as snowfall. The average maximum and minimum temperatures respectively are 63.4° F and 27.4° F. During the 1997 sampling season, precipitation at Browns Park was greatest during late September and early October. On the average, snowfall occurs every month of the year except during the summer months (June through September). With the exception of the month of December, snow does not accumulate (Appendix C.3b). Precipitation and evaporation can occur for all 12 months of the year. This indicates that the wetland functions of **atmosphere in** and **evapotranspiration** can occur.

3.3.5 Topographic Characterization

A 1:24,000 topographic map of the Lodore School, CO quadrangle (USGS 1954) was used to determine elevations and hydrography. The Browns Park wetland is poorly dissected by surface water channels indicating that a continuous ground-water system is present in the subsurface.

The lateral topographic slope across the Browns Park wetland from east to west is less than 2.0 %. As a result, the wetland is an area of ground-water recharge, and soil formation is the dominant physical process. The on-site wetland slope gradient indicates the wetland functions of **ground-water movement, ground-water storage dynamic, ground-water out-river, surface water storage dynamic,** and **energy dissipation.** The direction of the slope, from south to north on the southern boundary, and locally parallel to the river, indicates the wetland function of **ground-water movement.** The gentle hummocky meander scroll topography observed in the wetland indicates the wetland functions of **ground-water storage dynamic, surface water storage dynamic,** and **energy dissipation.**

The gradients of the slopes surrounding the Browns Park wetland are greater than 2%, and the predicted path of surface water is sheet flow along the direction of the gradient. This water may act as a recharge to the wetland during storm events. The predicted path of ground-water in the surrounding area is towards the wetland from the south, or towards the Green River. The steep boundary condition slope gradient indicates the wetlands function of **ground-water interception and ground-water movement.** The boundary slope direction into the wetland indicates the wetland functions of **ground-water interception.** The boundary slope direction towards the Green River indicates the wetland function of **ground-water out-river.**

3.3.6 Animals characterization

There is no beaver activity observed at this site. Therefore, there is no wetland function associated with beaver activity occurring.

3.3.7 Geomorphologic and Geologic Characterization

A 1:126,720 geologic map (Miller 1977) was used to determine geomorphology, structural geology, and geologic bedrock at the Browns Park site. The controlling of the Green River has had the largest impact on this wetland. By controlling the river levels, the processes of downcutting have been accelerated. A combination of the downcutting and the controlled river stages have resulted in decreased overbank flow to the wetland. As a result, new floodplains are being constructed, while old floodplains are abandoned to form terraces.

A history of fluvial processes are predominant throughout the wetland. Modern fluvial deposits are present on the surface near the staff gage on the southeastern section of the wetland. The presence of meander scrolls throughout the wetland may control hydrologic flow directions and velocities in the subsurface.

Two major sets of fractures are interpreted to be present in the area. The first set runs NE to SW and the second set runs NNE to SSW. These fracture zones are best identified by viewing aerial photography immediately to the SW of the wetland.

The quaternary alluvium located on the surface of the wetland is underlain by the Uinta Quartzite of precambrian age and the Tertiary aged Browns Park Formation. The Uinta Quartzite is crystalline and silica-rich. The crystalline nature has allowed fractures to be well preserved in the quartzite. By comparison, the Browns Park Formation is composed of sandstone, conglomerate, tuffaceous sandstone and siltstone. This unit is not crystalline and does not display great fracturing.

3.3.8 Hydrogeologic Characterization

The three dimensional structure of the Browns Park wetland is composed of two hydrogeologic layers that are water bearing. The Uinta Quartzite is the bedrock hydrogeologic unit that forms the bottom layer of the Browns Park wetland. The thick alluvium, composed of unconsolidated sand, silt, and clay, is the uppermost water-bearing hydrogeologic unit that is visible on the surface (Figure 3.9).

The hydraulic conductivity of the quaternary alluvium is estimated to range from 10^{-2} to 10^{-6} cm/sec. The soils near the surface of the wetland were found to vary with 29 to 95 percent sand, 0 to 30 percent clay, and 2 to 47 percent silt (Appendix A.3f). These variations are expected to result in varied hydraulic conductivities, ranging from 10 to 10^{-7} cm sec and variable storage values, ranging from 3 to 37 % for Sy.

The hydraulic conductivity of the quartzite is estimated to range from 10^{-2} to 10^{-6} cm/sec. Since this unit has a considerably lower hydraulic conductivity than the alluvium, it is anticipated that the wetland functions will be dominantly controlled by the upper hydrogeologic unit.

The hydrogeologic framework of the Browns Park wetland directly affects the wetland functions of **ground-water interception, ground-water movement, ground-water storage long term, ground-water storage dynamic,** and **surface water storage dynamic.** The two-layered hydrogeologic system represents complex dynamics that are not easily assessed on a brief site visit.

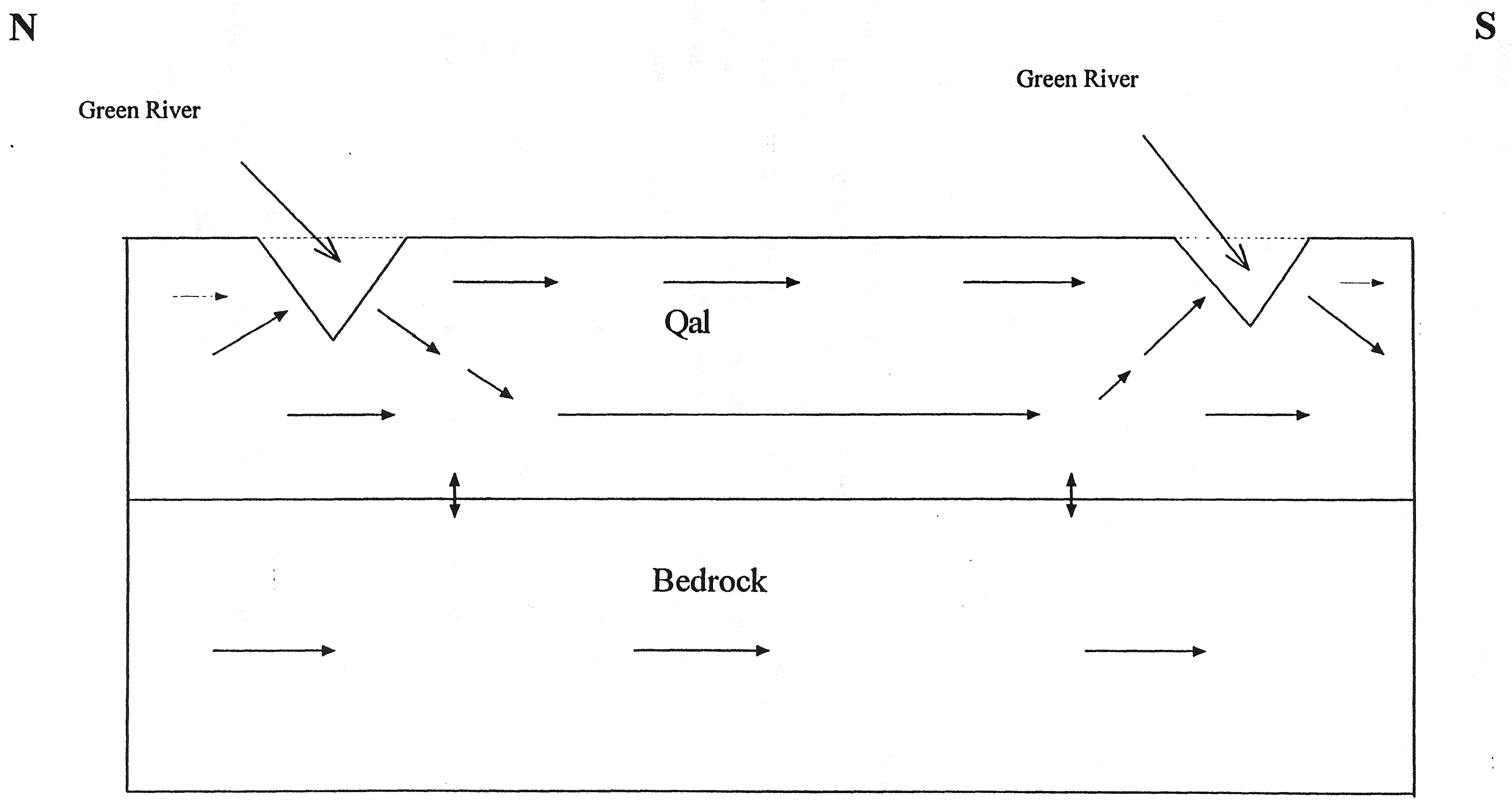
3.3.9 Ground-Water System

Water levels were measured from shallow wells in alluvium on 5/3/97, 5/21/97, 6/6/97, 7/22/97, and 10/31/97. These water levels were analyzed for potentiometric surfaces for the alluvial hydrogeologic unit, and seasonal and spatial comparisons were made. This analysis is used to confirm the proposed hydrologic functions.

Using the approach of Kolm (1993) and Kolm and van der Heijde (1996), combined with this paper, the ground-water system of the Browns Park wetland was conceptualized to be in two components: the bedrock system, and the alluvial system (Figure 3.9). Regional ground-water support for this wetland may be derived from the bedrock system, but measurements are not taken at this time to support this hypothesis (Figure 3.9). The recharge to this bedrock system is from infiltration of precipitation in the upland mountain ridges and valley sides. The ground-water flow paths in this system are from topographically high areas to the valley bottoms and streams in the topographically low areas, and ultimately to the Green River. The Browns Park wetland is located between the regional recharge and discharge zones. Therefore, the bedrock ground-water system will discharge water on a long term basis horizontally and vertically into the alluvial system supporting the wetland, and horizontally into the Green River. However, the amount of water contributed to this wetland is considerably less than water contributed directly by the seasonal fluctuations of the Green River.

The alluvial ground-water system is recharged by infiltration of precipitation and/or surface water inundation on the wetland surface, by stream losses along the northern,

Figure 3.9 Hydrogeologic Model of Allen Bottom Wetland. Arrows Indicate Direction of Ground-Water Inputs, Outputs and Flow.



eastern, and southeastern segments of Green River, and by discharge from the bedrock system horizontally and vertically into the alluvial system (Figure 3.9). In general, the potentiometric surface interpreted from the heads observed in the alluvial system show that the general flow direction is nearly horizontal from the Green River area along the northern, eastern, and southeastern area of the wetland, along the historical geomorphological meander scrolls in a westerly direction, to the southwestern segment of the Green River (Figure 3.8). This pattern correlated well with Green River flows that exceeded 3,000 cfs (Figure 3.8). However, during times of low flow, the wetland may function as a slope wetland, and the potentiometric surface may indicate that ground-water flows from bedrock ground-water sources through the alluvial system to all parts of the Green River (Figure 3.10). This would indicate that the alluvial fan and spring observed on the west side of the wetland delivers ground-water to the system that significantly affects the ground-water flow regime during low flow periods of the Green River.

It is also hypothesized that ground-water moves vertically to deeper levels of the alluvial system to connect to a large alluvial system involving both banks of the Green River. However, the sampling design was not constructed to verify this hypothesis.

In summary, ground-water movement was determined to move mostly horizontally to and from the Green River seasonally, to and from the Green River spatially, and from a deeper bedrock source to the alluvial deposits. It is hypothesized that the alluvial ground-water flow may move vertically into deeper parts of the alluvial system to and from the Green River. The analysis confirms that the ground-water functions of **ground-water movement, ground-water storage long term, ground-water storage dynamic, ground-water interception** and **surface water storage dynamic** occur in this wetland.

3.4 Deerlodge Wetland

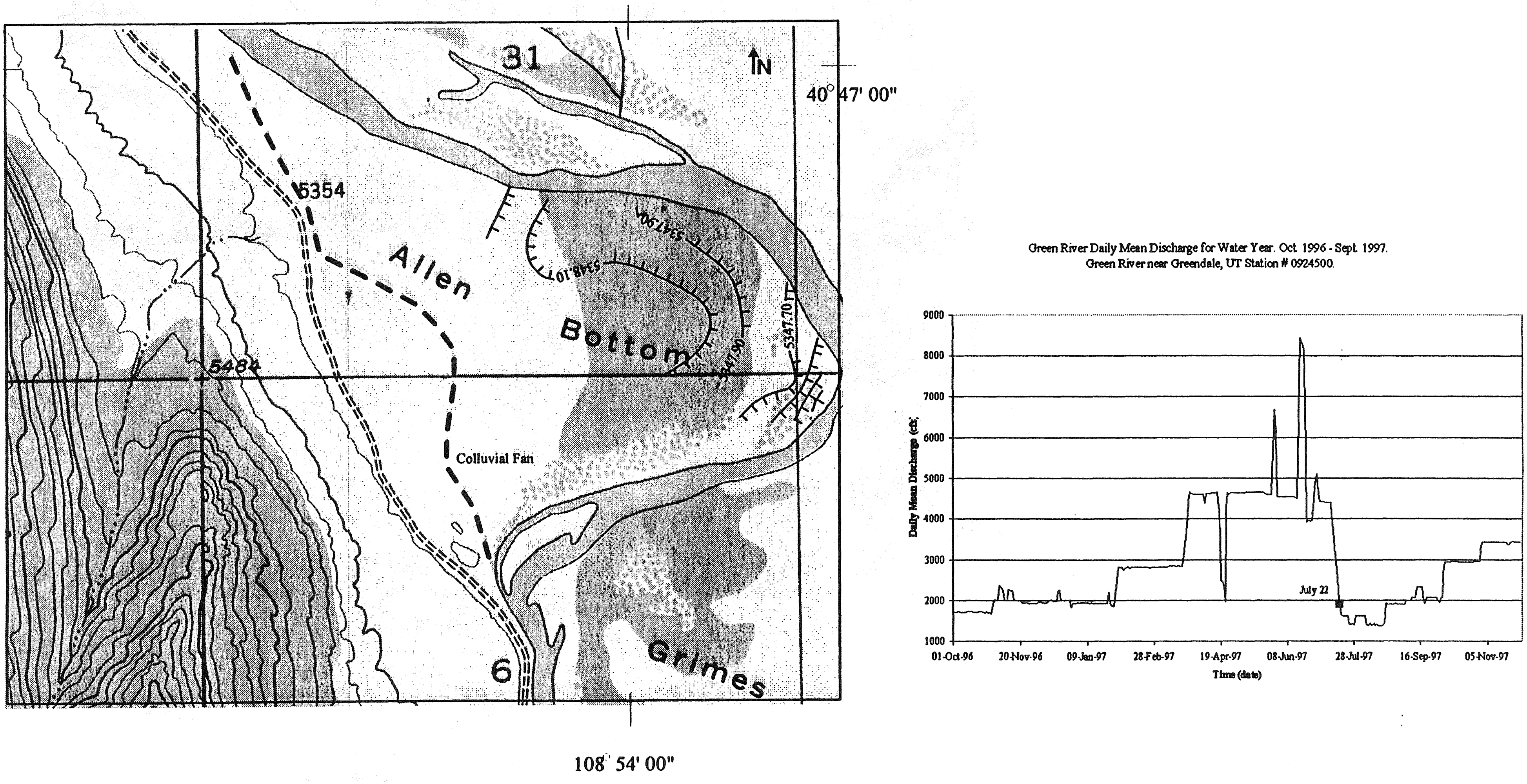
The Deerlodge wetland, located on the south side of the Yampa River in Dinosaur National Monument, northwest Colorado, was chosen as a riverine reference site (Figure 3.11). The elevation of the wetland is approximately 5,620 feet above sea level. The exact location of the wetland is S. 21, T. 6 N., R. 99 W.

3.4.1 Vegetation Characterization

Vegetation data was obtained from on-site visits and using NAPP aerial photography. The Deerlodge wetland is composed of *Populus deltoides* (cottonwoods) with an understory of grasses. These observations indicate that the wetland hydrologic function of **evapotranspiration** occurs, and that **ground-water movement** is governed locally by the vegetation (Table 2.1).

The vegetation surrounding the wetland ranges from *Sarcobatus vermiculatus* (black greasewood) and S*eriphidium tridentata* (big sagebrush) grading into S*abina osteosporum*. (juniper) and *Pinus edulis* (pinyon pine) on the steeper slopes. *Sarcobatus*

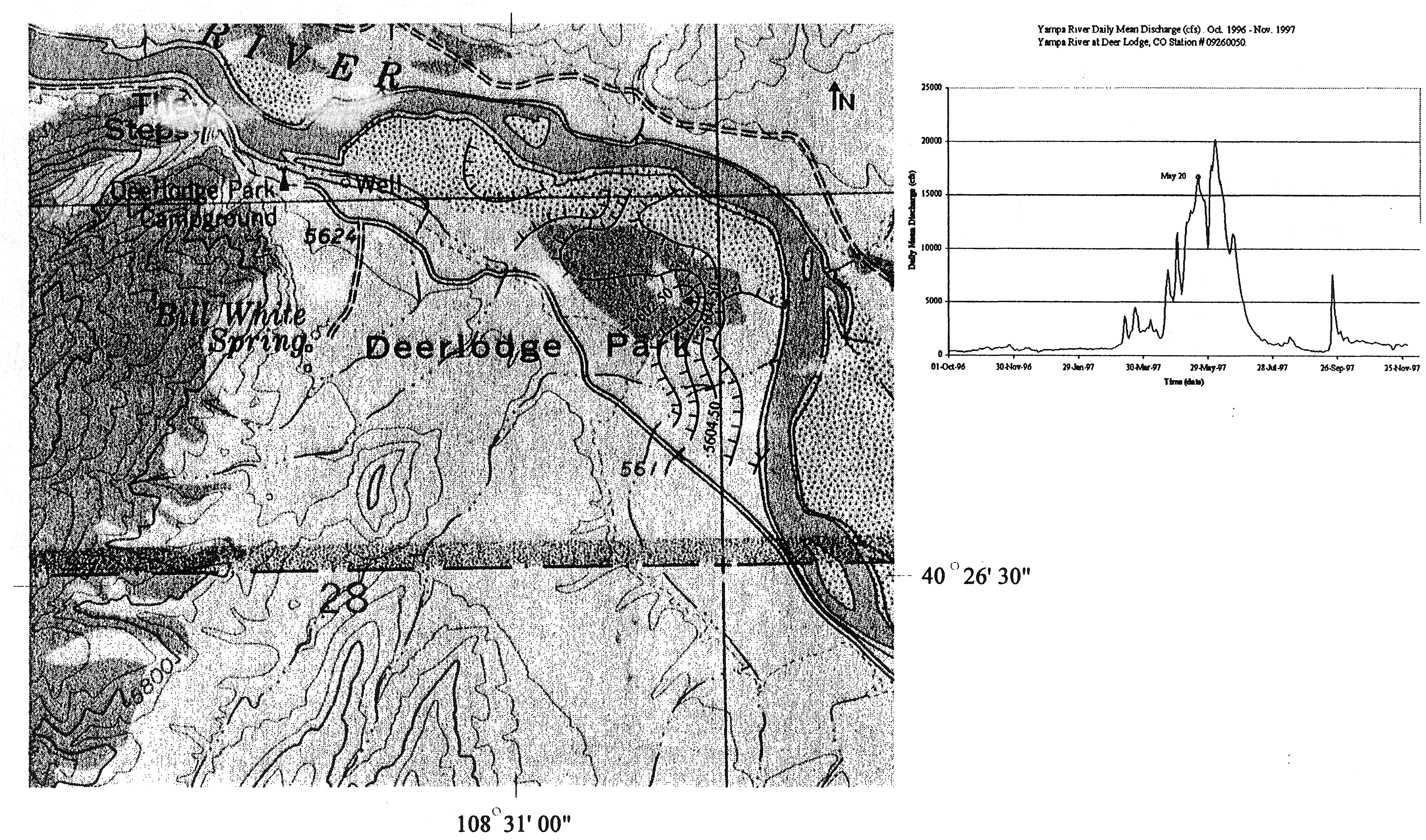
Figure 3.10 Potentiometric Surface on 7-22-97 and Hydrograph of the Green River.



Green River Daily Mean Discharge for Water Year. Oct 1996 - Sept 1997.
Green River near Greendale, UT Station # 0924500.

Contours Indicate 0.2 Foot Change. Hach Marks Indicate Downhill Direction.

Figure 3.11 Location of Deerlodge Wetland. Potentiometric Surface on 5-20-97 and Hydrograph of Yampa River.



Contours Indicate 1.0 Foot Change. Hach Marks Indicate Downhill Direction.

vermiculatus is present along the colluvial fan on the southern boundary of the wetland. *S. vermiculatus* is often considered an indicator of saline-sodic or relatively moist soils, and commonly occurs where a high water table is present seasonally with it ranging from 14.8 feet to 3.3 feet below the surface (Fire Effects Information System 1998). *Equisetum arvense* was present along the floodplain. These observations indicate that the wetland hydrologic function of **evapotranspiration** occurs, and that **ground-water movement** is governed locally by the vegetation (Table 2.1).

3.4.2 Soils Characterization

The soils observed on most of the wetland site are aerobic and are located in an unsaturated zone. Specifically, no peat or hydric soils are observed to be forming at this wetland. The mineral soils may be serving as a conduit for infiltration and eventual recharge to the aquifer in the subsurface. Therefore, the mineral soils indicate the wetland functions of **ground-water storage dynamic** and **energy dissipation** are present.

3.4.3 Surface Water Characterization

There are no springs or seeps observed at the Deerlodge wetland. There are also no permanent bodies of still water to be observed. The Yampa River is the only perennial surface water located along the northern and eastern boundary of the Deerlodge wetland. The elevational change of the river along the wetland was estimated to be 8.7 feet per mile. The segment of river adjacent to the northeastern boundary of the wetland is predicted to be losing indicating the wetland functions of **ground-water storage long term, ground-water movement,** and **energy dissipation.** The segment of river adjacent to the northwestern boundary of the wetland is predicted to be gaining indicating the wetland function of **ground-water out-river.**

The 1997 hydrograph of the Yampa River shows that two major peaks, which occurred in late May and early June, correspond to snow melt (Figure 3.11). The second peak in June was the result of heavy rains in the Yampa River basin on May 28 and May 29 followed by abnormally hot weather (Ryan 1997). The wetland was partially flooded during the May 20 sampling period. A third peak on the hydrograph occurs in late September; this corresponds to high precipitation inputs to the system (Figure 3.11). The overland flow as the result of flooding indicates the wetland functions of **surface water in, surface water storage dynamic, ground-water storage dynamic,** and **energy dissipation.**

Several drainages are present on the alluvial fan to the south and west of the wetland. These drainages are expected to provide channeled surface water flow during storm events. During these events, the wetland functions of **surface water in, ground-water storage dynamic,** and **energy dissipation** occur.

3.4.4 Climate Characterization

Historical precipitation data was collected from the Dinosaur National Monument station (# 52286) and the Maybell station (#55446). This data was accessed through the National Weather Service Western region home page at http://wrcc.sage.dri.edu. Precipitation data for 1997 was obtained from the Colorado State University, Department of Atmospheric Science.

The average annual precipitation over a 39 year period is 12.57"/yr as rain and 64.4"/yr as snowfall. The average maximum and minimum temperatures respectively are 59.7° F and 25.0° F. On the average, snowfall occurs every month of the year except during July and August. Average snow depths range from one inch in November to six inches in January; snow does not accumulate from April to October (Appendix C.4d). Precipitation and evaporation may occur for each month of the year. This indicates that the wetland functions of **atmosphere in** and **evapotranspiration** can occur.

3.4.5 Topographic Characterization

1:24,000 topographic map of the Indian Water Canyon, CO quadrangle (USGS 1962) was used to determine elevations and hydrography. The Deerlodge wetland is poorly dissected by surface water channels indicating that a continuous ground-water system is present in the subsurface.

The lateral topographic slope across the Deerlodge wetland from east to west is less than 2.0 %. As a result, the wetland is an area of ground-water recharge, and soil formation is the dominant physical process. The on-site wetland slope gradient indicates the wetland functions of **ground-water movement, ground-water storage dynamic, ground-water out-river, surface water storage dynamic,** and **energy dissipation.** The direction of the slope, from south to north on the southern boundary, and locally parallel to the river, indicates the wetland function of **ground-water movement.** The gentle hummocky meander scroll topography observed in the wetland indicates the wetland functions of **ground-water storage dynamic, surface water storage dynamic,** and **energy dissipation.**

The gradients of the slopes surrounding the Deerlodge wetland are greater than 2%, and the predicted path of surface water is sheet flow along the direction of the gradient. This water may act as a recharge to the wetland during storm events. The predicted path of ground-water in the surrounding area is towards the wetland from the south, or towards the Yampa River. The steep boundary condition slope gradient indicates the wetland functions of **ground-water interception** and **ground-water movement.** The boundary slope direction into the wetland indicates the wetland function of **ground-water interception.** The boundary slope direction towards the Yampa River indicates the wetland function of **ground-water out-river.**

3.4.6 Animals Characterization

There is no beaver activity observed at this site. Therefore, there is no wetland function associated with beaver activity occurring.

3.4.7 Geomorphologic and Geologic Characterization

A 1:50,000 geologic map (Hansen et al. 1983) was used to determine geomorphology, structural geology, and geologic bedrock at the Deerlodge wetland site. A history of fluvial processes are predominant throughout the wetland. Modern fluvial deposits are present on the surface near the western section of the wetland. Additionally, a sandbar is adjacent to the wetland. The presence of meander scrolls throughout the wetland may control hydrologic flow directions and velocities in the subsurface. An alluvial fan is present on the southern boundary of the wetland. This fan will be a source of ground-water recharge during flow events and will affect the wetland chemistry. The Quaternary alluvium located on the surface of the wetland is described by Hansen et al. (1983) as gravel sand and silt with a maximum thickness of a few tens of meters.

Cretaceous Mancos Shale, which is the bedrock that underlies the alluvium in the wetland, is as thick as 1,500 meters in areas near the wetland. This formation is described as shale with subordinate siltstone and sandstone in the upper half, and layered bentonite in the lower half. The bedrock is dipping gently to the east underneath the alluvium.

3.4.8 Hydrogeologic Characterization

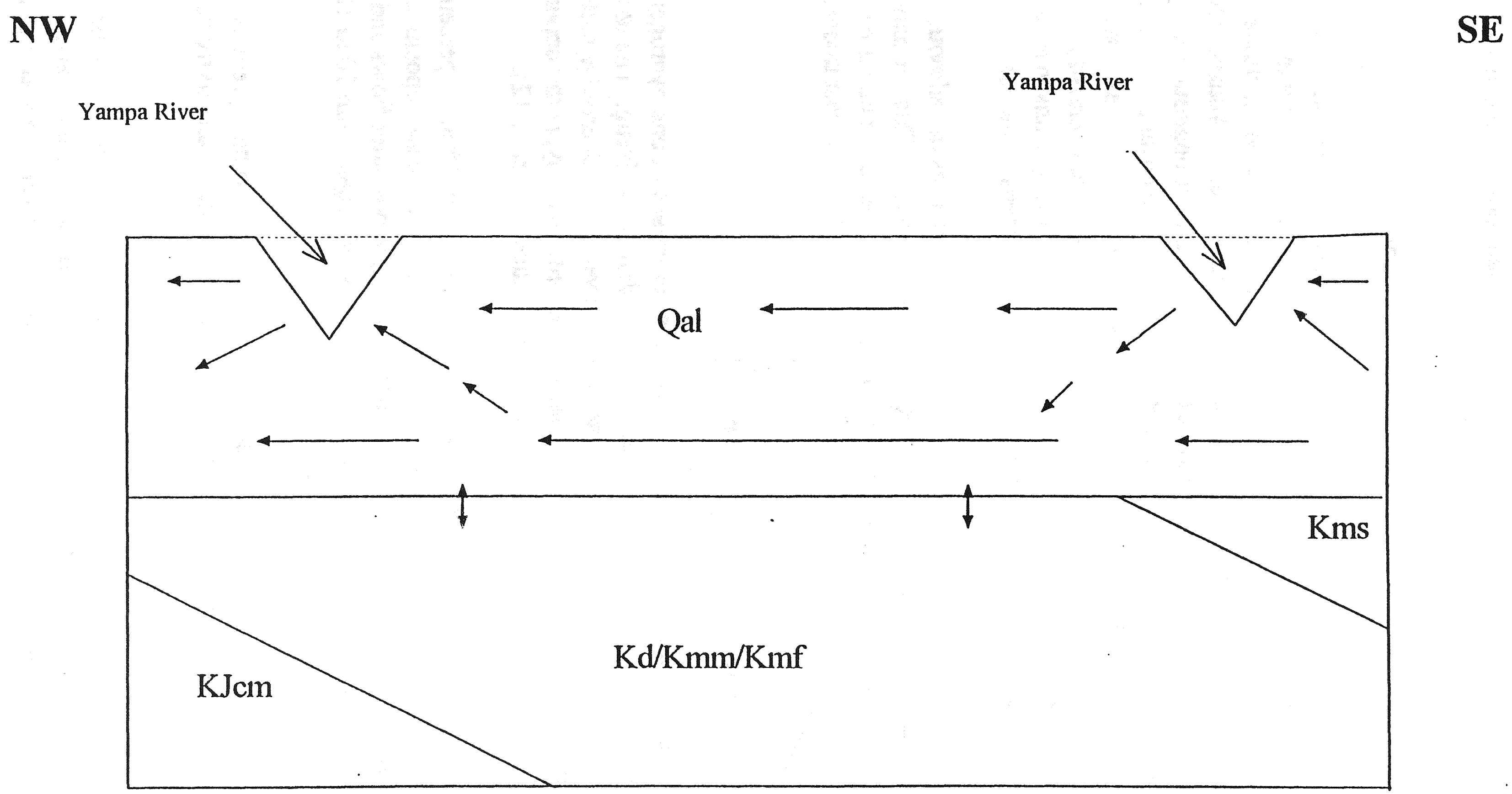
The three dimensional structure of the wetland is composed of one hydrogeologic layer that is water bearing, and one hydrogeologic layer that is confining. The Mancos shale is the confining bedrock unit that forms the bottom layer of the Deerlodge wetland. The thick alluvium, composed of unconsolidated sand, silt, and clay, is the uppermost water-bearing hydrogeologic unit that is visible on the surface (Figure 3.12).

The surface deposits on-site where found to be variable with 15 to 74 percent sand, 8 to 50 percent clay, and 15 to 44 percent silt (Appendix A.3f). These deposits are a result of fluvial processes and are expected to locally control ground-water flows and velocities. Estimated hydraulic conductivities for this surface layer ranges from 10 to 10^{-7} cm/sec with Sy ranging from 3 to 37 percent.

The hydraulic conductivity in the Mancos shale is expected to be extremely low and will act as a barrier to vertical ground-water flow, with hydraulic conductivity values estimated at 10^{-8} to 10^{-11} cm/sec.

The hydrogeologic framework of the Deerlodge wetland directly affects the wetland functions of **ground-water movement, ground-water storage long term, ground-water storage dynamic, ground-water interception** and **surface water storage**

Figure 3.12 Hydrogeologic Model of Deerlodge Wetland. Arrows Indicate Direction of Ground-Water Inputs, Outputs and Flow.



Qal- Alluvium
Kms- Mancos Shale
Kmf- Frontier Sandstone Member
Kmm- Mowry Shale Member
Kd- Dakota Sandstone
KJcm- Cedar Mountain Formation

dynamic. The two-layered hydrogeologic system represents complex dynamics that are not easily assessed on a brief site visit.

3.4.9 Ground-Water System

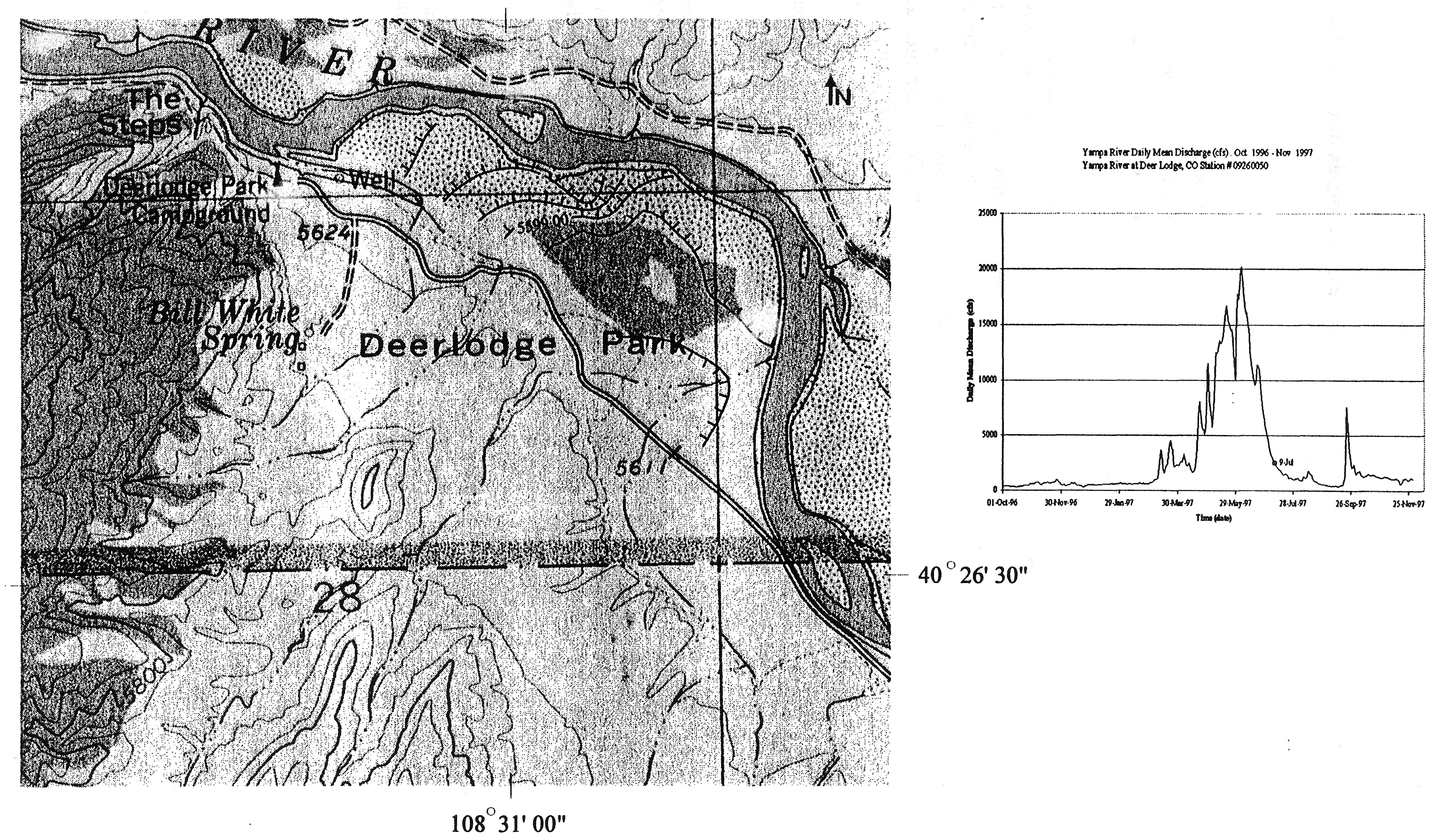
Water levels were measured from shallow wells in alluvium on 4/18/97, 5/3/97, 5/20/97, 7/9/97, and 11/1/97. These water levels were analyzed for potentiometric surfaces for the alluvial hydrogeologic unit, and seasonal and spatial comparisons were made. This analysis is used to confirm the proposed hydrologic functions.

Using the approach of Kolm (1993) and Kolm and van der Heijde (1996), combined with this paper, the ground-water system of the Deerlodge wetland was conceptualized to be in two components: the bedrock system, and the alluvial system (Figure 3.12). The bedrock system is primarily Mancos Shale, which is considered to be a confining unit. Therefore, regional ground-water support for this wetland can not be derived from the bedrock system. However, an upland alluvial system attaches directly to the Deerlodge alluvial system, and minor amounts of ground-water are expected to flow directly into the Deerlodge alluvial aquifer. This additional source of ground-water flow would directly affect the ground-water chemistry and flow paths of the Deerlodge alluvial system. However, the amount of water contributed to this wetland is considerably less than water contributed directly by the seasonal fluctuations of the Yampa River.

The alluvial ground-water system is recharged by infiltration of precipitation and/or surface water inundation on the wetland surface, by stream losses along the northeastern and eastern segments of Yampa River, and by discharge from the upland alluvial system horizontally into the Deerlodge alluvial system (Figure 3.12). In general, the potentiometric surface interpreted from the heads observed in the alluvial system show that the general flow direction is nearly horizontal from the Yampa River area along the northeastern and eastern area of the wetland, along the historical geomorphological meander scrolls in a southwesterly direction, to the northwestern segment of the Yampa River (Figure 3.11). This pattern correlated well with Yampa River flows that occurred after April 18, 1997 (Figure 3.11). However, during April, the wetland functioned partially as a slope wetland, and the potentiometric surface indicated that ground-water flowed from the upland alluvial ground-water sources through the alluvial system to the lover part (northwestern) of the Yampa River (Figure 3.13). This indicates that the upland alluvial system observed on the southwest side of the wetland delivers ground-water (or surface water) to the system that significantly affects the ground-water flow regime during early Spring periods.

It is also hypothesized that ground-water moves vertically to deeper levels of the alluvial system to connect to a large alluvial system involving both banks of the Yampa River. In addition, ground-water may enter or exit this system through the Dakota hydrogeologic group (Figure 3.12). However, the sampling design was not constructed to verify these hypotheses.

Figure 3.13 Location of Deerlodge Wetland. Potentiometric Surface on 7-09-97 and Hydrograph of Yampa River.



Contours Indicate 1.0 Foot Change. Hach Marks Indicate Downhill Direction.

In summary, ground-water movement was determined to move mostly horizontally to and from the Yampa River seasonally, to and from the Yampa River spatially, and from an upland alluvial aquifer to the Deerlodge alluvial deposits. It is hypothesized that the alluvial ground-water flow may move vertically into deeper parts of the alluvial system to and from the Yampa River. The analysis confirms that the ground-water functions of **ground-water movement, ground-water storage long term, ground-water storage dynamic, ground-water interception** and **surface water storage dynamic** occur in this wetland.

4.0 HYDROCHEMICAL CHARACTERIZATION

4.1 Introduction

The hydrochemistry of wetland sites is affected predominantly by the local hydrologic cycle and the carbon cycle, and may also be influenced by other biogeochemical cycles, including the iron, sulfur and nitrogen cycles. Retention, transport, and chemical reactions of metals and other nutrients are directly and indirectly influenced by these cycles.

4.1.1 Hydrologic Influences

The annual hydrologic cycle within the wetland and its associated watershed directly influences export from, import into, and transport within the wetland of elements and chemical compounds. These materials are carried by surface and ground-water in dissolved as well as particulate and colloidal phases. Metals are often transported adsorbed on particulates (or on iron hydroxide or oxyhydroxide coatings) or as soluble organic or inorganic complexes (Figure 4.1). Annual flooding cycles are particularly important to importation of nutrients and metals associated with sediment loads in riparian wetlands. Atmospheric precipitation may also contribute small amounts of certain chemical compounds.

The hydrologic cycle also influences the degree of saturation and inundation of soils, and the direction of transport of chemical constituents. Permanently flooded soils are usually anaerobic, depending on the rate of ground-water flow, the concentration of dissolved oxygen, and local oxygen demand. If the wetland is not permanently inundated, the annual flooding cycle may temporarily cause upper soil levels to become anaerobic. In riparian wetlands, the annual flooding cycle may also cause a reversal of shallow ground-water flow, with ground-water flowing in one direction during the rising limb of the hydrograph, and the opposite direction during the falling limb.

In slope wetlands that are characterized by peat soils, there is likely to be a sufficient hydraulic head during spring and early summer to force water upwards through the peat from saturated underlying unconsolidated materials. Later in the summer and during fall, if the ground-water flow through the unconsolidated materials lessens sufficiently, flow of water and transport of materials may be downward through the peat. Because of extremely low hydraulic conductivities in the peat, horizontal transport of chemical

Figure 4.1 Biogeochemical Cycling of Metals (Butcher et al. 1992).

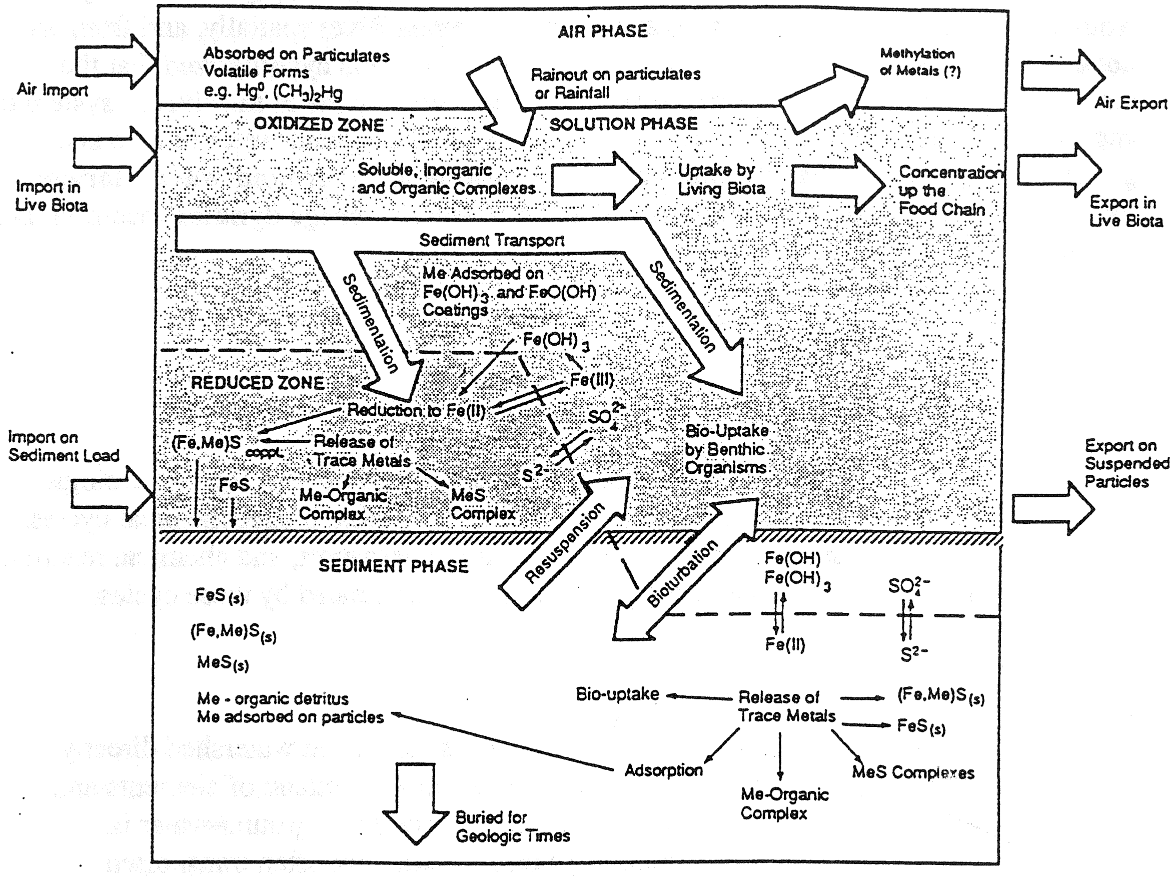
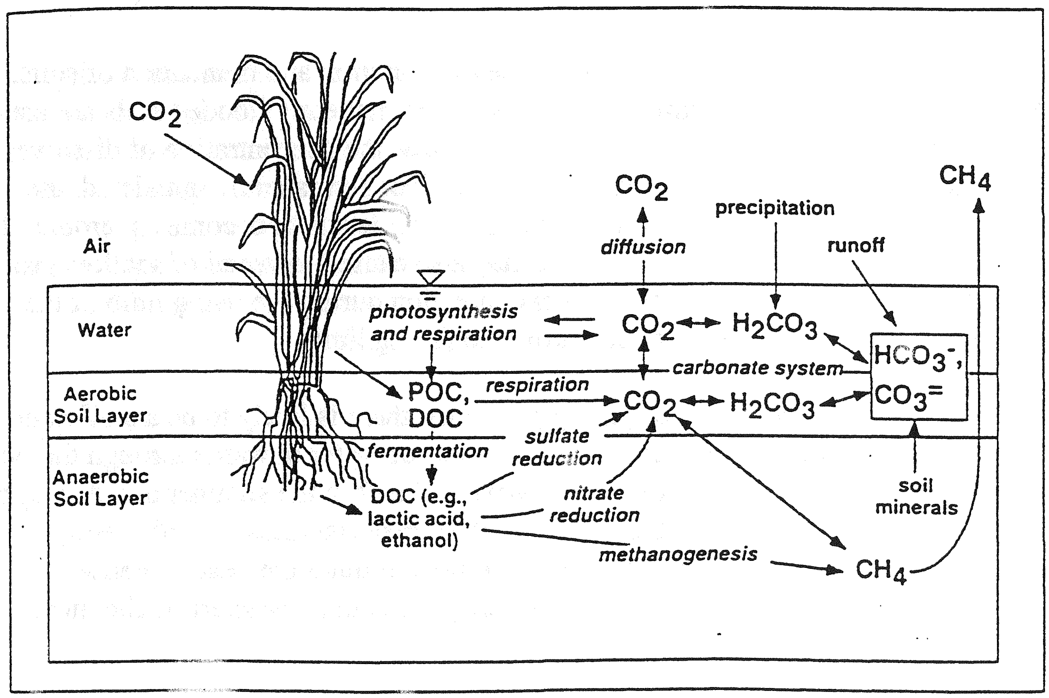


Figure 4.2 Carbon Transformations in Wetlands. POC Indicates Particulate Organic Carbon; DOC Indicates Dissolved Organic Carbon (Mitsch and Gosselink 1993).



constituents in the peat may represent only a small fraction of the total amount of materials transported in the wetland if there is any significant surface flow.

4.1.2 Influences of the Carbon Cycle

Seasonal cycles of production and decomposition are both important to fluxes of nutrients as well as metals. During the growing season, gross primary production exceeds respiration resulting in biomass accumulation, and nutrients and many other elements (whether nutrients or not) are taken up by the vegetation. During the rest of the year, biomass decomposition processes predominate, increasing biological oxygen demand in surface and near-surface water, and nutrients and other elements, as well as organic complexes are released by the decomposing vegetation. In wetlands more or less permanently saturated, low oxygen levels lead to long-term accumulation of organic matter, forming a layer of peat at the surface. In the Southern Rocky Mountains, peat soils are characterized by acid pH, often as low as 4.5, and reducing conditions, with Eh potentials reaching -250 mV or lower. In the oxic zone, aerobic respiration and some fermentations dominate. In the anoxic zone, fermentations and methanogenesis (if redox potentials are low enough) are the main carbon transformation processes (Figure 4.2). However, the lack of oxygen limits the extent of organic decomposition by microbes, especially of lignins and other woody or fibrous material, and subsequently favors organic accumulation. Anaerobic respiration processes, requiring inorganic electron acceptors, are discussed below.

4.1.3 Influences of other cycles on wetland hydrochemistry

Because wetlands commonly are characterized by anaerobic soils below the permanent depth of the water table, other biogeochemical cycles become important. Both sulfate and oxidized nitrogen compounds are important as electron acceptors in anaerobic respiration processes, resulting in dissimilatory nitrate and sulfate reduction (Figures 4.3 and 4.4), as well as aiding organic matter decomposition. Sulfate reduction also may lead to the precipitation of less soluble metal sulfides. Both of these cycles are mediated by microbes, which are an important factor in lowering reduction potentials of the soil environment. The iron cycle is another important influence on wetland biogeochemistry. Ferric iron complexes with other metals as well as organic ligands in the aerobic zone, and is an important scavenger of phosphate. Precipitation of oxyhydroxides of iron complexed with other metals tends to immobilize metal transport. Under anaerobic conditions, ferric iron is reduced to ferrous iron, and may precipitate as iron sulfide. Iron reduction also tends to increase soil pH (Figure 4.5). At the same time, other complexed elements, such as phosphorus, may become more mobile (Figure 4.6).

4.1.4 Key wetland processes affecting retention, release, and transformation of chemical components

The retention, release and transformation of chemical constituents is characterized or affected by several processes. These processes include biological

Figure 4.3 Nitrogen Transformations in Wetlands. SON Indicates Soluble Organic Nitrogen (Mitsch and Gosselink 1993).

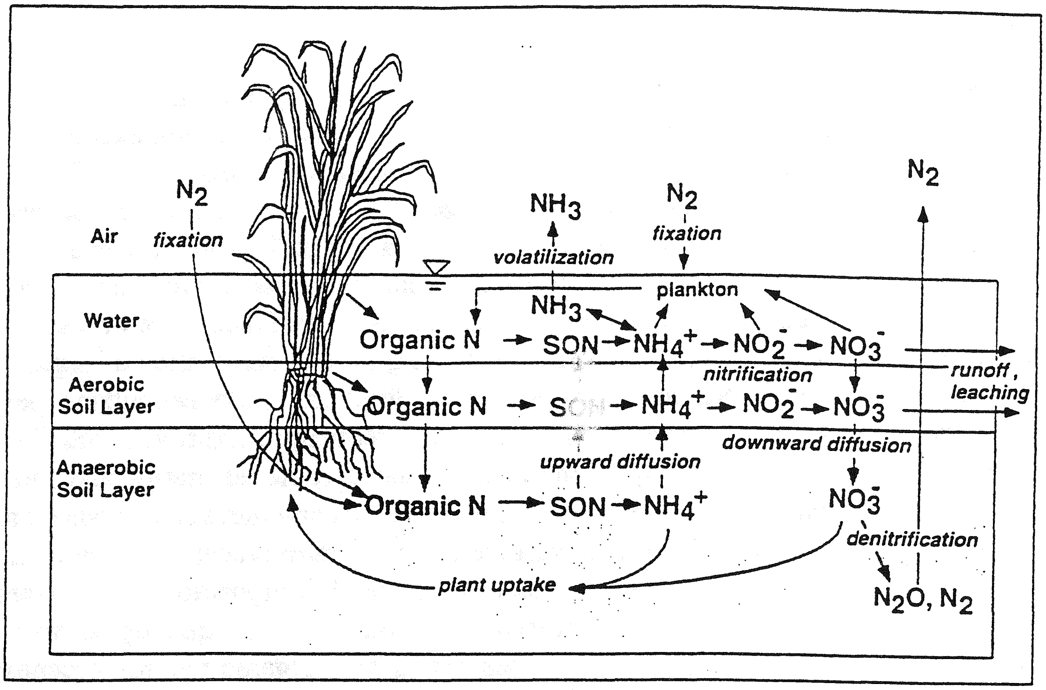


Figure 4.4 Sulfur Transformations in Wetlands (Mitsch and Gosselink 1993).

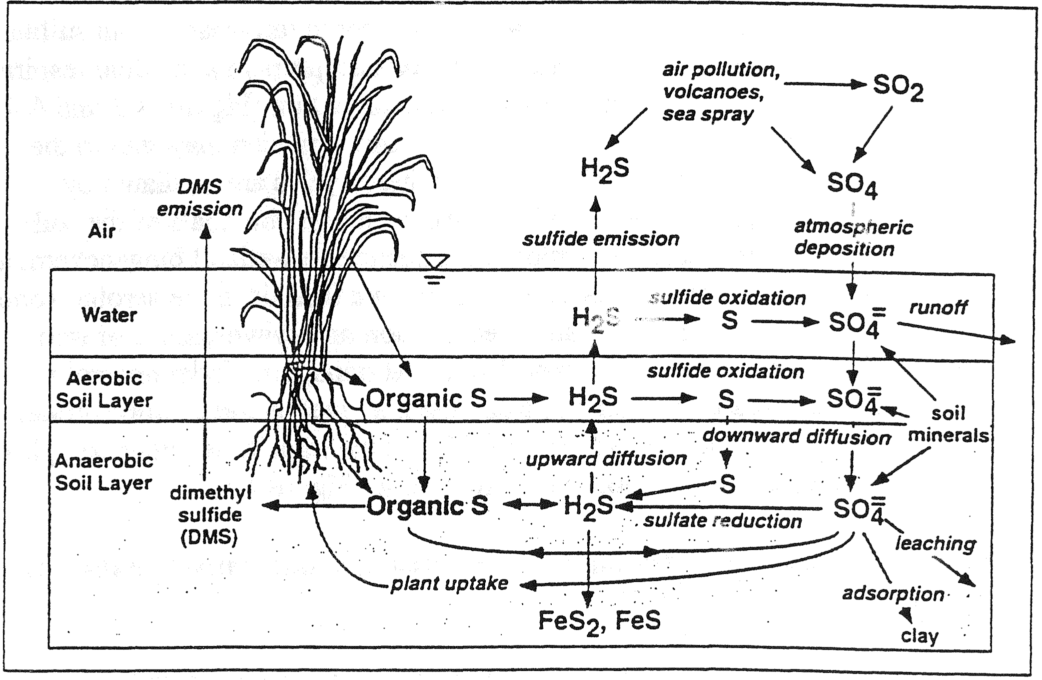


Figure 4.5 Changes in pH of Soils of Different Organic and Iron Content After Flooding (Mitsch and Gosselink 1993).

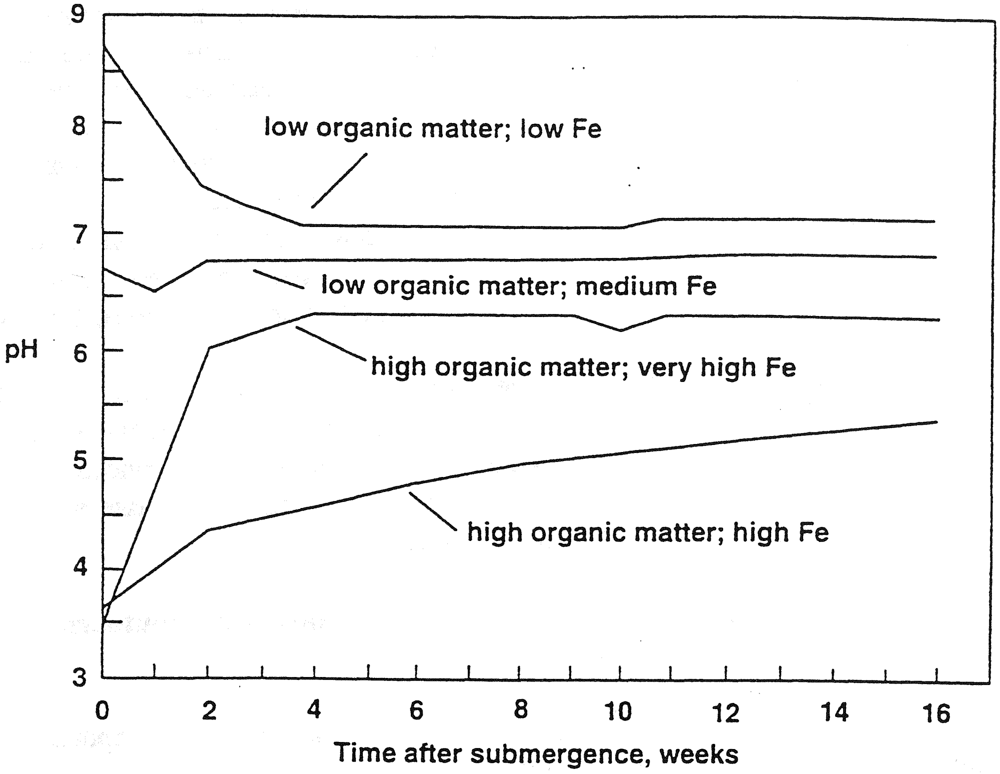
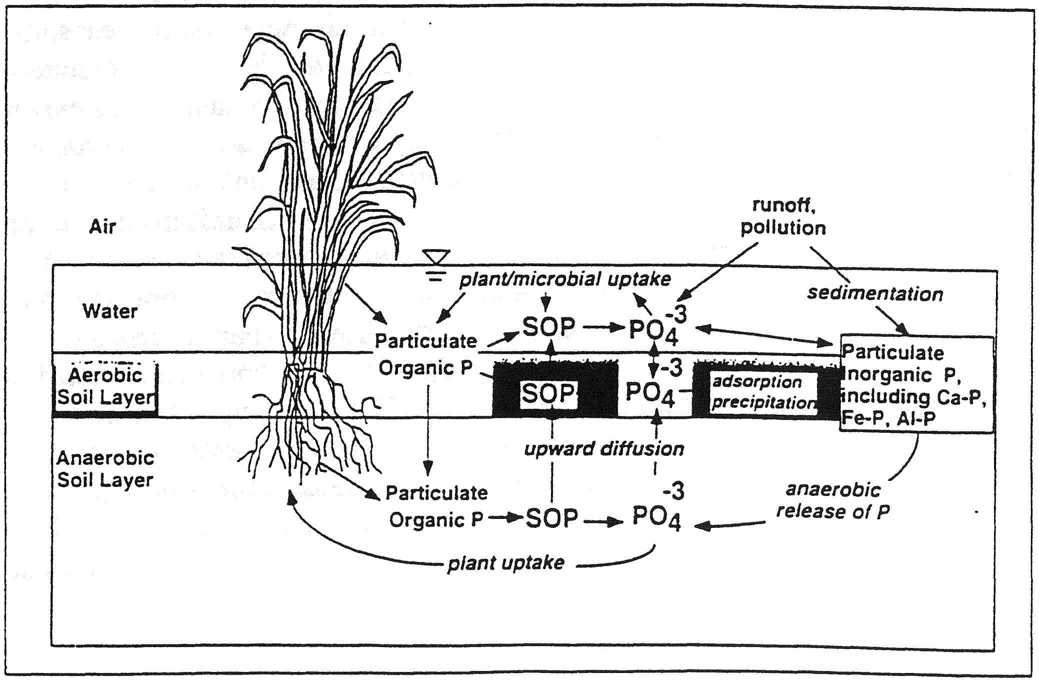


Figure 4.6 Phosphorus Transformations in Wetlands. SOP Indicates Soluble Organic Phosphorus (Mitsch and Gosselink 1993).



production/decomposition, nutrient uptake/release by plants, nitrogen fixation/denitrification, chemical dissolution/precipitation, dilution/concentration of dissolved constituents, and adsorption/desorption onto or from organic matter, mineral surfaces, and other materials. Biological production/decomposition is linked to nutrient uptake and release. Nitrogen fixation/denitrification probably depends mostly on the degree and duration of soil saturation, with saturated, anaerobic conditions favoring denitrification. During flooded conditions, dissolution, dilution, and desorption might be expected to predominate, although this is undoubtedly an over-simplification. Conversely, during drier conditions, precipitation, concentration, and adsorption might predominate. All of these processes are likely to fluctuate seasonally with the carbon cycle, temperature, and hydrologic events related to snowmelt, runoff, and summer rains.

Many of the processes will also be affected by the amount of soil organic matter. In short, the geochemical role of wetlands is influenced by **hydrologic status, the nature of the soils**, and by **plant community production**. While this may sound like an obvious statement, it underscores the need to take all three factors into account when assessing wetland geochemical function as part of the HGM process.

4.1.5 Expected differences between slope and riverine wetlands in the Southern Rocky Mountains

Slope wetlands would be expected to differ from riverine wetlands in several important features. 1) Slope wetlands would be expected to have more consistently saturated soils during the year, and especially during the growing season, mainly because of a more dependable hydrologic input as well as the greater water-holding capacity of highly organic soils typically associated with slope wetlands. Thus, there would be less of a seasonal hydrologic effect associated with slope wetlands. This should lower dissolved oxygen and enhance reduction processes, including nitrate reduction, sulfate reduction, and reduction of metals. 2) Slope wetlands would be expected to have a greater percentage of organic material, with many slope wetlands characterized by peat soils. This should also enhance reduction processes, as well as lower pH. Higher amounts of organic accumulation would favor cation adsorption and retention, though this may be offset by the effects of lower pH owing to the tendency for many cations to become more mobile at low pH. 3) Slope wetlands would be expected to have soils with a lower hydraulic conductivity, which, in spite of a potentially more geochemically active soil substrate, may effectively limit contact with water flowing through the wetland. 4) Slope wetlands would be expected to have more uniform soil conditions. Riverine soils are spatially diverse, with varying textures associated with different channel deposits, backwater sediments, and occasional alluvial fan deposits. This should be reflected in greater variance in measured geochemical parameters. 5) The timing of seasonal hydrologic fluctuations may differ between slope and riverine wetlands, with slope wetlands hydrology tied to snow melt and summer monsoons, while hydrologic fluctuations in riverine systems are tied mainly to the annual hydrograph. Tables 4.1 and 4.2 show the expected effect on the above processes due to hydrologic fluctuations in slope and riverine wetlands, respectively.

Predominant Process	Snow Melt	Post Snow Melt	Monsoon	Post Monsoon
Biological Decomposition	X	X		X
Biological Production			X	
Plant Uptake			X	
Nutrient Release	X	X		X
Fixation				
Denitrification	X	X	X	X
Dissolution	X		X	
Precipitation		X		X
Dilution	X		X	
Concentration		X		X
Adsorption		X		X
Desorption	X		X	
Flushing	X		X	
Drying		X		X

Table 4.1 Dominant Reactions Hypothesized to Occur in Slope Wetlands in the Southern Rocky Mountains.

Predominant Process	Base Flow	Climbing Limb	Peak	Declining Limb
Biological Decomposition	X			
Biological Production		X	X	X
Plant Uptake		X	X	X
Nutrient Release	X			
Fixation	X			X
Denitrification		X	X	
Dissolution		X	X	
Precipitation	X			X
Dilution		X	X	
Concentration	X			X
Adsorption	X			X
Desorption		X	X	
Flushing		X	X	
Drying	X			X

Table 4.2 Dominant Reactions Hypothesized to Occur in Riverine Wetlands in the Southern Rocky Mountains.

4.2 Geochemical Results

4.2.1 Peru Creek Geochemical Results

4.2.1.1 Mean Values

The average pH was greater in the majority of the peat wells than in the unconsolidated wells (Tables 4.3 through 4.6). Sulfate concentrations ranged from 75.22 mg/l to 433.36mg/l in the peat wells and from 62.42 mg/l to 419.28 mg/l in the unconsolidated wells. Average chloride and sulfate concentrations were the greatest in peat and unconsolidated wells during the snow melt sampling period.

4.2.1.2 Spatial and Temporal Variation

As shown in Tables 4.3 through 4.6, the sampling date generally affects the peat and unconsolidated wells in the same manner. Dissolved oxygen, pH, and anion concentrations are statistically different at $\alpha = 0.05$ from date to date, whereas, cation concentrations and Eh are not statistically different. Exceptions to this are dissolved oxygen and sulfate concentrations in the unconsolidated wells which were not statistically different between sampling dates. Dissolved oxygen, pH, and cation concentration in both the peat and unconsolidated wells were different between well locations. The effect of location on anion concentrations, however, was variable. Mean sulfate concentrations did vary with location in both sets of wells and mean chloride concentrations varied with location in peat wells only. Nitrate concentrations did not vary with location in either peat or unconsolidated wells.

4.2.1.3 Trend Analysis

Zinc concentrations in peat wells decreased with distance along hydrologic flow paths in all sampling periods. The slope of the line increased from snow melt to monsoon, but decreased to the lowest value of -0.1576 during monsoon season (Appendix C.1a).

In the peat wells, nitrate concentrations decreased with distance along hydrologic flow paths during snow melt and monsoon seasons. Eh values in the peat wells decreased with distance along hydrologic flow paths during all sampling periods. Eh values in the unconsolidated wells during post snow melt and post monsoon decreased with distance.

4.2.1.4 Correlations between Parameters

As shown in Appendix C.1b, herbaceous biomass, percent organic matter, and percent total pore space were seasonally correlated to anion and cation concentrations. Herbaceous biomass was positively correlated to anions and dissolved zinc, and negatively correlated to dissolved iron. Percent organic matter and percent total pore space were negatively correlated to anions and dissolved zinc, and positively correlated to dissolved iron. Positive correlations in both peat and unconsolidated wells during the

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
6/20/1997 (SM)	4.4	4.9	-18.7	3.80	3.42	244.59	8.12	3.07
8/5/1997 (PSM)	3.4	5.1	-34.6	0.52	4.20	187.62	11.48	2.16
9/13/1997 (M)	3.3	5.1	-42.0	0.96	0.52	209.55	13.15	2.30
10/18/1997 (PM)	3.8	5.0	-23.6	0.78	1.71	219.15	10.04	3.26
Results of Two-Way Anova[2]	+	+	-	+	+	+	-	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

SM= Snow Melt
PSM= Post Snow Melt
M= Monsoon
PM= Post Monsoon

Table 4.3 Mean Concentration of Measured Parameters in All Peat Wells and Results of Two-Way ANOVA in the Pennsylvania Mine Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
GWC1P	3.5	4.2	25.8	1.81	1.32	433.36	1.56	9.87
GWC2P	2.8	5.6	-65.9	1.13	2.59	231.42	7.71	0.17
GWE10P	3.7	5.1	-32.5	0.27	4.00	167.54	23.24	0.05
GWE2P	5.1	4.2	27.3	2.40	3.65	245.90	0.18	8.89
GWE3P	5.5	4.3	18.2	1.22	3.10	246.76	0.74	9.47
GWE4P	3.0	5.4	-51.0	1.13	2.37	104.77	4.60	0.03
GWE5P	4.0	5.9	-85.2	1.51	0.43	151.26	26.22	0.06
GWE6P	3.1	5.0	-25.6	1.59	1.23	260.95	25.32	0.08
GWE7P	3.2	5.7	-74.9	1.65	1.95	75.22	0.91	0.02
GWE8P	3.0	4.3	17.9	2.67	0.50	303.70	13.76	0.04
GWE9P	4.2	5.6	-79.0	1.41	7.78	125.65	13.44	0.99
Results of Two-Way Anova[2]	+	+	-	+	-	+	+	+

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

Table 4.4 Mean Concentration of Measured Parameters in Peat Wells on All Dates and Results of Two-Way ANOVA in the Pennsylvania Mine Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
6/20/1997 (SM)	3.7	4.3	16.8	3.79	2.44	274.64	10.75	4.98
8/5/1997 (PSM)	3.8	4.5	7.0	1.32	0.45	253.06	13.46	4.53
9/13/1997 (M)	4.5	4.6	-3.4	0.72	2.23	252.89	14.86	4.85
10/18/1997 (PM)	3.5	4.6	3.1	1.20	0.35	232.54	14.22	5.34
Results of Two-Way Anova[2]	-	+	-	+	+	-	-	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

SM= Snow Melt
PSM= Post Snow Melt
M= Monsoon
PM= Post Monsoon

Table 4.5 Mean Concentration of Measured Parameters in All Unconsolidated Wells and Results of Two-Way ANOVA in the Pennsylvania Mine Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
GWC1	3.2	4.1	29.2	1.61	1.79	419.28	1.16	16.93
GWC2	3.7	4.5	7.1	1.63	0.85	257.76	20.79	0.11
GWE10	2.8	3.8	48.4	2.17	0.27	291.07	17.34	0.36
GWE2	5.4	4.2	27.2	1.87	1.49	224.40	0.31	9.34
GWE3	5.9	4.3	19.6	2.46	2.31	207.92	0.60	9.42
GWE4	2.6	4.9	-23.5	1.90	0.00	182.99	34.00	0.09
GWE5	4.2	4.6	-0.5	1.89	2.37	265.05	18.43	0.10
GWE6	4.0	4.5	7.9	1.52	3.11	308.96	18.35	0.32
GWE7	3.7	4.2	28.9	1.39	0.00	293.80	2.63	17.36
GWE8	3.3	4.5	5.9	2.09	0.08	272.44	6.59	0.02
GWE9	4.1	5.9	-85.8	0.79	2.78	62.42	26.35	0.10
Results of Two-Way Anova[2]	+	+	-	-	-	+	+	+

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

Table 4.6 Mean Concentration of Measured Parameters in Unconsolidated Wells on All Dates and Results of Two-Way ANOVA in the Pennsylvania Mine Wetland.

majority of sampling periods existed for chloride and nitrate, dissolved iron and pH, and dissolved zinc and Eh. Negative correlations in both peat and unconsolidated wells during the majority of sampling periods existed for dissolved iron and Eh, dissolved iron and dissolved zinc, dissolved zinc and pH, and pH and Eh. In the peat wells, sulfate was positively correlated to dissolved zinc and Eh in the majority of the sampling seasons and negatively correlated to pH in three out of four of the sampling seasons. Temperature and specific conductivity had mixed correlations with the anion and cation concentrations in peat and unconsolidated wells.

4.2.1.5 Cumulative Percent Composition

There appears to be little difference between peat and unconsolidated wells in the percent composition of major ions. Snow melt does appear to be slightly different from the other three waters in both peat and unconsolidated wells. Sulfate makes up the largest percent of ions based on mg/l (Appendix C.1c and C.1d).

4.2.1.6 Mean Values in Soil, Water, and Plants

As Table 4.7 shows, the greatest percentage of heavy metals was partitioned in the soil. Less than five percent of the metals was partitioned in the plants. The plants had the largest percentage of calcium. Potassium, magnesium, and sodium were primarily partitioned in the soils, but had relatively large percentage of mean loading in the plants. The water had small percentages of all of the cations.

4.2.2 Big Meadows Geochemical Results

4.2.2.1 Mean Values

The average pH values measured were similar in the peat wells and the unconsolidated wells; the range of pH values was 5.9 to 6.8 in the peat wells, and 5.4 to 6.2 in the unconsolidated wells. Average dissolved iron concentrations were less than 6.5 mg/l in all wells except BMA, BM22, and BM32 (Tables 4.8 through 4.9). Average chloride, sulfate, dissolved iron, and dissolved zinc concentrations were greatest in the peat wells during the post snow melt sampling event. In the unconsolidated wells, average sulfate and nitrate concentrations were greatest during the snow melt sampling period; average dissolved iron and dissolved zinc concentrations were smallest during the snow melt sampling period.

4.2.2.2 Spatial and Temporal Variation

As tables 4.8 through 4.11 indicate, the mean values of chemical environment, anion concentration and cation concentration in the peat wells were statistically different between dates and sampling locations. An exception was that the mean of Eh values was not statistically different between dates or locations. In the unconsolidated wells, chemical environment, cation concentrations or anion concentrations were not

	Mean Concentration[2]	Mean Mass[3]	Mean Loading[4]	Percentage of Mean Loading[4]
Aluminum				
Water (mg/kg)[1]	9.26	6.72	62.20	0.16
Soil (mg/kg)	8325.31	4.51	37539.60	98.61
Plant (mg/kg)	433.08	1.08	465.96	1.22
Calcium				
Water (mg/kg)[1]	33.86	6.72	227.45	3.66
Soil (mg/kg)	589.34	4.51	2657.37	42.75
Plant (mg/kg)	3096.08	1.08	3331.10	53.59
Iron				
Water (mg/kg)[1]	9.55	6.72	64.18	0.03
Soil (mg/kg)	56760.17	4.51	255936.76	99.85
Plant (mg/kg)	303.02	1.08	326.03	0.13
Potassium				
Water (mg/kg)[1]	2.48	6.72	16.66	0.06
Soil (mg/kg)	3142.62	4.51	14170.34	53.61
Plant (mg/kg)	11380.80	1.08	12244.70	46.33
Magnesium				
Water (mg/kg)[1]	15.49	6.72	104.04	1.56
Soil (mg/kg)	1104.89	4.51	4982.04	74.81
Plant (mg/kg)	1462.78	1.08	1573.82	23.63
Zinc				
Water (mg/kg)[1]	3.31	6.72	22.27	0.07
Soil (mg/kg)	6601.87	4.51	29768.43	98.40
Plant (mg/kg)	430.32	1.08	462.99	1.53
Sodium				
Water (mg/kg)[1]	4.82	6.72	32.35	1.97
Soil (mg/kg)	266.85	4.51	1203.25	73.41
Plant (mg/kg)	374.98	1.08	403.44	24.61

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

[2] mg cation/ kg media

[3] kg media/ .01m^3 soil

[4] mg cation in media/ .01 m^3 soil

Table 4.7 Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Pennsylvania Mine Peat Samples Collected on 10/18/97.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
6/25/1997 (PSM)	6.1	5.9	-88.75	11.48	2.72	4.71	7.86	0.19
8/12/1997 (M)	5.5	6.4	-94.27	2.12	4.73	3.99	4.81	0.03
9/27/1997 (PM)	NM	6.3	-85.41	1.67	0.32	3.67	3.26	0.03
Results of Two-Way Anova[2]	-	-	-	-	-	-	-	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

PSM= Post Snow Melt
M= Monsoon
PM= Post Monsoon

Table 4.8 Mean Concentration of Measured Parameters in All Peat Wells and Results of Two-Way ANOVA in the Big Meadows Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
BMA	6.0	5.9	-89.77	3.90	3.05	5.62	11.33	0.07
BMB	4.3	6.0	-93.73	4.19	0.95	5.84	4.12	0.23
BMC	7.0	6.2	-111.10	2.77	2.97	1.97	6.06	0.04
BMD	6.0	6.8	-140.27	3.78	4.47	4.47	1.47	0.03
BME	5.8	5.9	-89.27	11.49	0.25	3.32	3.57	0.05
Results of Two-Way Anova[2]	-	-	-	-	-	-	-	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

Table 4.9 Mean Concentration of Measured Parameters in Peat Wells on All Dates and Results of Two-Way ANOVA in the Big Meadows Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
6/10/1997 (SM)	5.8	5.9	-79.32	2.22	2.44	2.87	3.35	0.00
6/25/1997 (PSM)	6.4	6.0	-94.27	4.27	1.43	2.18	8.13	0.05
8/12/1997 (M)	5.6	5.9	-85.41	1.13	0.95	3.06	8.21	0.02
9/27/1997 (PM)	NM	6.1	-98.94	0.58	1.84	2.81	6.93	0.03
Results of Two-Way Anova[2]	-	-	-	+	-	-	-	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

SM= Snow Melt
PSM= Post Snow Melt
M= Monsoon
PM= Post Monsoon

Table 4.10 Mean Concentration of Measured Parameters in All Unconsolidated Wells and Results of Two-Way ANOVA in the Big Meadows Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
BM13	4.8	6.0	-92.90	2.17	0.30	1.03	5.39	0.03
BM15	5.6	6.0	-86.22	2.42	2.26	1.18	5.17	0.04
BM22	5.5	6.1	-102.38	0.20	0.00	2.07	14.68	0.02
BM28	6.1	6.2	-107.79	2.20	5.51	5.67	1.88	0.02
BM32	6.5	6.1	-95.37	2.54	0.67	1.97	13.89	0.02
BM35	6.8	5.6	-76.57	NM	NM	NM	5.77	0.01
BM54	5.1	6.2	-101.63	1.54	0.00	4.75	6.01	0.01
BM55	7.0	5.4	-50.59	1.92	4.26	3.15	1.32	0.03
Results of Two-Way Anova[2]	-	+	-	-	-	-	+	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

NM= Not Measured

Table 4.11 Mean Concentration of Measured Parameters in Unconsolidated Wells on All Dates and Results of Two-Way ANOVA in the Big Meadows Wetland.

statistically different between dates with the exception of chloride. Anion concentrations were not statistically different between sampling locations. Statistical differences between means of dissolved oxygen and dissolved zinc were not present at $\alpha = 0.05$.

4.2.2.3 Trend Analysis

The only linear regression performed on Big Meadows unconsolidated wells with an R^2 greater than 0.50 was during monsoon season. Dissolved oxygen decreased with distance along hydrologic flow paths (Appendix C.1a).

4.2.2.4 Correlations between Parameters

The results of correlations greater than 0.85 are presented in Appendix C.1b. According to this table, percent organic matter was generally not correlated with cation concentrations or anion concentrations. An exception to this was during post monsoon season where nitrate was negatively correlated to percent organic matter. Herbaceous biomass and percent total pore space had varied correlations with anion and cation concentrations. The only consistent correlations between seasons was a positive correlation between percent total pore space and dissolved iron.

In general, there were fewer correlations greater than 0.85 in Big Meadows than in Peru Creek. In the two sampling seasons reported, there are no correlations of the same sign for the parameters correlated with the exception of Eh and pH, %TPS and dissolved iron, temperature and dissolved zinc, and specific conductivity and dissolved iron.

4.2.2.5 Cumulative Percent Composition

Peat wells have a lower percent HCO_3 than unconsolidated wells according to Appendix C.2a and C.2b. The ion composition in the peat wells appears to vary more from season to season in the peat wells than in the unconsolidated wells. HCO_3 makes up the largest percent ion based on mg/l in both the peat and unconsolidated wells.

4.2.2.6 Mean Values in Soil, Water, and Plants

As table 4.12 shows, the soils contain the largest percentage of mean loading of all cations with the exception of potassium which was highest in the plants. Greater than 20 percent of mean loading of zinc, magnesium, and calcium was partitioned in plants. The water contained the smallest percentage of cations in all of the samples.

4.2.3 Browns Park Geochemical Results

4.2.3.1 Mean Values

As tables 4.13 and 4.14 show, the range of average pH was small. Sulfate, chloride, and iron concentrations were greatest during the declining limb sampling period. Among

	Mean Concentration[2]	Mean Mass[3]	Mean Loading[4]	Percentage of Mean Loading[4]
Aluminum				
Water (mg/kg)[1]	31.53	8.27	0.26	0.46
Soil (mg/kg)	14597.47	3.90	56930.13	99.47
Plant (mg/kg)	28.06	1.43	39.98	0.07
Calcium				
Water (mg/kg)[1]	16.16	8.27	0.13	0.93
Soil (mg/kg)	2367.65	3.90	9233.84	64.20
Plant (mg/kg)	3520.11	1.43	5016.16	34.87
Iron				
Water (mg/kg)[1]	24.13	8.27	0.20	0.62
Soil (mg/kg)	8135.87	3.90	31729.89	98.78
Plant (mg/kg)	134.93	1.43	192.27	0.60
Potassium				
Water (mg/kg)[1]	2.50	8.27	0.02	0.12
Soil (mg/kg)	1535.17	3.90	5987.18	33.51
Plant (mg/kg)	8322.57	1.43	11859.66	66.38
Magnesium				
Water (mg/kg)[1]	6.63	8.27	0.05	0.54
Soil (mg/kg)	2008.55	3.90	7833.34	76.71
Plant (mg/kg)	1630.65	1.43	2323.68	22.75
Zinc				
Water (mg/kg)[1]	0.07	8.27	0.00	0.35
Soil (mg/kg)	30.39	3.90	118.52	68.50
Plant (mg/kg)	37.82	1.43	53.90	31.15
Sodium				
Water (mg/kg)[1]	3.90	8.27	0.03	3.30
Soil (mg/kg)	222.47	3.90	867.63	88.79
Plant (mg/kg)	54.25	1.43	77.30	7.91

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

[2] mg cation/ kg media

[3] kg media/ .01m^3 soil

[4] mg cation in media/ .01 m^3 soil

Table 4.12 Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Big Meadows Peat Samples Collected on 9/27/97.

wells, dissolved iron and zinc concentrations were consistent with the exception of BP 4 which had concentration up to three orders of magnitude larger than the other wells.

4.2.3.2 Spatial and Temporal Variation

According to tables 4.13 and 4.14, mean anion concentrations did not significantly differ between dates or between locations. Dissolved oxygen varied with sampling date and location; pH and Eh did not vary by sampling date or location. Dissolved iron concentrations were statistically different between sampling locations, but not between sampling dates; dissolved zinc concentrations did not vary by sampling location, but were varied between sampling dates.

4.2.3.3 Trend Analysis

No linear regressions with an R^2 greater than 0.50 were reported during the post-peak sampling season. However dissolved oxygen and pH decreases with distance along hydrologic flow paths in all sampling periods, and Eh and dissolved iron increased with distance in all sampling periods (Appendix C.3a).

4.2.3.4 Correlations between Parameters

According to table Appendix C.3b, percent organic matter, percent carbonate, percent total pore space, and above ground herbaceous biomass showed no consistent trends with the measured chemical parameters. In the majority of sampling seasons pH and Eh, and dissolved iron and pH were negatively correlated.

4.2.3.5 Cumulative Percent Composition

The percent ion composition is similar during all seasons except during post peak. Sulfate and bicarbonate appear to make up the largest percent of ions based on mg/l in all sampling periods (Appendix C.3c).

4.2.3.6 Mean Values in Soil, Water, and Plants

Soils had the greatest percentage of all cations. The percentage of mean loading of potassium was greater than 20 percent in the plants. The water samples had the smallest percentage of all cations (Table 4.15).

4.2.4 Deerlodge Geochemical Results

4.2.4.1 Mean Values

As tables 4.16 and 4.17 show, the average pH values were consistent from sampling period to sampling period. The average concentration of chloride, nitrate, sulfate, dissolved iron, and dissolved zinc was greatest during the declining limb of the

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
5/22/1997 (CL)	3.2	7.2	-172.30	22.46	3.78	252.79	1.09	0.00
6/6/1997 (PP)	2.7	7.7	-201.62	24.47	3.41	260.62	0.74	0.00
7/22/1997 (DL)	4.8	7.3	-184.62	47.73	2.13	366.59	4.94	10.69
11/1/1997 (BF)	3.8	7.3	-182.98	32.98	2.67	281.81	4.23	0.02
Results of Two-Way Anova[2]	+	-	-	-	-	-	+	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

CL= Climbing Limb of Hydrograph
P= Peak
DL= Declining Limb of Hydrograph
BF= Baseflow

Table 4.13 Mean Concentration of Measured Parameters in All Wells and Results of Two-Way ANOVA in the Allen Bottom Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
BP1	5.0	7.4	-188.38	21.16	3.14	205.97	0.11	1.40
BP10	3.6	7.4	-186.26	33.37	4.14	303.59	4.76	2.35
BP11	3.7	7.3	-183.56	132.75	1.07	754.30	1.94	0.68
BP2	4.0	7.6	-199.93	17.24	0.58	199.43	0.49	1.52
BP3	3.9	7.4	-190.94	26.41	4.02	304.03	0.21	1.65
BP4	1.3	7.0	-164.05	22.59	1.10	17.36	27.08	19.77
BP5	4.7	7.6	-197.04	20.12	3.02	226.61	0.94	3.84
BP6	4.1	7.3	-182.72	24.12	3.65	275.76	0.04	1.81
BP7	2.8	7.3	-183.49	17.59	1.68	189.23	0.97	2.44
BP8	3.0	7.3	-178.41	54.76	5.17	543.55	3.74	2.48
BP9	4.5	7.1	-172.01	22.00	3.26	176.08	4.62	3.20
Results of Two-Way Anova[2]	+	-	-	-	-	-	-	+

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

Table 4.14 Mean Concentration of Measured Parameters on All Dates and Results of Two-Way ANOVA in the Allen Bottom Wetland.

	Mean Concentration[2]	Mean Mass[3]	Mean Loading[4]	Percentage of Mean Loading[4]
Aluminum				
Water (mg/kg)[1]	2.49	2.76	6.86	0.00
Soil (mg/kg)	12341.69	12.63	155840.52	99.98
Plant (mg/kg)	12.99	1.91	24.81	0.02
Calcium				
Water (mg/kg)[1]	660.71	2.76	1821.52	0.42
Soil (mg/kg)	33052.83	12.63	417363.64	97.00
Plant (mg/kg)	5801.38	1.91	11080.63	2.58
Iron				
Water (mg/kg)[1]	4.18	2.76	11.53	0.01
Soil (mg/kg)	13630.69	12.63	172117.00	99.90
Plant (mg/kg)	82.61	1.91	157.78	0.09
Potassium				
Water (mg/kg)[1]	7.06	2.76	19.50	0.03
Soil (mg/kg)	4415.68	12.63	55757.58	77.75
Plant (mg/kg)	8346.30	1.91	15941.44	22.23
Magnesium				
Water (mg/kg)[1]	91.02	2.76	250.92	0.20
Soil (mg/kg)	9690.66	12.63	122365.59	97.50
Plant (mg/kg)	1510.95	1.91	2885.91	2.30
Zinc				
Water (mg/kg)[1]	0.06	2.76	0.16	0.02
Soil (mg/kg)	47.11	12.63	594.89	89.01
Plant (mg/kg)	38.38	1.91	73.30	10.97
Sodium				
Water (mg/kg)[1]	84.84	2.76	233.90	1.62
Soil (mg/kg)	967.51	12.63	12216.86	84.42
Plant (mg/kg)	1058.35	1.91	2021.46	13.97

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

[2] mg cation/ kg media

[3] kg media/ .01m^3 soil

[4] mg cation in media/ .01 m^3 soil

Table 4.15 Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Allen Bottom Samples Collected on 11/1/97.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
5/20/97 (P)	3	7.4	-182.46	58.38	3.09	433.47	1.06	0
7/9/97 (DL)	3.4	7.4	-184.88	91.92	4.19	1605.79	1.51	0.12
11/2/1997 (BF)	3.4	7.4	-186.52	55.04	0.41	1645.54	1.32	0.02
Results of Two-Way Anova[2]	-	-	-	+	-	+	+	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

P= Peak
DL= Declining Limb of Hydrograph
BF= Baseflow

Table 4.16 Mean Concentration of Measured Parameters in All Wells and Results of Two-Way ANOVA in the Deerlodge Wetland.

	Dissolved Oxygen (mg/l)	pH	Eh (mV) [1]	Chloride (mg/l)	Nitrate (mg/l)	Sulfate (mg/l)	Dissolved Iron (mg/l)	Dissolved Zinc (mg/l)
DL12	3.3	7.1	-166.44	7.14	3.54	150.6	5.47	0.01
DL13	3.4	7.7	-202.40	14.56	2.05	93.03	0.08	0.01
DL14	4.1	7.4	-175.32	203.67	5.79	7804.56	0.87	0.01
DL2	2.9	7.6	-197.69	10.54	1.21	151.61	0.18	0.02
DL26	3.7	7.5	-193.38	30.72	4.48	277.48	0.98	0.01
DL27	3.7	7.3	-181.56	193.47	1.17	1177.13	0.56	0.03
DL3A	2.2	7.3	-179.64	18.77	0.67	201.35	2.81	0.03
DL4	3.1	7.2	-169.92	180.69	1.28	2768.02	1.68	0.03
DL5	3.4	7.5	-189.66	45.85	3.24	351.05	0.73	0.35
DL8	3.1	7.4	-185.37	49.08	2.11	405.81	0.11	0.02
DL9	3.4	7.6	-197.95	22.15	2.19	272.56	0.36	0.01
Results of Two-Way Anova[2]	+	+	-	-	+	-	-	-

[1] Eh values calculated from Sulfur Measurements.

[2] + indicates mean concentrations are statistically different between sampling dates at alpha= 0.05,
- indicates mean concentrations are not statistically different between sampling dates at alpha = 0.05.

Table 4.17 Mean Concentration of Measured Parameters on All Dates and Results of Two-Way ANOVA in the Deerlodge Wetland.

hydrograph. Sulfate levels were greatest in DL14, DL27, and DL4; these sulfate concentrations were up to two orders of magnitude greater than in the other wells.

4.2.4.2 Spatial and Temporal Variation

Statistical differences between mean concentrations of cations were not present from date to date. The results of the ANOVA on chemical environment and anion concentrations were varied; Eh, chloride, and sulfate were not statistically different from date to date. Means of the chemical environment were not different between locations. In addition, mean nitrate and dissolved zinc concentrations were not statistically different from location to location (Tables 4.16 and 4.17).

4.2.4.3 Trend Analysis

No linear regressions with an R^2 greater than 0.50 were reported during the post-peak sampling season. However, during the peak season, pH and dissolved oxygen decreased with distance. During baseflow, dissolved oxygen increased and dissolved zinc decreased with distance (Appendix D.3a).

4.2.4.4 Correlations between Parameters:

According to Appendix D.3b, the majority of correlations greater than 0.85 between measured chemical parameters and percent organic matter, percent carbonate, percent total pore space, and above ground herbaceous biomass were positive. Chloride was negatively correlated with pH in two out of three of the sampling seasons. Positive correlations in two out of three of the sampling seasons existed between chloride and sulfate, sulfate and nitrate, and dissolved iron and dissolved zinc. Specific conductivity had strong positive correlations with the majority of measured parameters in Deerlodge.

4.2.4.5 Cumulative Percent Composition

The percent ion composition of water sampled during peak season appears to be different than the waters collected during the other sampling periods. Sulfate makes up the largest percent of ions based on mg/l during all sampling periods (Appendix C.4a).

4.2.4.6 Mean Values in Soil, Water, and Plants

The soils had the greatest average percentage of all cations. The average percentages of potassium and sodium concentrations were greater than 20 percent in the plants. Sodium was partitioned in approximately 11 percent of the water (Table 4.18).

	Mean Concentration[2]	Mean Mass[3]	Mean Loading[4]	Percentage of Mean Loading[4]
Aluminum				
Water (mg/kg)[1]	2.69	3.31	8.91	0.00
Soil (mg/kg)	13808.77	13.28	183350.09	99.95
Plant (mg/kg)	33.12	2.59	85.64	0.05
Calcium				
Water (mg/kg)[1]	145.39	3.31	480.83	0.18
Soil (mg/kg)	18952.58	13.28	251648.53	94.31
Plant (mg/kg)	5687.39	2.59	14704.48	5.51
Iron				
Water (mg/kg)[1]	5.74	3.31	18.99	0.01
Soil (mg/kg)	11449.17	13.28	152019.73	99.80
Plant (mg/kg)	108.01	2.59	279.26	0.18
Potassium				
Water (mg/kg)[1]	5.87	3.31	19.41	0.02
Soil (mg/kg)	3895.74	13.28	51726.87	66.46
Plant (mg/kg)	10089.53	2.59	26086.03	33.52
Magnesium				
Water (mg/kg)[1]	44.85	3.31	148.34	0.18
Soil (mg/kg)	5852.73	13.28	77711.32	95.31
Plant (mg/kg)	1420.47	2.59	3672.57	4.50
Zinc				
Water (mg/kg)[1]	0.04	3.31	0.14	0.02
Soil (mg/kg)	47.19	13.28	626.58	86.39
Plant (mg/kg)	38.11	2.59	98.54	13.59
Sodium				
Water (mg/kg)[1]	217.87	3.31	720.54	10.81
Soil (mg/kg)	330.24	13.28	4384.92	65.78
Plant (mg/kg)	603.53	2.59	1560.39	23.41

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

[2] mg cation/ kg media

[3] kg media/ $.01 m^3$ soil

[4] mg cation in media/ $.01 m^3$ soil

Table 4.18 Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Deerlodge Samples Collected on 11/2/97.

5.0 GEOCHEMICAL DISCUSSION

5.1 Peru Creek Geochemical Discussion

The water collected from Peru Creek wells appears to be similar in percent composition of major ions from season to season with the exception of the first sampling period, snow melt. This sampling period was hydrologically distinct with the peat reservoir filling with water; the peat was saturated to the surface during the three remaining sampling events. Although there does not appear to be any significant differences between the ratios of ions in the peat and unconsolidated waters, there were from 12% to 22% more ions (mg/l) present in the unconsolidated waters than in the peat waters in all sampling periods. This may indicate that as water enters the peat layer from the unconsolidated layer, the peat acts to retain the ions in similar ratios as they exist in the unconsolidated layer.

According to Appendix C.1a, zinc is removed from the water passing through the peat, regardless of season, which indicates that this wetland is retaining the zinc. In addition, percent organic matter and percentage of total pore space are negatively correlated to dissolved zinc concentrations (Appendix C.1b). This indicates that soil properties affect the function of zinc retention and provides insight into the possible mechanisms for removal of zinc. A larger percent organic matter provides more sorptive capacity of the peat, and a larger volume of pore space allows more water to pass through. This potentially allows more dissolved cations to contact the peat surfaces.

In the unconsolidated wells, zinc levels decrease from upstream to downstream. This decrease could result from sorption of zinc to the peat layer as the ground-water contacts the lower peat surface.

Chemical parameters in Peru Creek varied with sampling date and sampling location (Figures 4.3 through 4.6). The presence of buried tailings deposits may act as isolated sources of cations and sulfates to the ground-water system in the wetland, resulting in the difference in means of element concentrations from location to location. It is hypothesized that hydrologic regime affects the concentration of anions and chemical parameters from date to date, but not cation concentrations. This may be due to the relatively high cation exchange capacity of the peat substrate which might decrease the mobility of the cations.

5. 2 Big Meadows Geochemical Discussion

The water collected from unconsolidated wells (those installed prior to 1997) and from peat wells (installed 1997) are dissimilar (Appendix C.2a and C.2b). The biggest difference is that in the unconsolidated wells, nitrates appear to make up the largest percent of ions in the waters. The water samples collected from the peat wells during the two drier seasons (post snow melt and post monsoon) appear to be similar. The monsoon season, however, is distinct; nitrate makes up the largest percent composition during this period. This can be explained by flushing of nitrates which are concentrated in the upper surface of the peat to subsurface layers during high water events. This is supported by Fenn et al. (1977) who states that the solubility of nitrates results in mobility impeded only by the restrictions of water percolation.

Although the linear regression of Big Meadows did not yield any strong trends, the wetland appears to be a sink for iron during all sampling seasons, and a source for sulfate and zinc during the low water events. The correlations of chemical parameters provides little insight into the causes of these observations. The lack of correlations and statistically significant regression could be due to poorly sealed unconsolidated wells, which were not originally intended for geochemical sampling, and are not a true representation of the processes taking place. The majority of these wells were screened to the surface water above ground. Although attempts were made to insure that these wells recharged from below the surface, it is possible that surface water was able to enter the voids around some of the wells. This is supported by the two-way ANOVA performed on the Big Meadows unconsolidated wells (Tables 4.10 and 4.11); if a combination of surface water and/or ground-water was sampled from the wells, location would be expected to affect some of the chemical parameters and cation concentrations in, as was the case. In addition, this lack of statistical difference between unconsolidated well locations is inconsistent with the effects of location on peat wells where neither cation nor anion concentrations were statistically different between dates or locations.

5. 3 Browns Park Geochemical Discussion

The percent composition of ions in Browns Park waters do not appear to vary seasonally, even though the concentrations of dissolved iron varied between sampling dates (Appendix C.3c). Although hydrologic flow paths were different throughout the season, ground-water generally flowed toward the river. The wetland was a source of metals and sulfate to the river throughout the sampling season. The slope of sulfate is greatest during the post peak sampling event (Appendix C.3a). This is immediately following a high water event and could result in the greatest amount of flushing of sulfates from surface layers. However, this pattern is not followed by the other chemical constituents, as would be expected if flushing is the dominant process.

The two-way ANOVA indicates that mean values of anion concentrations were not statistically different between sampling dates or locations. Effects on cation concentrations and chemical parameters were mixed (Tables 4.13 and 4.14). There were no consistent correlations identified throughout the season in Browns Park (Appendix C.3b). The lack of definite trends in this wetland could be due to the extreme heterogeneity in the subsurface. If the controlling factors of biogeochemical processes are related to the subsurface, then an investigation of the subsurface properties surrounding each well may lead to an increased understanding of the processes which affect the wetland functions.

5.4 Deerlodge Geochemical Discussion

As with Browns Park, there are no consistent correlations identified throughout the season (Appendix C.3b). The subsurface of Deerlodge is also highly heterogeneous and could dominate hydrologic flow paths and velocities, which may in turn affect biogeochemical cycles. The two-way ANOVA shows that the concentrations of three out of five of the chemical constituents varied with sampling date (Tables 4.16 and 4.17) . This tends to support the hydrologic conclusion that the dominant ground-water source varies from season to season, with the river contributing the greatest volume to the ground-water season during high water events.

The wetland is a source of sulfate during the peak and base flow events. The slope is greatest during peak flows which indicates that sulfate concentrations increase over the dry season and are flushed from the system during peak flows (Appendix C.3a). Reversed flows occur during the declining limb of the hydrograph; during this event, the wetland acts as a sink for sulfate. Given that flow paths are altered during this event and that heterogeneity in the subsurface exists, the processes that affect sulfate retention and release are different than during the peak and base flow events.

5. 5 Discussion of Seasonal Effects on Biogeochemical Cycles

The variations of concentrations of chemical constituents are hypothesized to be controlled predominantly by hydrologic cycles. In analyzing the data, clear relationships between hydrologic regime and chemical concentrations do not always exist. Several reasons exist for this lack of simple relationships. Biological cycles and chemical reactions with other elements will affect chemical concentrations. In addition the hydrologic factors which do affect chemical concentrations do not act separately; for example, a high water table during snow melt season would result in flushing and dilution. Flushing would be expected to increase concentrations of constituents which were concentrated in the upper layers, whereas dilution would be expected to decrease concentrations. Also, different chemical constituents would be expected to behave differently in the same environment. For example, nitrates and sulfates are soluble and should be easily flushed from the systems, whereas zinc may be bound to organic matter and may not flush as easily. Finally, the hydrologic cycles will affect the chemical environment by altering the redox potentials of the system. This will affect what oxidation state, and therefore in what physical state, chemical constituents are present.

Given the difficulty in assigning hydrologic causes to chemical results, it is possible to preliminarily explain the geochemical results presented here based upon the hydrology of the wetlands. Chloride is expected to be unreactive; as a result, chloride would be a good indicator of flushing versus drying and of concentration versus dilution. Iron, which would be expected to precipitate in reducing conditions, may indicate how long soils have been saturated. Variations in sulfate and nitrate concentrations may also be used to interpret redox conditions. Adsorption and desorption processes would be controlled by the amount of water present, and the length of saturation; zinc may be a good indicator of these processes. A final seasonal process which may affect all of geochemical cycles is biological activity; these processes are affected by hydrologic cycles, as well as general climatic cycles.

The Peru Creek wetland is discussed here as an example of possible interpretations of simplified geochemical cycles in relation to hydrologic cycles. In the Peru Creek wetland, average chloride concentration are greatest during snow melt in the peat and the unconsolidated wells. During this sampling event, although the peat reservoir was filling, the water table in the peat was at the lowest levels. The process of the filling of the peat reservoir could have resulted in flushing of chloride, while the relatively low water table levels mean the chloride concentrations in the water were more concentrated than during the remaining sampling periods. After the snow melt sampling period, the levels of the water table in the peat were relatively constant so that concentration and dilution in the peat layer was not a factor. Average chloride concentrations in the peat decreased during post snow melt, increased during monsoon, and decreased during post monsoon. The increase during monsoon could be the result of flushing. It also possible that the precipitation contained chloride which would have increased chloride inputs to the wetland system. In order to determine how much effect precipitation inputs had on the wetland system, it would be necessary to analyze precipitation. In the unconsolidated wells, the average chloride concentrations decreased from snow melt to post snow melt to monsoon, and increased from monsoon to post monsoon. This pattern is not easily explained and may be a result of a combination of hydrologic factors, as well as the interactions between the peat layer and the unconsolidated layer.

The approximate redox potentials for reduction of nitrate, iron, and sulfate are 250 mV, 120 mV, and -75 to -150 mV, respectively, given that these values will change with pH (Mitsch and Gosselink 1993). In interpreting the sulfate, nitrate and iron data, certain patterns should be present if redox conditions are the factors which control the concentrations of these constituents. As the Eh decreases, which would be expected during long periods of saturation, the concentrations of nitrate and sulfate should decrease as they are reduced and iron concentrations should increase as the solubility of iron increases with reducing conditions. Average sulfate concentrations do decrease over time in the unconsolidated wells, and average iron concentrations increase through the monsoon season in both the unconsolidated and peat wells. Calculated average Eh values do decrease through the monsoon sampling season and then increase slightly during post monsoon season. The average dissolved iron concentration decreases from monsoon season to post monsoon. In the presence of sulfide (reduced sulfate) the solubility of iron decreases. In the unconsolidated wells the decrease in iron concentrations coincides with a decrease in sulfate concentrations. If it is assumed that sulfate is reduced to sulfides, then the decrease in dissolved iron could be a result of iron sulfide precipitating. Nitrate concentrations do not show a consistent pattern. Although average nitrate concentrations do increase in the unconsolidated wells during high water input events, which may be the result of flushing, the nitrate cycle is biologically influenced. A combination of localized biological cycles, chemical interactions, and hydrologic cycles makes the interpretation of nitrate concentrations a difficult one. It is also possible that storage techniques of the water samples did not adequately preserve the nitrates in the water.

The concentration of zinc in water samples is affected by several processes. In anaerobic conditions and in the presence of sulfides, zinc sulfide precipitates will remove zinc from the water. Sorption of zinc to peat is affected by pH, contact time, and availability of sites. Reported pH values for sorption of zinc to peat range from 4.5 to 5.0 (Viraraghavan and Dronamraju 1993; Machemer and Wildeman 1992). McKay and Porter (1997) report that the sorption of zinc onto peat is irreversible at low pH and at increasing pH, processes other than sorption are involved in zinc removal, although the nature of these processes are not understood. Given the uncertainty in what the mechanisms for removal of zinc are, the greatest concentrations of zinc during the snow melt sampling period may be the result of flushing and concentration. Desorption and dilution may affect zinc concentrations over time.

6.0 WETLAND FUNCTIONS

An approach for determining the hydrologic functions of slope and riverine wetlands in the southern Rocky Mountains of Colorado was presented in Chapter 2.0. The application of this approach to four reference sites was presented in Chapter 3.0. Chapter 4.0 presented the approach used to characterize geochemical function for these same wetlands, and the application of the geochemical approach to four reference sites was presented in Chapter 5.0. The purpose of this chapter is to synthesize the results and observations to propose the quantitative form of these hydrologic and geochemical functions that occur in the southern Rocky Mountain wetlands. The hydrological and geochemical variables needed to complete the HGM assessment are defined, and a proposed ranking is provided. The testing of these functions and variables is proposed as future work. The design of this study was to determine the HGM functions, and did not enable the investigators to actually test the functions for quantitative values.

6.1 Hydrologic Functions

Fifteen hydrologic function equations are proposed for the southern Rocky Mountain wetlands (Table 6.1). These functions are defined in Table 2.2. Two of the functions pertain to the atmospheric processes (ATMin and ET); seven of the functions pertain to the surface water processes (SWin-riverine, SWin-slope, SWout-riverine, SWout-slope, SWstore-dynamic, SWstore-long term, and ED); and six of the functions pertain to the ground-water processes (GWinterception, GWmovement, GWout-river, GWout-springs and seeps, GWstorage-dynamic, and GWstorage-long term) (Table 6.1). Many of the functions were written so that the person evaluating the wetland had choices of selecting different variables in order to complete the HGM process (for example, see GWmove). The proposed hydrologic functions may be applied to all of the southern Rocky Mountains wetlands, regardless of HGM class, except SWin and SWout, which are separated on the basis of slope or riverine. However, the reference standards for each of

Hydrologic Function	Equation	Possible Substitutions
ATMin	$(V_{SP} + V_R)/2$	
ED	$\{[(V_K + V_{MT} + V_{TGL})/3] * V_{OFF}\}^{1/2}$	V_{OFF} may be replaced by V_{LS}
	or $\{[(V_K + V_B)/2] * V_{OFF}\}^{1/2}$	V_{OFF} may be replaced by V_{LS}
ET	$(V_{HY} + V_E)/2$	
GWinter	$(V_K * V_{HI} * V_{GWSS})^{1/3}$	
	or $(V_K * V_{DBC} * V_{TGBC} * V_{GWSS})^{1/4}$	
GWmove	{[(VK * VHGL)1/2 + VHY]/2 * (ATMIN)} 1/2	(ATMIN) may be replaced by (GWINTER) or VLS
	or {[((VK * ((VTGL + TTGBC)/2))1/2 + VHY]/2 * (ATMIN)} 1/2	(ATMIN) may be replaced by (GWINTER) or VLS
GWoutr	V_{GS}	
	or V_{HO}	
	or $(V_{TGBC} * V_{DBC})^{1/2}$	
GWoutss	V_{SS}	
	or V_{SW}	
GWstoredyn	[(VK * VSWH * VMT)1/3 * (ATMIN)]1/2	V_{MT} may be replaced by V_{TGL}
	or [(VK * VSWH * VMT)1/3 * (SWIN)]1/2	V_{MT} may be replaced by V_{TGL}
	or $[(V_K * V_{SWH} * V_{MT})^{1/3} * (V_{OFF})]^{1/2}$	V_{MT} may be replaced by V_{TGL}
GWstorelt	[VS * (ATMIN)]1/2	
	or $[V_S * V_{LS}]^{1/2}$	
	or [VS * (GWINTER)]1/2	
SWin (riverine)	$(V_{CHE} + V_{OFF})/2$	
SWin (slope)	$(V_{SS} + V_{CHE} + V_{OFF})/3$	
SWout (riverine)	V_{CHO}	
SWout (slope)	$(V_{OFSS} + V_{CHO})/2$	
SWstoredyn	{[(VTGL + VMT + VK)/3] * (ATMIN)} 1/2	(ATMIN) may be replaced by VOFF
SWstorelt	$\{[(V_{TGL} + V_{MT} + V_K)/3] * V_{SW}\}^{1/2}$	
	or $\{[(V_B + V_K)/2] * V_{SW}\}^{1/2}$	

Table 6.1 Proposed Hydrologic Functions for Slope and Riverine Wetlands in the Southern Rocky Mountain Wetlands. Unless Noted as Slope or Riverine, the Funtion Equations are Used for Both Classes.

the variables will vary between classes and subclasses. This indicates that the majority of hydrologic functions occur in both riverine and slope wetlands, but to different degrees.

Twenty-four variables were defined in order to complete the hydrologic function assessment process (Table 6.2). Table 6.3 provides a convenient reference for relating the hydrologic variables needed for the assessment of specific hydrologic functions.

Each of the variables was assigned a ranking between 0.0 and 1.0 with respect to the reference site (Table 6.4). The variables are listed with respect to hydrologic function that is being evaluated for a given wetland (Table 6.4). A high ranking (1.0) for a given variable indicates that the wetland is characterized as being at or near the same level as the reference site that has been studied. Similarly, a high ranking (1.0) for a given function (Table 6.1) indicates that the wetland is functioning at or near the same level as the reference site that has been studied. Generally, a high ranking (1.0) indicates that, for that function, the wetland is functioning to a high degree, whereas a low ranking (0.0) indicates that, for that function, the wetland is not functioning to a high degree or the function is not present.

6.2 Geochemical Functions

The hydrologic system is important to the assessment of biogeochemical function. Ground-water and surface water provides the source and transport mechanisms for metals and nutrients to move into and through the wetlands both horizontally and vertically. Degree of inundation in the wetland will affect the chemical environment which will affect the form in which the chemicals are present. Given these hydrologic system effects, the hydrologic variables and functions of Vw, ATMin, GWinter, and SWin (slope and riverine) (Table 6.1) were considered in the development of biogeochemical functions.

Soil characteristics provide the media through which chemicals are transported and a surface area on which reactions can occur. After the 3-D structure of the wetland has been determined, reactive layers can be identified. A determination of the input of each of the reactive layers would provide information as to what chemical species enter each layer. GWinter and ATMin may be the variables which would best indicate input and output of each layer. The volume of each reactive layer should also be considered. Finally, the reactive properties of each layer, such as cation exchange capacity, percent organic matter, and number of binding sites, should be considered.

The biological activity of a wetland provides the mechanisms for transformation and retention, and can alter the chemical environment. A measurement of biomass would indicate the degree to which plants transform and store nutrients and chemicals. However, the majority of metals and nutrients were located primarily in the soils. The variables which indicate herbaceous plants, therefore, should not be weighted as heavily as the soils. Microbial activity was not investigated in this study, but is a major component of biogeochemical cycles.

Hydrologic Variables	Definition
V_B	Beaver activity.
V_{CHE}	Surface water channel flow in the wetland. In riverine wetlands, wetland is defined as being on both sides of channel.
V_{CHO}	Surface water channel flow out of wetland. In riverine wetlands, wetland is defined as being on both sides of channel.
V_{DBC}	Direction of topographic slope on boundary conditions.
V_E	Evaporation due to wind, temperature, etc.
V_{GS}	Gaining stream in or on boundary of wetland.
V_{GWSS}	Subsurface source of ground-water outside wetland.
V_{HGL}	Head gradient on-site.
V_{HI}	Head off-site > head on-site, ground-water flows into wetland.
V_{HO}	Head of river < head on-site, ground-water flows out of wetland to river.
V_{HY}	Density and type of species of hydrophytes.
V_K	Hydraulic Conductivity of layers specified in ranking table.
V_{LS}	Losing stream in or on boundary of the wetland.
V_{MT}	Microtopography on-site.
V_{OFF}	Overland flow in the wetland due to flooding.
V_{OFSS}	Overland flow in wetland due to springs and/or seeps.
V_R	Infiltration and recharge of water into wetland from rain.
V_S	Storativity of subsurface layers.
V_{SP}	Infiltration and recharge of water into wetland from melting snowpack.
V_{SS}	Surface water flow in the wetland due to springs and/or seeps.
V_{SW}	Still water present on-site.
V_{SWH}	Head of surface water > head in ground-water system.
V_{TGBC}	Topographic gradient on boundary conditions.
V_{TGL}	Topographic gradient on-site.

Table 6.2 Identification and Definition of Hydrologic Variables Proposed for Southern Rocky Mountain Wetlands.

Hydrologic Variables	ATMin	ED	ET	GWinter	GWmove	GWoutr	GWoutss	GWstoredyn	GWstorelt	SWin	SWout	SWstoredyn	SWstorelt
V_{B}	O	X	O	O	O	O	O	O	O	O	O	O	X
V_{CHE}	O	O	O	O	O	O	O	O	O	X	O	O	O
V_{CHO}	O	O	O	O	O	O	O	O	O	O	X	O	O
V_{DBC}	O	O	O	X	O	X	O	O	O	O	O	O	O
V_{E}	O	O	X	O	O	O	O	O	O	O	O	O	O
V_{GS}	O	O	O	O	O	X	O	O	O	O	O	O	O
V_{GWSS}	O	O	O	X	O	O	O	O	O	O	O	O	O
V_{HGL}	O	O	O	O	X	O	O	O	O	O	O	O	O
V_{HI}	O	O	O	X	O	O	O	O	O	O	O	O	O
V_{HO}	O	O	O	O	O	X	O	O	O	O	O	O	O
V_{HY}	O	O	X	O	X	O	O	O	O	O	O	O	O
V_{K}	O	X	O	X	X	O	O	X	O	O	O	X	X
V_{LS}	O	X	O	O	X	O	O	O	X	O	O	O	O
V_{MT}	O	X	O	O	O	O	O	X	O	O	O	X	X
V_{OFF}	O	X	O	O	O	O	O	X	O	X	O	X	O
V_{OFSS}	O	O	O	O	O	O	O	O	O	O	X	O	O
V_{R}	X	O	O	O	O	O	O	O	O	O	O	O	O
V_{S}	O	O	O	O	O	O	O	O	X	O	O	O	O
V_{SP}	X	O	O	O	O	O	O	O	O	O	O	O	O
V_{SS}	O	O	O	O	O	O	X	O	O	X	O	O	O
V_{SW}	O	O	O	O	O	O	X	O	O	O	O	O	X
V_{SWH}	O	O	O	O	O	O	O	X	O	O	O	O	O
V_{TGBC}	O	O	O	X	X	X	O	O	O	O	O	O	O
V_{TGL}	O	X	O	O	X	O	O	X	O	O	O	X	X
Gwinter	O	O	O	O	X	O	O	O	X	O	O	O	O
SW_{IN}	O	O	O	O	O	O	O	X	O	O	O	O	O
ATMin	O	O	O	O	X	O	O	X	X	O	O	X	O

Table 6.3 Relationship Between Variables and Proposed Wetland Hydrologic Funtion in the Southern Rocky Mountains.

Function	Variables		
ATMin	Snowpack (V_{SP})	High Rank (1.0)	Average inches of snow per year = or > reference site
		Mid Rank (0.5)	Average inches of snow per year = 0.5 reference site
		Not Present (0.0)	Average inches per year of snow = 0.0
	Rain (V_R)	High Rank (1.0)	Average inches of rain per year = or > reference site
		Mid Rank (0.5)	Average inches of rain per year = 0.5 reference site
		Not Present (0.0)	Average inches of rain per year = 0.0
ED	Overland Flow- source flooding (V_{OFF})	High Rank (1.0)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where overland flow occurs) = or > reference site
		Mid Rank (0.5)	(Average volume of overland flow* Number of days per yearoverland flow present* Area of Wetland where overland flow occurs) = 0.5 reference site
		Not Present (0.0)	No Overland flow due to flooding present
	Losing Stream in or on Boundary of Wetland (V_{LS})	High Rank (1.0)	(Area of wetland in contact with losing stream/ area of wetland) = or > reference site
		Mid Rank (0.5)	(Area of wetland in contact with losing stream/ area of wetland) = 0.5 reference site
		Not Present (0.0)	No losing stream in or on boundary of wetland
	Microtopography (V_{MT})	High Rank (1.0)	Microtopographic complexity = or > reference site
		Mid Rank (0.5)	Microtopographic complexity = 0.5 reference site
		Not Present (0.0)	No microtopography present
	Beaver Activity (V_B)	High Rank (1.0)	Area of wetland affected by beaver activity = or > reference site
		Mid Rank (0.5)	Area of wetland affected by beaver activity = 0.5 reference site
		Not Present (0.0)	No beaver activity present
	Hydraulic Conductivity (V_K)	High Rank (1.0)	Hydraulic Conductivity of surface layer = or > reference site
		Mid Rank (0.5)	Hydraulic Conductivity of surface layer < reference site and = 0.5 reference site
		Not Present (0.0)	Hydraulic Conductivity of surface layer <<< reference site
	Low gradient on-site (V_{TGL})	High Rank (1.0)	Gradient on-site = or < reference site
		Mid Rank (0.5)	Gradient on-site > reference site, and = 0.5 reference site
		Not Present (0.0)	Gradient on-site >>> reference site

Table 6.4 Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
ET	Hydrophyte (V_{HY})	High Rank (1.0)	Rate of evapotranspiration = or > reference site and mass of biomass = or > reference site
		Mid Rank (0.5)	Either rate of evapotranspiration = or > reference site or mass of biomass = or > reference site.
		Not Present (0.0)	Hydrophytes not present
	Evaporation (V_E)	High Rank (1.0)	Evaporation >> precipitation, and (evaporation- precipitation) = or > reference site.
		Mid Rank (0.5)	Evaporation > precipitation, and (evaporation- precipitation) = 0.5 reference site.
		Not Present (0.0)	Precipitation < evaporation
GWinter	Peat		Used to aid in Hydraulic Conductivity Measurements
	BC slope direction into wetland (V_{DBC})	High Rank (1.0)	Gradient on Boundary Condition sloped towards wetland
		Mid Rank (0.5)	Gradient on Boundary Condition flat
		Not Present (0.0)	Gradient on All Boundary Conditions sloped away from wetland
	BC high gradient (V_{TGBC})	High Rank (1.0)	Gradient on boundary condition >> gradient on-site and (Gradient on boundary condition- gradient on-site) = or > reference site
		Mid Rank (0.5)	Gradient on boundary condition > gradient on-site and (Gradient on boundary condition- gradient on-site) = 0.5 reference site
		Not Present (0.0)	Gradient on Boundary Condition < Gradient on-site
	Head (V_{HI})	High Rank (1.0)	Head off-site >> head on-site and (head off-site - head on site) = or > reference site
		Mid Rank (0.5)	Head off-site > head on-site and (head off-site - head on site) = 0.5 reference site
		Not Present (0.0)	Head off-site < head on-site
	3-D structure		Use to determine ground-water subsurface source
	Hydraulic Conductivity (V_K)	High Rank (1.0)	Hydraulic conductivity of subsurface layers = or > reference site
		Mid Rank (0.5)	Hydraulic conductivity of subsurface layers = 0.5 reference site
		Not Present (0.0)	Surface layer a no-flow layer
	Ground-water Subsurface Source (V_{GWSS})	High Rank (1.0)	Ground-water in boundary conditions present year round and ground-water in boundary condition connected to ground-water in wetland
		Mid Rank (0.5)	Ground-water in boundary condition present seasonally, or ground-water in boundary condition not connected to ground-water in wetland
		Not Present (0.0)	Ground-water not present in boudary condition

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
GWmove	Hydrophyte (V_{HY})	High Rank (1.0)	Rate of evapotranspiration * biomass = or > reference site
		Mid Rank (0.5)	Rate of evapotranspiration * biomass = 0.5 reference site
		Not Present (0.0)	Hydrophytes not present
	Peat		Used to aid in Hydraulic Conductivity Estimate
	On-site gradient (V_{TGL})	High Rank (1.0)	On-site gradient = or > reference site
		Mid Rank (0.5)	On-site gradient =0.5 reference site
		Not Present (0.0)	On-site gradient < reference site
	(V_{HGL})	High Rank (1.0)	Head gradient on-site = or > reference site
		Mid Rank (0.5)	Head gradient on-site = 0.5 reference site
		Not Present (0.0)	Head gradient on-site = 0
	BC gradient (V_{TGBC})	High Rank (1.0)	Boundary Condition gradient = or > reference site
		Mid Rank (0.5)	Boundary Condition gradient = 0.5 reference site
		Not Present (0.0)	Boundary Condition gradient < reference site
	Hydraulic Conductivity (V_K)	High Rank (1.0)	Hydraulic conductivity of water bearing-units = or > reference site
		Mid Rank (0.5)	Hydraulic conductivity of water bearing-units = 0.5 reference site
		Not Present (0.0)	No water-bearing units present

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
GWoutr	Gaining Stream in or on the Boundary (V_{GS})	High Rank (1.0)	(Area of wetland in contact with gaining stream/ area of wetland) = or > reference site
		Mid Rank (0.5)	(Area of wetland in contact with gaining stream/ area of wetland) = 0.5 reference site
		Not Present (0.0)	No stream or gaining stream present
	BC slope direction away from wetland (V_{DBC})	High Rank (1.0)	Boundary condition gradient towards stream
		Mid Rank (0.5)	Boundary condition gradeint flat near stream
		Not Present (0.0)	Gradient not towards stream or no stream or channel present
	(V_{HO})	High Rank (1.0)	Head of stream <<< head on-site and (head of stream - head on site) = or > reference site
		Mid Rank (0.5)	Head of stream<< head on-site and (head of stream - head on site) = 0.5 reference site
		Not Present (0.0)	Head of stream > head on-site
	BC gradeint (V_{TGBC})	High Rank (1.0)	Topographic slope gradient towards river = or > reference site
		Mid Rank (0.5)	Topographic slope gradient towards river = 0.5 reference site
		Not Present (0.0)	Topographic slope gradient = 0.0
GWoutss	Spring/seeps (V_{SS})	High Rank (1.0)	(Number of springs present on site or immediate boundary conditions * volume of water from springs* number of days per year present) = or > reference site.
		Mid Rank (0.5)	(Number of springs present on site or immediate boundary conditions * volume of water from springs* number of days per year present) = 0.5 reference site.
		Not Present (0.0)	No springs or seeps present

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
GWstoredyn	Mineral		Used to aid in Hydraulic Conductivity estimates
	Low Gradient on-site (V_{TGL})	High Rank (1.0)	Gradient on-site = or < reference site
		Mid Rank (0.5)	Gradient on-site = 0.5 reference site
		Not Present (0.0)	Gradient on-site > reference site
	Microtopography (V_{MT})	High Rank (1.0)	Microtopographic complexity = or > reference site
		Mid Rank (0.5)	Microtopographic complexity = 0.5 reference site
		Not Present (0.0)	No microtopography present
	Hydraulic Conductivity (V_K)	High Rank (1.0)	Hydraulic conductivity of surface layer = or > reference site
		Mid Rank (0.5)	Hydraulic conductivity of surface layer = 0.5 reference site
		Not Present (0.0)	Surface layer a no-flow layer
	Surface Water Head (V_{SWH})	High Rank (1.0)	Head of surface water >>> head in ground-water system and (head of surface water- head of ground-water) = or> reference site
		Mid Rank (0.5)	Head of surface water >> head in ground-water system and (head of surface water- head of ground-water) = 0.5 reference site
		Not Present (0.0)	Head of surface water < head in ground-water system
	Overland Flow- Source Flooding (V_{OFF})	High Rank (1.0)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where flow occurs) = or > reference site
		Mid Rank (0.5)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where flow occurs) = 0.5 reference site
		Not Present (0.0)	No Overland flow due to flooding present

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
GWstoreIt	Peat		Used to aid in Storativity estimates
	Losing stream in or on Boundary of Wetland (V_{LS})	High Rank (1.0)	(Area of wetland in contact with losing stream/ area of wetland) = or > reference site
		Mid Rank (0.5)	(Area of wetland in contact with losing stream/ area of wetland) = 0.5 reference site
		Not Present (0.0)	No stream or losing stream present
	Storativity (V_S)	High Rank (1.0)	Storativity of Connected Subsurface aquifers * Volume of Connected Subsurface Aquifers = or > reference site
		Mid Rank (0.5)	Storativity of Connected Subsurface aquifers * Volume of Connected Subsurface Aquifers = 0.5 reference site
		Not Present (0.0)	No subsurface aquifers present
SWin	Springs/seeps (V_{SS})	High Rank (1.0)	(Number of springs present on site or immediate boundary conditions * volume of water from springs* number of days per year present) = or > reference site.
		Mid Rank (0.5)	(Number of springs present on site or immediate boundary conditions * volume of water from springs* number of days per year present) = 0.5 reference site.
		Not Present (0.0)	No springs or seeps present
	Overland Flow- source flooding (V_{OFF})	High Rank (1.0)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where flow occurs) = or > reference site
		Mid Rank (0.5)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where flow occurs) = 0.5 reference site
		Not Present (0.0)	No Overland flow due to flooding present
	Channel Enters Wetland (V_{CHE})	High Rank (1.0)	Average volume of water in channel * number of days water present= or > reference site
		Mid Rank (0.5)	Average volume of water in channel * number of days water present= 0.5 reference site
		Not Present (0.0)	No channel present or no water in channel

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
SWout	Overland Flow- source springs/seeps (V_{OFSS})	High Rank (1.0)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where overland flow occurs) = or > reference site
		Mid Rank (0.5)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where overland flow occurs) = 0.5 reference site
		Not Present (0.0)	No overland flow due to flooding present
	Channel Exits Wetland (V_{CHO})	High Rank (1.0)	Volume of Water which exits wetland as surface water = or > reference site
		Mid Rank (0.5)	Volume of Water which exits wetland as surface water = 0.5 reference site
		Not Present (0.0)	No channel present or no water exits wetland as surface water
SWstoredyn	Peat/Mineral		Used to aid in hydraulic conductivity estimates
	Overland Flow- Source Flooding (V_{OFF})	High Rank (1.0)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where flow occurs) = or > reference site
		Mid Rank (0.5)	(Average volume of overland flow* Number of days per year overland flow present* Area of Wetland where flow occurs) = 0.5 reference site
		Not Present (0.0)	No Overland flow due to flooding present
	Low Gradient on-site (V_{TGL})	High Rank (1.0)	Gradient on-site = or < reference site
		Mid Rank (0.5)	Gradient on-site > reference site, and = 0.5 reference site
		Not Present (0.0)	Gradient on-site >>> reference site
	Microtopography (V_{MT})	High Rank (1.0)	Microtopographic complexity = or > reference site
		Mid Rank (0.5)	Microtopographic complexity = 0.5 reference site
		Not Present (0.0)	No microtopography present
	Hydraulic Conductivity (V_K)	High Rank (1.0)	Hydraulic Conductivity of surface layer = or < reference site
		Mid Rank (0.5)	Hydraulic Conductivity of surface layer > reference site and = 0.5 reference site
		Not Present (0.0)	Hydraulic Conductivity of surface layer >>> reference site

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Function	Variables		
SWstoreIt	Low gradient on-site (V_{TGL})	High Rank (1.0)	Gradient on-site = or < reference site
		Mid Rank (0.5)	Gradient on-site > reference site, and = 0.5 reference site
		Not Present (0.0)	Gradient on-site >>> reference site
	Microtopography (V_{MT})	High Rank (1.0)	Microtopographic complexity = or > reference site
		Mid Rank (0.5)	Microtopographic complexity = 0.5 reference site
		Not Present (0.0)	No microtopography present
	Beaver activity (V_B)	High Rank (1.0)	Area of wetland affected by beaver activity = or > reference site
		Mid Rank (0.5)	Area of wetland affected by beaver activity = 0.5 reference site
		Not Present (0.0)	No beaver activity present
	Hydraulic Conductivity (V_K)	High Rank (1.0)	Hydraulic Conductivity of surface layer = or < reference site
		Mid Rank (0.5)	Hydraulic Conductivity of surface layer > reference site and = 0.5 reference site
		Not Present (0.0)	Hydraulic Conductivity of surface layer >>> reference site
	Peat		Used to aid in estimation of hydraulic conductivity
	Still Water (V_{SW})	High Rank (1.0)	Volume of wateer present * Number of days water present = or > reference site
		Mid Rank (0.5)	Volume of wateer present * Number of days water present = 0.5 reference site
		Not Present (0.0)	No still water present on surface of wetland

Table 6.4cont. Proposed Ranking of Variables for Hydrologic Functions in Southern Rocky Mountain Wetlands.

Biogeochemical Function	Equation
MN_{move}	$\{[(V_K + V_n) +((V_{VEG} +V_D)/2)]/3 * [(ATM_{IN}) + (SW_{IN}) + (GW_{INTER}) + (V_W)]/4\} 1/2$
M_{store}	$\{[(V_M + V_O)/2] * [(ATM_{IN}) + (SW_{IN}) + (GW_{INTER}) + (V_W)]/4\} 1/2$
or M_{store} (riverine)	$[(0.4 * (V_{DEPTH} * V_{DUR})) + (0.4 * (V_{SORPT} * V_{THICK})) + (0.2 * (V_{PROD} - V_{TURN}))]$
or MN_{store} (slope)	$[((V_{DEPTH} * V_{DUR})^{1/2}) * ((V_{SORPT} * V_{THICK})^{1/2}) * ((V_{PROD} - V_{TURN})/2)]^{1/3}$
M_{trans}	$\{[(V_M + V_O + V_{MIC} + (GW_{STORELT}) + (GW_{MOVE}))/5] * [(ATM_{IN}) + (SW_{IN}) + (GW_{INTER}) + (V_W)]/4\} 1/2$
N_{store}	$\{[(V_M + V_O + V_{VEG})/3] * [(ATM_{IN}) + (SW_{IN}) + (GW_{INTER}) + (V_W)]/4\} 1/2$
or N_{store} (riverine)	$[((V_{DEPTH} * V_{DUR})^{1/2}) * ((V_{SORPT} * V_{THICK})^{1/2}) * ((V_{PROD} - V_{TURN})/2)]^{1/3}$
or MN_{store} (slope)	$[((V_{DEPTH} * V_{DUR})^{1/2}) * ((V_{SORPT} * V_{THICK})^{1/2}) * ((V_{PROD} - V_{TURN})/2)]^{1/3}$
N_{trans}	$\{[(V_M + V_O + V_{MIC} + V_{VEG} + (GW_{STORELT}) + (GW_{MOVE}))/6] * [(ATM_{IN}) + (SW_{IN}) + (GW_{INTER}) + (V_W)]/4\} 1/2$

Table 6.5 Proposed Biogeochemical Functions for Slope and Riverine Wetlands in the Southern Rocky Mountain Wetlands. Unless Noted as Slope or Riverine, the Function Equations are Used for Both Classes.

Function Abbreviation	Function Name	Function Defined
MN_{move}	Movement of chemicals	The movement of cations and anions through the wetland by advection and dispersion, chemical properties do not change.
MN_{store}	Storage of chemicals	The retention of chemicals by the wetland.
M_{store}	Storage of cations (e.g. heavy metals)	The storage of cations in the wetland.
M_{trans}	Conversion of cations (e.g. heavy metals)	The conversion and/or transformation of cations in the wetland.
N_{store}	Storage of anions (e.g. sulfate, nitrate)	The storage of anions in the wetland.
N_{trans}	Conversion of anions (i.e sulfate, nitrate)	The conversion and/or transformation of anions in the wetland.

Table 6.6 Definition of Proposed Biogeochemical Functions in the Southern Rocky Mountain Wetlands.

Biogeochemical Variables	Definition
V_n	Porosity of media.
V_K	Hydraulic conductivity of media.
V_{VEG}	Density and type of vegetation present.
V_D	Dispersion of ground-water in wetland.
V_M	Composition of mineral soils.
V_O	Composition of organic matter (e.g. peat).
V_{MIC}	Microbial activity.
V_W	Weathering of geologic/geomorphic materials.
V_{DEPTH}	Depth of water-table or flooding.
V_{DUR}	Duration of high water table or flooding.
V_{SORPT}	Sorptive properties of biogeochemically active layer.
V_{THICK}	Thickness of biogeochemically layer.
V_{PROD}	Aerial net primary productivity.
V_{TURN}	Annual turnover of detritus.

Table 6.7 Identification and Definition of Biogeochemical Variables Proposed for Southern Rocky Mountain Wetlands.

Biogeochemistry Variables	MN_{move}	M_{store}	M_{trans}	N_{store}	N_{trans}	M_{store} (riverine)	N_{store} (riverine)	MN_{store} (slope)
V_n	X	O	O	O	O	O	O	O
V_K	X	O	O	O	O	O	O	O
V_{VEG}	X	O	O	X	X	O	O	O
V_D	X	O	O	O	O	O	O	O
V_M	O	X	X	X	X	O	O	O
V_O	O	X	X	X	X	O	O	O
V_{MIC}	O	X	X	X	X	O	O	O
V_W	X	X	X	X	X	O	O	O
V_{DEPTH}	O	O	O	O	O	X	X	X
V_{DUR}	O	O	O	O	O	X	X	X
V_{SORPT}	O	O	O	O	O	X	X	X
V_{THICK}	O	O	O	O	O	X	X	X
V_{PROD}	O	O	O	O	O	X	X	X
V_{TURN}	O	O	O	O	O	X	X	X
ATM_{IN}	X	X	X	X	X	O	O	O
SW_{IN}	X	X	X	X	X	O	O	O
GW_{INTER}	X	X	X	X	X	O	O	O
$GW_{STORELT}$	O	O	X	O	X	O	O	O
GW_{MOVE}	O	O	X	O	X	O	O	O

Table 6.8 Relationship Between Variables and Proposed Wetland Biogeochemical Function in the Southern Rocky Mountain Wetlands.

Function	Variables		
M_{move}	V_n	High Rank (1.0)	Porosity of subsurface layer = or > reference site.
		Mid Rank (0.5)	Porosity of subsurface layer = 0.5 reference site.
		Not Present (0.0)	Porosity of subsurface layer <<<< reference site.
	V_K	High Rank (1.0)	Hydraulic conductivity of subsurface layer = or > reference site.
		Mid Rank (0.5)	Hydraulic conductivity of subsurface layer = 0.5 reference site.
		Not Present (0.0)	Hydraulic conductivity of subsurface layer <<<< reference site.
	V_{VEG}	High Rank (1.0)	Biomass of on-site vegetation = or > reference site.
		Mid Rank (0.5)	Biomass of on-site vegetation = 0.5 reference site.
		Not Present (0.0)	No vegetation present on-site.
	V_D	High Rank (1.0)	Dispersion coefficient = or > reference site.
		Mid Rank (0.5)	Dispersion coefficient = 0.5 reference site.
		Not Present (0.0)	Dispersion coefficient <<<< reference site.
	V_W	High Rank (1.0)	Rate of weathering * surface area of geologic/geomorphic materials = or > reference site.
		Mid Rank (0.5)	Rate of weathering * surface area of geologic/geomorphic materials = 0.5 reference site.
		Not Present (0.0)	Rate of weathering * surface area of geologic/geomorphic materials = 0
M_{store}	V_M	High Rank (1.0)	Percent silt/sand/clay similar to reference standard.
		Mid Rank (0.5)	Percent sand >> reference site.
		Not Present (0.0)	Percent sand >>>> reference site.
	V_{VEG}	High Rank (1.0)	Biomass of on-site vegetation = or > reference site.
		Mid Rank (0.5)	Biomass of on-site vegetation = 0.5 reference site.
		Not Present (0.0)	No vegetation present on-site.
	V_P	High Rank (1.0)	Percent organic matter = or > reference site.
		Mid Rank (0.5)	Percent organic matter = 0.5 reference site.
		Not Present (0.0)	No organic matter present.
	V_W	High Rank (1.0)	Rate of weathering * surface area of geologic/geomorphic materials = or > reference site.
		Mid Rank (0.5)	Rate of weathering * surface area of geologic/geomorphic materials = 0.5 reference site.
		Not Present (0.0)	Rate of weathering * surface area of geologic/geomorphic materials = 0

Table 6.9 Proposed Ranking of Variables for Geochemical Functions in Southern Rocky Mountain Slope and Riverine Wetlands.

Function	Variables		
M_{trans}	V_M	High Rank (1.0)	Percent silt/sand/clay similar to reference standard.
		Mid Rank (0.5)	Percent sand >> reference site.
		Not Present (0.0)	Percent sand >>>> reference site.
	V_{VEG}	High Rank (1.0)	Biomass of on-site vegetation = or > reference site.
		Mid Rank (0.5)	Biomass of on-site vegetation = 0.5 reference site.
		Not Present (0.0)	No vegetation present on-site.
	V_P	High Rank (1.0)	Percent organic matter = or > reference site.
		Mid Rank (0.5)	Percent organic matter = 0.5 reference site.
		Not Present (0.0)	No organic matter present.
	V_{MIC}	High Rank (1.0)	Substrate available for microbial activity = or > reference site.
		Mid Rank (0.5)	Substrate available for microbial activity = 0.5 reference site.
		Not Present (0.0)	No substrate avilable for microbial activity.
	V_W	High Rank (1.0)	Rate of weathering * surface area of geologic/geomorphic materials = or > reference site.
		Mid Rank (0.5)	Rate of weathering * surface area of geologic/geomorphic materials = 0.5 reference site.
		Not Present (0.0)	Rate of weathering * surface area of geologic/geomorphic materials = 0

Table 6.9cont. Proposed Ranking of Variables for Geochemical Functions in Southern Rocky Mountain Slope and Riverine Wetlands.

Function	Variables		
M_{store} (riverine), Nstore (riverine), and MNstore (slope)	V_{depth}	High Rank (1.0)	Depth to water table or depth of inundation is = or > reference standard.
		Mid Rank (0.5)	Depth to water table or depth of inundation is = 0.5 reference standard.
		Not Present (0.0)	Depth to water table or depth of inundation is <<<< reference standard.
	Vdur	High Rank (1.0)	Number of days high water table present = or > reference standard
		Mid Rank (0.5)	Number of days high water table present = 0.5 reference standard
		Not Present (0.0)	Number of days high water table present <<< reference standard
	Vsorpt	High Rank (1.0)	Sorptive properties of soil = or > reference standards (e.g. % organic matter, cation exchange capacity, and/or base saturation)
		Mid Rank (0.5)	Sorptive properties of soil = 0.5 reference standards (e.g. % organic matter, cation exchange capacity, and/or base saturation)
		Not Present (0.0)	Sorptive properties of soil <<< reference standards (e.g. % organic matter, cation exchange capacity, and/or base saturation)
	Vthick	High Rank (1.0)	Thickness of biogeochemical layer = or > reference standard
		Mid Rank (0.5)	Thickness of biogeochemical layer = 0.5 reference standard
		Not Present (0.0)	Thickness of biogeochemical layer <<< reference standard
	Vprod	High Rank (1.0)	Productivity = or > reference standard
		Mid Rank (0.5)	Productivity = 0.5 reference standard
		Not Present (0.0)	Productivity <<< reference standard
	Vturn	High Rank (1.0)	Turnover = or > reference standard
		Mid Rank (0.5)	Turnover = 0.5 reference standard
		Not Present (0.0)	Turnover <<< reference standard

Table 6.9cont. Proposed Ranking of Variables for Geochemical Functions in Southern Rocky Mountain Slope and Riverine Wetlands.

As has been presented in Chapters 4.0 and 5.0, the biogeochemistry of wetlands is complex. The data have shown that hydrologic regime, soil characteristics, and biological activity do affect the retention, transformation, and release of metals and nutrients.

Eight geochemical function equations are proposed for the southern Rocky Mountain wetlands (Table 6.5). These functions are defined in Table 6.6. Two of the functions pertain to cations, such as zinc, (Mstore, and Mtrans); two of the functions pertain to anions, such as nitrate and sulfate, (Ntrans and Nstore); and one of the functions pertains to both the anions and cations (MNmove). Three alternate functions are also presented in Table 6.5 (Mstore (riverine), MNstore (slope), and Nstore (riverine)). The alternate functions are proposed in an attempt to develop geochemical functions which are easily measured in the field during the wetland delineation. Unless noted, the proposed biogeochemical functions may be applied to all of the southern Rocky Mountains wetlands, regardless of class or subclass. As with the proposed hydrologic functions, the reference standards will vary between classes and subclasses.

Fourteen variables and five hydrologic functions were defined in order to complete the biogeochemical function assessment process (Table 6.7). Table 6.8 provides a convenient reference for relating the biogeochemical variables needed for the assessment of specific hydrologic functions.

As described in section 6.1, each of the variables was assigned a ranking between 0.0 and 1.0 with respect to the reference site (Table 6.9). The variables are listed with respect to biogeochemical function that is being evaluated for a given wetland (Table 6.9).

7.0 CONCLUSIONS

A step-wise, integrated hydrogeomorphic approach for the classification of wetlands in the southern Rocky Mountains, Colorado, was developed. This approach is used to classify the main wetland types, and to provide a framework for determining wetland hydrologic function. The conceptualization and characterization of ground-water flow systems approach and logic developed by Kolm (1993), Kolm et al. (1996), and Kolm and van der Heijde (1996) was incorporated with the Hydrogeomorphic Approach (HGM) as developed by Brinson (1993) to develop this classification and to determine wetland function.

Five reference sites representing southern Rocky Mountain wetlands were selected and accompanying field studies were conducted. The reference wetlands were used to study site-specific hydrogeomorphic characteristics, such as ground-water and surface water, soils, and geomorphology, using the procedures developed as part of the new approach, and to determine wetland hydrologic functions. In addition, the geochemistry of these reference wetlands was characterized, and the variables that should be measured to determine geochemical functions of Colorado wetlands were identified. The result was an enhanced understanding of the surface water, ground-water, and geochemical functions observed in the reference wetland sites in the southern Rocky Mountains.

The approach to wetlands characterization and HGM classification included the following analyses: surface features, including hydrophytes, peat and mineral soils, surface water, topography, beaver activity; subsurface features, including geomorphologic deposits, geology, and hydrogeology; and ground-water system features, including water levels, recharge, and discharge. These analyses resulted in identifying the critical hydrologic functions in the southern Rocky Mountain wetlands, the critical variables that could be assessed for determining wetland function, and the two classes: slope and riverine, that are observed. Four reference sites, including two slope wetland sites: Peru Creek Wetland and Big Meadows Wetland, and two riverine wetland sites: Browns Park Wetland and Deerlodge Wetland, were characterized by variables and function, and classified using this new HGM approach and classification.

As a result of the reference site analysis and HGM method development, 15 hydrologic function equations are proposed for the southern Rocky Mountain wetlands (Table 6.1). two of the functions pertain to the atmospheric processes (ATMin and ET); seven of the functions pertain to the surface water processes (SWin-riverine, SWin-slope, SWout-riverine, SWout-slope, SWstore-dynamic, SWstore-long term, and ED); and six of the functions pertain to the ground-water processes (GWinterception, GWmovement, GWout-river, GWout-springs and seeps, GWstorage-dynamic, and GWstorage-long term) (Table 6.1). Twenty-four variables were defined in order to complete the hydrologic function assessment process (Table 6.2). Each of the variables was assigned a ranking between 0.0 and 1.0 with respect to the reference site (Table 6.4).

The results of the geochemical analysis conducted at the four reference sites were analyzed using ANOVA, linear regression, correlation, mass balances, and spatial analysis. The results showed that the geochemistry of wetland sites is spatially affected by the hydrology, and is influenced by other biogeochemical cycles, including the iron, sulfur and nitrogen cycles. Retention, transport, and chemical reactions of metals and other nutrients were observed to be directly and indirectly influenced by hydrology, soil properties, and biological activity of the wetland.

As a result of the reference site analyses, eight geochemical function equations are proposed for the southern Rocky Mountain wetlands (Table 6.5). Two of the functions pertain to cations (Mstore and Mtrans); two of the functions pertain to anions (Nstore and Ntrans); one of the functions pertains to both the metals and nutrients (MNmove), and three of the functions are proposed as alternative functions (Mstore (riverine), MNstore (slope), and Nstore (riverine)) (Table 6.5). Fourteen variables and five hydrologic functions were defined in order to complete the biogeochemical function assessment process (Table 6.6). Each of the variables was assigned a ranking between 0.0 and 1.0 with respect to the reference site (Table 6.8).

8.0 RECOMMENDATIONS

Based upon the research presented in this paper, our recommendations include the following topics: selection of additional reference sites, refinement of sampling and characterization program, and testing and refinement of the functions proposed in this paper.

8.1 Selection of Additional Reference Sites

Additional reference sites should be chosen to include a broader range of HGM classes and subclasses. The slope reference wetlands that were chosen include only the peat subclass. The wetlands of Peru Creek and Big Meadows, which were chosen to represent the peat subclass, are considered to be good choices for HGM reference sites. Despite the apparent complexity of these systems, these slope wetlands appear to represent classic wetland system structures.

It is our belief that willow carr wetlands, which were not investigated in this study, comprise an equally important HGM subclass of slope wetlands. Willow carrs are more common than peat wetlands in the southern Rocky Mountains. In addition, willow carrs, given their typical location, are expected to be more impacted by urban growth and development.

The two riverine wetlands located in north western Colorado, Deerlodge and Browns Park, are not considered by the investigators to be typical of the southern Rocky Mountains, and may be more representative of Colorado Plateau wetlands. It is our belief that future studies of riverine wetlands should be located within the mountainous regions of Colorado where variables, such as climate, and functions, such as the **atmosphere in,** are more representative. In addition, HGM riverine wetland investigations should include the entire system (both sides of the river) instead of one bottom adjacent to a river. It is believed that these bottom lands are connected by ground-water and surface water, and, therefore, do not function as two separate units, but rather as a single wetland system.

8.2 Refinement of Sampling and Characterization Program

The sampling program that was used to characterize the reference wetlands should be refined. Initially, the wetland system should be conceptualized based upon the HGM classification presented in chapter 2 of this paper. By incorporating this analysis as an initial step, the location and installation of wells for hydrologic and geochemical sampling can be designed to best address the hypotheses developed during the system analysis.

The depth, location, and design of the wells at the four HGM reference sites was not optimal for addressing the HGM classification needs. Most of the wells were at shallow depths, and the well design and completion were primitive. Many of the wells were completed in multiple hydrogeologic units (for example, peat and unconsolidated materials). Drilling records were not completed when the wells were installed. As a result, the top few feet of the ground-water system could be characterized, but the three-dimensional flow could not be assessed. Additional wells were placed to partially offset this problem, but future wells should be installed spatially to test the three-dimensional nature and boundary conditions of the wetland system reference sites.

The geochemical sampling could be redesigned so that a more complete understanding of the geochemical cycles can be achieved. The carbon, sulfur, and metals cycles are interrelated and are, therefore, hypothesized to be the cycles which must be fully investigated for determinations of wetland geochemical functions in the southern Rocky Mountains. It is suggested that a more controlled field study be conducted, with samples taken which are representative of the boundary conditions of all soil and/or rock layers and analyses be conducted which represent different parts of the chemical cycles.

8.3 Testing and Refinement of Proposed Functions

This study proposed function equations and variables that are useful for HGM classification. Further testing and refinement is needed to determine if the functions and variables proposed are valid, and if the functions and variables are weighted correctly within the equations. In order to test these functions, variables, and equations, additional field studies at existing sites, and at additional reference sites should be undertaken as recommended in Sections 8.1 and 8.2. In order for the implementation of HGM classification to be effective, specific reference site variables and weightings must be measured, estimated, or assigned, and classification keys developed.

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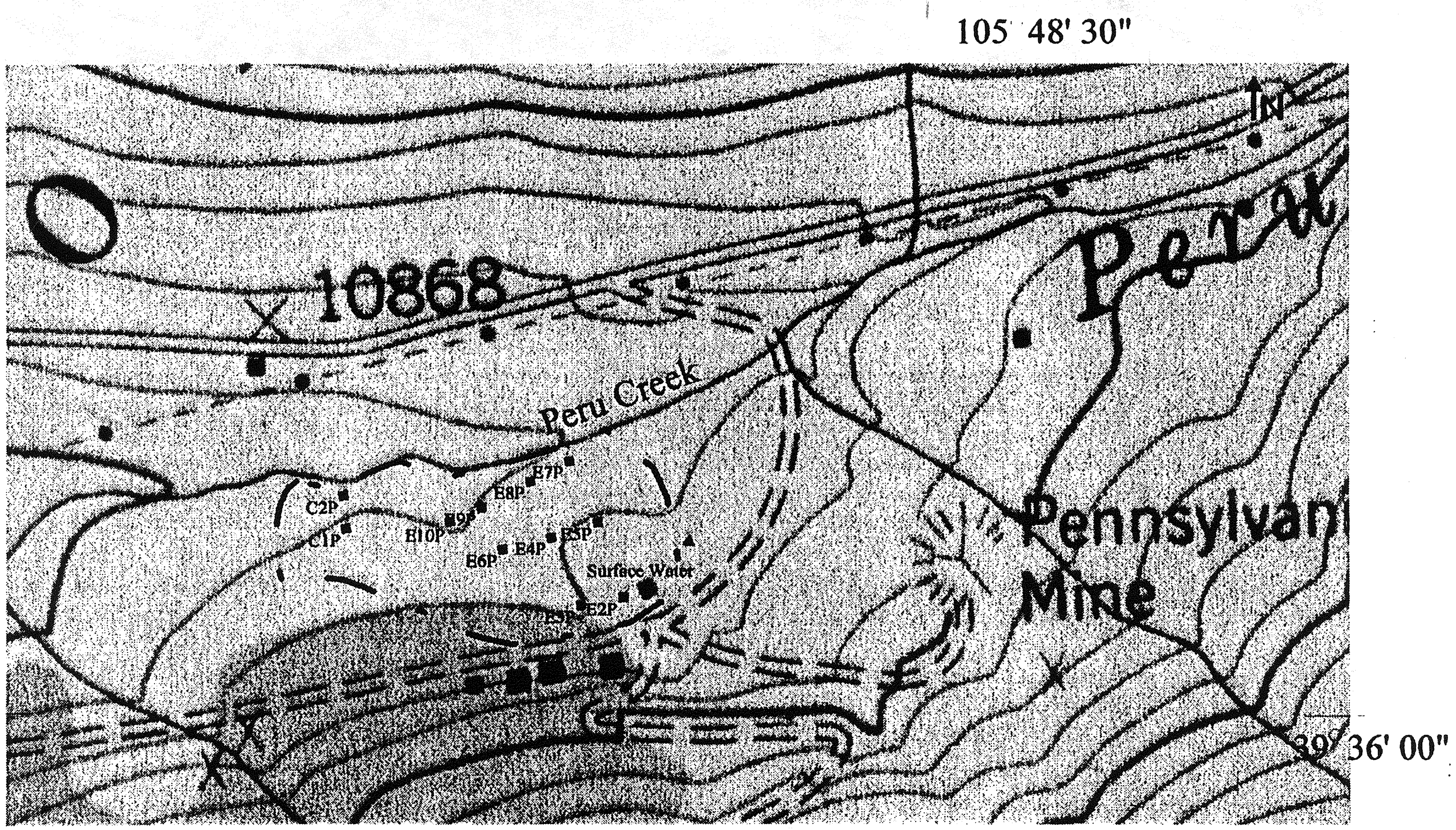
Appendix A.1a Sampling Locations at Pennsylvania Mine.

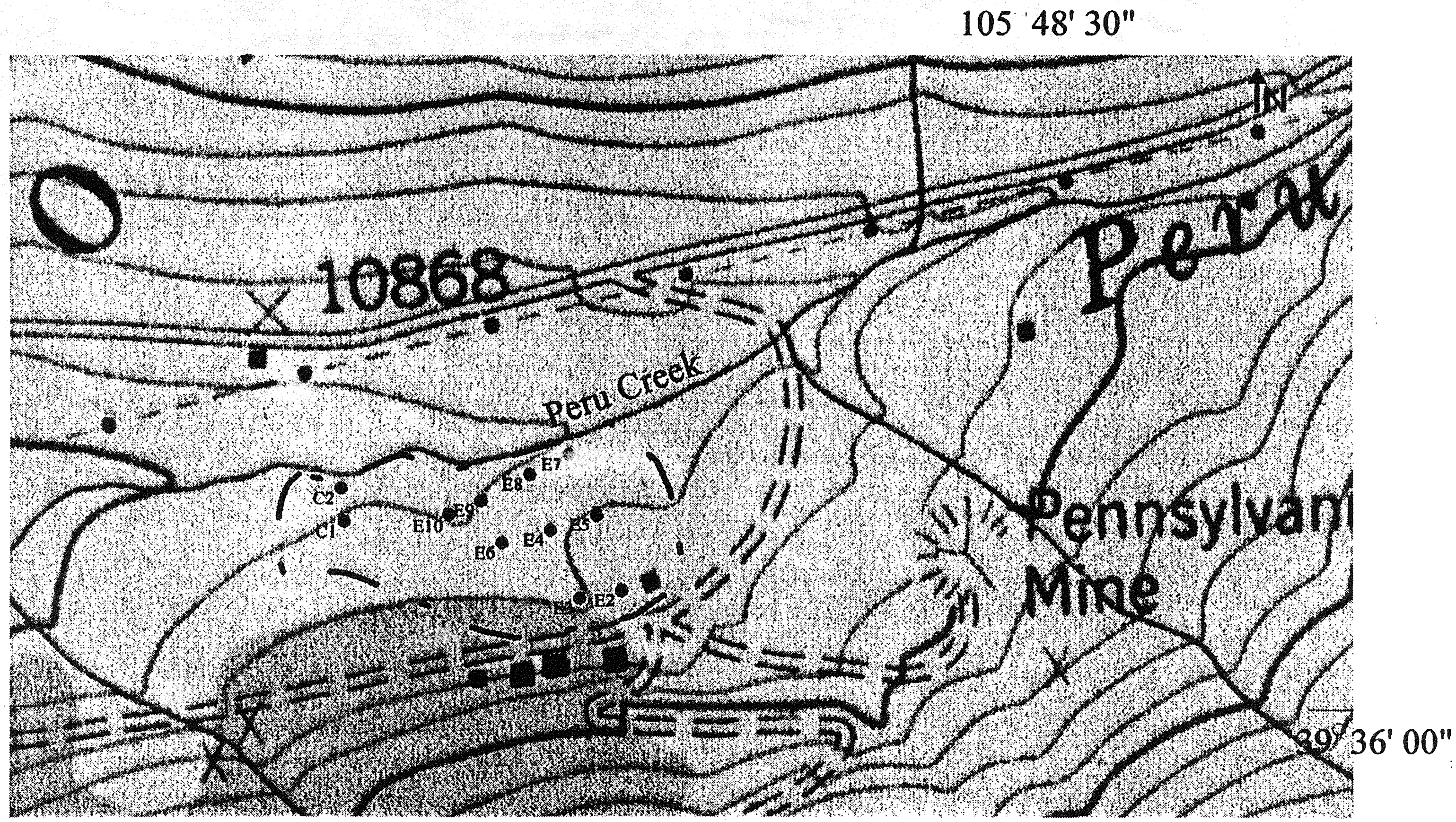


▲ Surface Water

◆ Peat Ground-Water Wells

— - Pennsylvania Mine Wetland Boundary

Appendix A.1a Sampling Locations at Pennsylvania Mine.



- ● Unconsolidated Ground-Water Wells
- —— - Pennsylvania Mine Wetland Boundary

Analysis Performed												
Well Number	GWC1	GWC1	GWC1	GWC1	GWC1P	GWC1P	GWC1P	GWC1P	GWC2	GWC2	GWC2	GWC2
Date of Collection	6/19/97	8/4/97	9/13/97	10/18/97	6/20/97	8/5/97	9/13/97	10/18/97	6/19/97	8/4/97	9/13/97	10/18/97
Field Measurements												
Eh (mV)	389.2	340.2	376.8	431.1	421.6	413.4	365.2	367.2	121.4	121.7	71.0	239.6
pH	4.1	4.1	4.2	4.1	4.3	4.2	4.2	4.1	4.3	4.3	4.7	4.6
Temp (°C)	11.3	8.8	16.0	10.2	9.1	9.9	16.3	3.9	9.7	14.1	14.9	7.1
D.O. (mg/l)	2.6	3.2	3.3	3.6	4.1	2.8	3.2	3.8	3.9	3.0	3.9	3.8
Alkalinity in field (mg/l $CaCO_3$)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Field Eh to H_2 electrode (mV)	576.1	533.1	567.9	622.2	619.3	604.1	669.3	671.3	308.3	314.6	262.1	430.7
Calculated Eh (mV)	32.8	30.5	20.9	32.7	22.5	23.0	24.9	32.9	22.5	15.5	-11.4	1.8
Anions												
Fluoride	4.10	2.66	3.60	2.81	4.68	2.94	3.11	2.93	2.83	1.69	2.77	1.36
Chloride	5.04	0.21	0.93	0.26	5.64	0.63	0.88	0.09	3.81	0.40	0.74	1.57
Nitrate	3.77	0.00	0.00	3.38	0.00	5.27	0.00	0.00	2.40	1.01	0.00	0.00
Phosphate	0.00	0.00	8.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	n	0.00
Sulfate	578.27	424.35	352.12	322.40	488.22	428.04	409.20	407.98	261.36	298.63	252.02	219.02
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	21.34	20.58	20.37	20.95	21.98	20.60	20.60	22.57	5.18	5.24	4.33	5.73
As (Dissolved)	0.02	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00
B (Dissolved)	0.02	0.01	0.05	0.02	0.08	0.01	0.02	0.02	0.04	0.04	0.05	0.06
Ba (Dissolved)	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	63.16	60.50	61.10	59.17	61.65	60.89	60.52	63.46	37.19	51.87	44.81	43.93
Cd (Dissolved)	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.01	0.21	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00
Fe (Dissolved)	1.21	1.16	1.04	1.22	1.66	1.61	1.52	1.43	7.49	23.29	25.55	26.82
K (Dissolved)	2.56	6.09	3.67	2.35	5.20	4.34	2.72	2.74	2.29	2.79	2.58	2.10
Li (Dissolved)	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00
Mg (Dissolved)	21.98	20.94	21.04	20.46	21.04	21.30	21.08	21.91	11.68	17.10	14.80	15.77
Mn (Dissolved)	23.63	22.50	22.31	21.87	22.01	21.70	21.28	22.36	10.44	15.23	12.86	13.43
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	10.01	9.61	9.79	9.21	9.45	10.22	9.85	9.26	5.46	8.80	7.92	8.37
Ni (Dissolved)	0.12	0.12	0.12	0.12	0.12	0.11	0.13	0.12	0.02	0.04	0.03	0.03
Pb (Dissolved)	0.01	0.00	0.01	0.00	0.00	0.02	0.01	0.01	0.01	0.00	0.00	0.01
S (Dissolved)	138.01	141.81	221.05	186.99	140.02	138.24	219.19	197.69	66.28	103.21	147.90	126.86
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Si (Dissolved)	12.85	12.61	13.62	13.71	12.78	12.66	12.97	14.82	8.57	12.67	12.14	13.27
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.53	0.53	0.60	0.50	0.51	0.54	0.67	0.54	0.34	1.18	1.18	1.12
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	17.41	17.07	16.74	16.51	13.42	7.75	8.43	9.90	0.20	0.07	0.12	0.05
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	25.52	23.02	49.67	35.15	24.14	20.82	23.17	21.33	13.90	7.66	11.27	6.30
As (Total)	0.03	0.02	0.03	0.00	0.04	0.00	0.00	0.00	0.03	0.00	0.00	0.00
B (Total)	0.02	0.01	0.05	0.04	0.07	0.01	0.01	0.02	0.04	0.04	0.07	0.05
Ba (Total)	0.06	0.02	0.06	0.05	0.02	0.02	0.02	0.02	0.14	0.03	0.04	0.02
Be (Total)	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	62.55	63.46	64.61	62.15	63.64	61.62	62.07	59.12	36.27	54.64	46.36	43.81
Cd (Total)	0.04	0.01	0.16	0.06	0.01	0.00	0.01	0.00	0.05	0.01	0.02	0.01
Co (Total)	0.03	0.03	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01
Cr (Total)	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Cu (Total)	0.05	0.00	0.24	0.36	0.07	0.01	0.05	0.01	2.10	0.26	0.69	0.15
Fe (Total)	2.79	1.79	8.82	13.41	2.47	1.57	2.88	1.38	14.98	26.15	38.54	23.91
K (Total)	2.64	2.45	4.06	4.12	5.43	3.65	2.73	2.46	2.74	3.30	3.05	2.17
Li (Total)	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Mg (Total)	22.16	21.96	23.56	23.10	22.27	21.62	21.98	20.43	12.69	18.28	17.03	15.88
Mn (Total)	23.26	23.51	22.81	22.82	22.76	22.01	22.36	20.83	9.98	15.94	13.04	13.36
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	9.77	9.63	10.03	10.27	9.29	10.33	9.03	8.80	6.04	9.50	7.89	8.56
Ni (Total)	0.13	0.13	0.18	0.15	0.13	0.11	0.11	0.11	0.04	0.04	0.05	0.03
Pb (Total)	0.07	0.02	0.38	0.16	0.03	0.00	0.02	0.00	2.78	0.39	0.69	0.17
S (Total)	138.30	147.79	329.34	204.77	147.02	139.37	143.62	185.12	73.44	109.01	162.85	126.79
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Si (Total)	14.92	13.48	20.07	20.17	13.45	12.81	13.94	13.51	11.89	13.97	16.65	13.02
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.53	0.58	0.93	0.88	0.53	0.58	0.62	0.49	0.35	1.29	1.63	1.05
Ti (Total)	0.08	0.01	0.04	0.03	0.04	0.00	0.01	0.01	0.07	0.01	0.03	0.01
V (Total)	0.02	0.01	0.06	0.04	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00
Zn (Total)	25.06	20.53	118.96	46.74	14.92	7.84	10.78	9.50	24.62	4.45	15.20	2.13

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed											
Well Number	GWC2P	GWC2P	GWC2P	GWC2P	GWE10	GWE10	GWE10	GWE10	GWE10P	GWE10P	GWE10P
Date of Collection	6/20/97	8/5/97	9/13/97	10/18/97	6/19/97	8/4/97	9/13/97	10/18/97	6/20/97	8/4/97	9/13/97
Field Measurements											
Eh (mV)	145.8	231.0	160.5	59.5	100.0	106.6	130.2	233.0	-58.5	-79.6	-40.8
pH	5.5	5.7	5.7	5.6	3.8	3.9	4.0	3.8	4.9	5.3	5.1
Temp (°C)	9.6	10.1	13.6	3.0	10.2	13.7	15.0	6.5	8.1	10.3	15.2
D.O. (mg/l)	4.4	2.1	1.8	3.0	3.7	1.9	3.3	2.3	4.1	4.6	2.6
Alkalinity in field (mg/l $CaCO_3$)	30.5	26.4	8.0	18.0	N/A	N/A	N/A	N/A	11.0	10.5	9.0
Field Eh to H_2 electrode (mV)	343.5	421.7	464.6	363.6	286.9	299.5	321.3	424.1	139.2	113.3	263.3
Calculated Eh (mV)	-61.3	-69.0	-74.9	-58.5	54.1	45.9	38.4	55.4	-19.2	-36.0	-40.0
Anions											
Fluoride	1.27	1.15	1.96	0.00	2.12	2.25	1.05	1.77	1.89	0.19	0.23
Chloride	3.94	0.09	0.01	0.49	3.91	2.85	0.40	1.52	0.00	0.36	0.49
Nitrate	2.21	8.14	0.00	0.00	0.00	0.81	0.00	0.26	2.79	4.02	0.00
Phosphate	0.00	0.00	12.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	226.81	271.85	217.32	209.68	240.47	330.06	303.21	290.54	192.06	181.82	150.40
Dissolved Cations											
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.37	0.86	1.24	1.58	8.70	9.00	7.05	11.46	2.46	0.64	0.68
As (Dissolved)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.05	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.06	0.04	0.04
Ba (Dissolved)	0.04	0.04	0.04	0.04	0.01	0.02	0.02	0.02	0.02	0.02	0.02
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	54.52	53.60	53.30	51.01	40.12	52.04	48.95	61.92	25.80	23.03	23.63
Cd (Dissolved)	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.02	0.01	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cu (Dissolved)	0.01	0.01	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	1.22	8.39	10.81	10.43	7.38	21.47	22.75	17.76	23.90	28.92	21.20
K (Dissolved)	2.28	2.18	2.02	1.89	2.32	3.69	3.66	3.11	6.39	6.08	6.02
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00
Mg (Dissolved)	13.58	14.31	14.42	14.12	13.66	18.50	18.05	23.77	11.68	11.18	11.54
Mn (Dissolved)	7.83	9.19	9.46	9.40	10.29	13.32	12.69	17.46	7.24	6.64	6.85
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	8.69	9.12	8.27	7.66	3.64	6.15	6.21	6.03	6.66	6.46	6.85
Ni (Dissolved)	0.00	0.01	0.01	0.01	0.06	0.09	0.07	0.07	0.04	0.02	0.04
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	61.76	71.00	125.34	103.19	78.54	116.96	111.91	130.73	60.88	61.27	55.20
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	9.92	10.80	11.34	12.13	7.62	10.91	11.42	12.94	8.80	7.26	7.63
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.53	0.81	0.87	0.74	0.38	1.00	1.16	1.04	0.21	0.88	0.76
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.04	0.04	0.57	0.05	0.75	0.17	0.09	0.43	0.02	0.01	0.09
Total Cations											
Ag (Total)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	8.32	3.32	5.78	2.01	11.74	11.32	9.03	11.98	1.98	3.54	2.08
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.07	0.02	0.04	0.03	0.04	0.03	0.04	0.03	0.06	0.04	0.04
Ba (Total)	0.16	0.05	0.06	0.05	0.07	0.03	0.03	0.02	0.02	0.08	0.03
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	57.89	54.88	55.99	54.44	38.39	52.73	49.40	59.81	25.91	23.29	25.14
Cd (Total)	0.01	0.00	0.01	0.00	0.04	0.02	0.04	0.02	0.00	0.04	0.02
Co (Total)	0.01	0.00	0.01	0.00	0.02	0.02	0.02	0.02	0.01	0.00	0.00
Cr (Total)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Total)	0.42	0.01	0.17	0.01	0.85	0.00	0.46	0.24	0.00	0.04	0.20
Fe (Total)	15.98	9.08	23.72	11.28	8.93	22.15	23.86	17.80	23.10	30.20	23.88
K (Total)	2.10	2.57	2.08	2.21	2.44	3.82	3.81	3.17	6.20	6.22	6.36
Li (Total)	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Mg (Total)	14.38	14.53	14.95	15.08	13.51	18.91	18.33	23.25	11.37	11.55	12.39
Mn (Total)	8.45	9.44	9.74	10.01	9.83	13.48	12.67	16.91	7.28	6.82	7.12
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	8.52	9.05	8.43	8.31	3.77	6.15	6.37	6.00	6.72	6.61	6.80
Ni (Total)	0.02	0.01	0.02	0.01	0.06	0.09	0.07	0.07	0.04	0.02	0.02
Pb (Total)	0.51	0.03	0.12	0.02	3.24	0.24	1.98	0.92	0.04	0.25	0.51
S (Total)	77.16	72.47	151.23	109.65	76.80	118.86	115.89	127.01	62.17	62.36	71.57
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	12.40	11.36	12.68	12.44	8.74	11.31	12.35	12.67	8.42	7.48	8.85
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.57	0.77	1.26	0.85	0.36	0.97	1.19	1.02	0.21	0.90	0.84
Ti (Total)	0.04	0.00	0.00	0.00	0.09	0.00	0.01	0.01	0.00	0.00	0.00
V (Total)	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00
Zn (Total)	2.72	0.51	1.25	0.14	4.16	1.91	4.18	1.47	0.10	2.06	0.97

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed												
Well Number	GWE10P	GWE2	GWE2	GWE2	GWE2	GWE2P	GWE2P	GWE2P	GWE2P	GWE3	GWE3	GWE3
Date of Collection	10/18/97	6/20/97	8/4/97	9/13/97	10/18/97	6/20/97	8/4/97	9/13/97	10/18/97	6/20/97	8/4/97	9/13/97
Field Measurements												
Eh (mV)	32.0	215.5	305.6	398.7	381.3	148.2	243.4	290.1	427.8	167.9	466.0	261.0
pH	5.2	4.0	4.2	4.3	4.3	3.8	4.3	4.4	4.3	4.3	4.2	4.3
Temp (°C)	4.2	6.7	7.2	7.1	4.2	6.9	8.1	10.4	6.4	6.0	8.0	8.8
D.O. (mg/l)	3.4	4.7	6.5	6.0	4.4	6.1	5.5	4.1	4.5	6.6	5.6	6.8
Alkalinity in field (mg/l $CaCO_3$)	4.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Field Eh to H_2 electrode (mV)	336.1	413.2	498.5	702.8	685.4	345.9	436.3	481.2	618.9	365.6	658.9	565.1
Calculated Eh (mV)	-34.7	37.9	29.4	21.3	20.2	54.8	21.9	12.1	20.5	19.2	23.6	16.1
Anions												
Fluoride	0.43	1.67	0.99	2.58	2.07	1.87	3.40	1.29	1.92	1.95	1.39	2.28
Chloride	0.23	3.87	1.03	0.84	1.74	4.01	1.74	1.68	2.16	4.00	5.36	0.39
Nitrate	9.21	3.79	1.27	0.92	0.00	7.96	1.96	4.66	0.00	7.45	0.94	0.85
Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	6.87	0.00	0.11	0.00	1.55	0.00
Sulfate	145.88	233.82	173.51	256.08	234.18	292.88	186.33	222.28	282.10	207.89	167.62	177.99
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	1.20	10.85	11.57	16.72	23.80	9.85	9.29	12.64	17.78	6.21	10.41	15.78
As (Dissolved)	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.03	0.03	0.00	0.01	0.02	0.03	0.00	0.01	0.01	0.08	0.00	0.00
Ba (Dissolved)	0.02	0.01	0.01	0.02	0.03	0.02	0.01	0.02	0.02	0.01	0.01	0.01
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	25.93	34.47	20.26	20.40	24.77	44.24	23.97	21.64	23.09	33.99	21.10	20.09
Cd (Dissolved)	0.00	0.05	0.04	0.05	0.06	0.04	0.04	0.04	0.05	0.04	0.04	0.04
Co (Dissolved)	0.00	0.02	0.01	0.02	0.03	0.02	0.01	0.01	0.02	0.02	0.02	0.03
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	1.38	1.43	1.81	2.30	1.37	1.27	1.55	1.88	1.15	1.48	1.82
Fe (Dissolved)	18.93	0.10	0.08	0.22	0.82	0.14	0.10	0.06	0.42	0.18	0.10	0.29
K (Dissolved)	5.45	1.42	1.84	3.73	4.97	2.70	1.92	3.94	5.16	0.94	1.31	1.44
Li (Dissolved)	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01
Mg (Dissolved)	12.03	13.70	11.12	16.85	24.39	15.55	11.21	13.90	20.42	11.37	11.53	14.39
Mn (Dissolved)	7.49	10.17	7.55	10.30	15.56	10.71	7.87	8.62	12.45	8.79	7.49	8.87
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	6.25	2.60	3.23	2.79	3.48	3.16	2.84	3.31	3.33	2.51	2.58	2.47
Ni (Dissolved)	0.01	0.08	0.07	0.10	0.15	0.06	0.07	0.08	0.11	0.06	0.08	0.16
Pb (Dissolved)	0.00	0.01	0.00	0.02	0.02	0.02	0.01	0.01	0.02	0.00	0.00	0.00
S (Dissolved)	57.58	75.61	61.61	138.10	154.95	82.11	61.60	119.57	130.22	60.76	61.38	130.27
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	9.10	7.93	7.98	8.97	12.00	7.85	8.04	8.92	10.56	7.21	7.67	8.68
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.73	0.33	0.19	0.19	0.18	0.44	0.25	0.21	0.17	0.35	0.25	0.19
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.09	10.05	7.17	8.58	11.57	10.26	8.03	7.60	9.65	9.54	7.75	8.59
Total Cations												
Ag (Total)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Al (Total)	1.25	15.57	14.70	59.76	22.19	41.62	16.45	52.38	25.88	24.85	12.13	99.15
As (Total)	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
B (Total)	0.03	0.04	0.00	0.01	0.01	0.11	0.00	0.01	0.02	0.11	0.00	0.05
Ba (Total)	0.02	0.09	0.04	0.08	0.03	0.41	0.06	0.08	0.10	0.23	0.02	0.18
Be (Total)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Ca (Total)	26.26	34.34	20.70	25.38	22.52	47.16	25.49	27.51	23.22	35.69	21.48	32.04
Cd (Total)	0.00	0.05	0.04	0.06	0.06	0.05	0.04	0.05	0.05	0.05	0.04	0.06
Co (Total)	0.00	0.02	0.01	0.03	0.03	0.03	0.01	0.02	0.02	0.03	0.02	0.04
Cr (Total)	0.00	0.01	0.00	0.01	0.00	0.03	0.00	0.00	0.01	0.04	0.00	0.08
Cu (Total)	0.03	1.54	1.60	4.28	2.11	4.34	1.94	5.26	2.44	1.96	1.60	6.55
Fe (Total)	19.90	7.57	2.73	0.28	1.17	57.24	2.62	0.35	9.95	41.61	2.51	30.50
K (Total)	5.34	1.87	1.91	4.23	4.53	4.71	2.20	4.22	5.53	3.11	1.23	3.29
Li (Total)	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.03
Mg (Total)	12.29	14.35	11.40	17.85	22.19	20.35	12.02	14.94	21.85	17.15	11.66	21.19
Mn (Total)	7.56	10.13	7.72	12.64	14.14	11.31	8.30	9.12	12.46	9.25	7.60	9.74
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	6.48	2.71	2.85	3.00	3.27	3.63	2.80	3.20	3.37	2.79	2.41	3.10
Ni (Total)	0.01	0.08	0.07	0.12	0.13	0.09	0.08	0.10	0.12	0.09	0.07	0.13
Pb (Total)	0.05	0.18	0.06	0.13	0.03	0.89	0.16	0.21	0.23	0.41	0.03	0.33
S (Total)	58.86	75.11	62.27	144.26	141.57	88.71	65.03	130.03	130.85	63.57	61.70	133.97
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	10.37	11.56	8.91	16.60	10.46	21.24	9.74	13.36	14.29	21.07	8.00	31.11
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.77	0.32	0.26	0.24	0.20	0.47	0.29	0.42	0.45	0.38	0.29	1.16
Ti (Total)	0.00	0.07	0.01	0.00	0.01	0.13	0.00	0.00	0.02	0.23	0.01	0.00
V (Total)	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.02	0.00	0.00
Zn (Total)	0.15	9.98	7.30	9.25	10.58	11.26	8.50	8.31	9.81	9.89	7.77	8.91

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed												
Well Number	GWE3	GWE3P	GWE3P	GWE3P	GWE3P	GWE4	GWE4	GWE4	GWE4	GWE4P	GWE4P	GWE4P
Date of Collection	10/18/97	6/20/97	8/4/97	9/13/97	10/18/97	6/19/97	8/4/97	9/13/97	10/18/97	6/20/97	8/5/97	9/13/97
Field Measurements												
Eh (mV)	398.1	177.5	483.2	260.9	411.7	-186.1	39.6	37.5	153.2	-146.8	37.2	-97.5
pH	4.3	4.5	4.2	4.4	4.3	4.3	5.1	5.2	5.2	5.4	5.4	5.3
Temp (°C)	4.3	6.7	6.8	9.3	3.4	8.3	13.1	9.3	5.4	5.7	9.9	12.9
D.O. (mg/l)	4.7	5.2	6.2	5.7	4.8	2.5	2.0	3.2	2.6	4.0	2.2	2.5
Alkalinity in field (mg/l $CaCO_3$)	N/A	N/A	N/A	N/A	N/A	N/A	1.2	4.0	3.0	10.0	13.8	4.0
Field Eh to H_2 electrode (mV)	702.2	375.2	676.1	565.0	715.8	0.8	232.5	228.6	344.3	50.9	227.9	93.6
Calculated Eh (mV)	19.4	11.4	24.6	16.2	20.4	17.4	-36.2	-40.2	-34.8	-48.1	-53.5	-50.1
Anions												
Fluoride	0.77	1.99	1.12	1.55	1.84	1.39	0.07	0.77	2.62	1.85	0.70	0.87
Chloride	0.11	3.76	0.33	0.25	0.54	3.83	1.24	0.66	1.89	3.68	0.25	0.57
Nitrate	0.00	2.95	6.59	0.58	2.28	0.00	0.00	0.00	0.00	9.46	0.00	0.00
Phosphate	0.00	0.00	0.00	0.00	6.59	0.00	0.00	0.00	4.62	0.00	0.00	0.00
Sulfate	278.18	262.89	180.63	273.39	270.13	174.87	149.99	238.27	168.82	112.00	103.19	111.16
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	22.17	7.47	9.67	15.37	23.57	1.34	1.27	1.11	1.29	0.74	1.01	1.05
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.01	0.05	0.00	0.00	0.01	0.07	0.09	0.07	0.07	0.05	0.04	0.01
Ba (Dissolved)	0.02	0.04	0.01	0.01	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.04
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	27.98	35.11	22.17	20.59	29.08	25.53	27.32	27.86	27.30	23.18	20.14	22.29
Cd (Dissolved)	0.06	0.04	0.04	0.04	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.03	0.02	0.02	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	2.16	1.14	1.45	1.78	2.25	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Fe (Dissolved)	1.85	2.37	0.05	0.18	0.35	30.19	32.82	36.69	36.31	5.97	3.92	4.22
K (Dissolved)	1.48	1.24	1.10	1.23	1.57	1.79	2.16	1.90	1.82	1.82	1.95	1.98
Li (Dissolved)	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Dissolved)	17.99	12.38	11.58	14.66	19.09	10.05	10.29	10.10	9.96	8.87	8.46	9.59
Mn (Dissolved)	13.11	8.86	7.61	9.03	13.90	5.71	5.93	5.81	5.74	4.78	4.69	5.34
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	2.95	2.78	2.34	2.40	3.16	3.41	3.67	3.65	3.25	3.26	3.32	3.30
Ni (Dissolved)	0.11	0.06	0.08	0.09	0.12	0.01	0.01	0.01	0.01	0.00	0.00	0.02
Pb (Dissolved)	0.02	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	144.48	62.22	60.72	77.21	153.95	54.00	60.66	68.49	91.90	34.08	32.31	42.64
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.01
Si (Dissolved)	10.46	7.94	7.65	8.30	13.97	10.20	11.09	10.54	11.89	11.32	11.71	12.06
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.23	0.37	0.22	0.13	0.20	0.21	1.17	1.32	1.15	0.20	0.27	0.29
Ti (Dissolved)	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	11.81	9.42	7.83	8.26	12.35	0.02	0.26	0.04	0.03	0.05	0.01	0.03
Total Cations												
Ag (Total)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	22.32	18.58	14.32	60.00	23.05	13.34	6.43	68.11	1.98	1.67	1.73	8.41
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
B (Total)	0.01	0.07	0.00	0.04	0.01	0.07	0.09	0.06	0.06	0.04	0.03	0.01
Ba (Total)	0.03	0.32	0.05	0.12	0.04	0.15	0.05	0.08	0.04	0.07	0.06	0.14
Be (Total)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	27.83	36.88	22.80	26.61	27.42	25.90	29.31	32.69	27.52	23.94	20.98	23.23
Cd (Total)	0.06	0.05	0.04	0.05	0.06	0.02	0.01	0.13	0.01	0.00	0.00	0.02
Co (Total)	0.03	0.02	0.02	0.03	0.03	0.01	0.01	0.05	0.00	0.00	0.00	0.00
Cr (Total)	0.00	0.02	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cu (Total)	2.17	1.56	1.74	4.16	2.17	0.00	0.06	14.74	0.01	0.01	0.00	0.23
Fe (Total)	1.70	25.18	4.88	23.12	1.83	33.35	37.47	31.74	36.90	6.50	4.43	7.84
K (Total)	1.40	2.11	1.20	1.59	1.20	2.03	2.00	1.99	1.72	1.88	1.90	2.39
Li (Total)	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Total)	17.98	15.79	11.98	19.33	18.26	10.71	11.18	11.07	10.07	9.46	8.91	11.28
Mn (Total)	13.08	9.34	7.77	9.31	13.12	5.78	6.34	6.38	5.75	4.92	4.88	5.46
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	3.00	2.67	2.25	2.61	2.86	3.45	3.58	3.61	3.34	3.45	3.33	3.39
Ni (Total)	0.11	0.08	0.07	0.11	0.11	0.02	0.02	0.14	0.01	0.01	0.00	0.03
Pb (Total)	0.00	0.56	0.08	0.40	0.05	0.04	0.04	3.97	0.02	0.05	0.01	0.36
S (Total)	145.01	64.54	62.20	78.29	145.86	67.57	65.71	110.57	92.78	33.32	33.56	44.39
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Si (Total)	10.07	16.34	8.63	22.00	10.43	14.75	13.60	32.36	11.73	11.98	12.49	15.54
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.25	0.40	0.36	0.90	0.23	0.23	1.24	1.24	1.22	0.21	0.30	0.45
Ti (Total)	0.00	0.10	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00
V (Total)	0.00	0.02	0.00	0.00	0.00	0.02	0.01	0.09	0.00	0.00	0.00	0.01
Zn (Total)	11.82	9.86	7.99	8.73	11.79	27.58	11.82	90.16	1.89	0.40	0.22	2.86

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed												
Well Number	GWE4P	GWE5	GWE5	GWE5	GWE5	GWE5P	GWE5P	GWE5P	GWE5P	GWE6	GWE6	GWE6
Date of Collection	10/18/97	6/20/97	8/4/97	9/13/97	10/18/97	6/20/97	8/5/97	9/13/97	10/18/97	6/20/97	8/4/97	9/13/97
Field Measurements												
Eh (mV)	58.2	46.9	49.9	127.6	214.7	87.3	14.9	0.8	102.8	23.6	162.8	277.0
pH	5.4	4.6	4.6	4.7	4.6	5.4	6.1	6.0	6.2	4.4	4.3	4.6
Temp (°C)	5.4	7.1	9.5	9.5	4.9	7.2	8.0	13.1	5.5	8.4	13.3	13.6
D.O. (mg/l)	3.4	1.5	6.0	4.6	4.8	4.6	2.9	3.5	4.8	4.2	3.1	5.8
Alkalinity in field (mg/l $CaCO_3$)	7.0	N/A	N/A	N/A	N/A	6.0	41.2	31.0	28.0	N/A	N/A	N/A
Field Eh to H_2 electrode (mV)	249.3	244.6	242.8	431.7	518.8	285.0	205.6	191.9	293.9	221.3	355.7	468.1
Calculated Eh (mV)	-52.3	1.7	1.1	-6.6	1.8	-50.2	-93.4	-94.3	-103.0	11.5	17.4	-2.4
Anions												
Fluoride	0.00	2.44	2.16	0.85	2.78	1.44	0.18	0.24	0.51	2.71	1.78	1.94
Chloride	0.01	4.58	0.87	0.87	1.26	4.32	0.40	0.39	0.92	3.96	0.72	0.46
Nitrate	0.00	2.20	0.00	7.27	0.00	1.07	0.00	0.00	0.69	4.22	0.00	7.98
Phosphate	0.00	0.00	0.00	0.00	1.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	92.74	270.14	270.06	247.72	272.29	223.40	87.61	124.26	169.78	324.75	318.63	336.67
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	1.43	5.52	7.81	5.56	9.01	0.65	0.15	0.26	0.77	12.19	9.26	9.16
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.02	0.05	0.04	0.04	0.03	0.03	0.05	0.06	0.06	0.07	0.04	0.03
Ba (Dissolved)	0.03	0.04	0.02	0.03	0.02	0.13	0.08	0.07	0.06	0.02	0.03	0.02
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	20.95	38.04	36.22	37.08	37.87	37.25	21.77	26.33	30.78	57.64	54.13	53.14
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.02	0.02
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fe (Dissolved)	4.30	21.42	15.81	21.87	14.62	13.23	20.63	35.92	35.09	16.67	17.74	19.64
K (Dissolved)	1.84	1.24	1.62	2.12	1.78	2.52	2.37	2.28	2.54	0.58	2.29	1.01
Li (Dissolved)	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Mg (Dissolved)	9.09	18.81	18.51	18.78	19.54	15.02	9.05	12.36	14.87	20.63	18.83	19.09
Mn (Dissolved)	5.02	14.05	13.37	12.89	14.03	6.12	3.56	6.05	8.43	14.36	13.49	13.41
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	3.12	3.44	4.02	3.62	3.40	3.53	3.73	3.63	3.90	4.86	5.82	5.17
Ni (Dissolved)	0.00	0.05	0.06	0.05	0.06	0.01	0.01	0.03	0.02	0.08	0.08	0.08
Pb (Dissolved)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
S (Dissolved)	51.65	80.73	88.02	106.22	135.72	57.24	32.43	61.86	91.67	109.90	109.02	143.89
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.02
Si (Dissolved)	13.29	9.63	10.82	10.89	11.91	7.35	8.73	9.43	0.86	9.65	9.69	10.20
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.26	0.36	0.83	0.99	0.74	0.33	0.80	1.28	1.20	0.51	1.09	1.02
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.04	0.04	0.19	0.09	0.09	0.10	0.03	0.05	0.08	0.63	0.24	0.17
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	1.74	287.91	13.17	92.11	10.25	5.64	0.35	0.58	1.86	22.44	14.84	49.48
As (Total)	0.00	0.09	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
B (Total)	0.01	0.20	0.05	0.00	0.02	0.04	0.05	0.06	0.12	0.07	0.04	0.02
Ba (Total)	0.06	0.97	0.07	0.07	0.06	0.25	0.09	0.07	0.08	0.19	0.06	0.13
Be (Total)	0.00	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ca (Total)	21.63	58.44	37.89	53.98	38.10	41.02	22.20	26.56	30.72	55.13	56.28	54.77
Cd (Total)	0.00	0.29	0.01	0.33	0.00	0.02	0.00	0.01	0.01	0.02	0.01	0.09
Co (Total)	0.00	0.07	0.02	0.09	0.01	0.00	0.00	0.00	0.00	0.03	0.02	0.04
Cr (Total)	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Cu (Total)	0.01	0.54	0.01	0.38	0.01	0.19	0.00	0.01	0.04	0.36	0.03	2.26
Fe (Total)	4.00	151.35	18.31	0.30	15.00	17.91	21.43	37.36	37.04	23.21	18.91	18.90
K (Total)	1.83	11.43	1.98	2.65	1.78	2.98	2.38	2.26	2.46	0.90	1.75	1.06
Li (Total)	0.00	0.10	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Mg (Total)	9.40	54.71	19.42	22.44	19.83	15.97	9.21	12.51	14.85	20.02	19.75	20.48
Mn (Total)	5.15	19.63	13.93	17.33	14.14	6.63	3.62	6.09	8.35	13.68	13.98	13.40
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	3.25	4.34	4.29	3.93	3.43	3.87	3.82	3.67	3.87	5.23	5.54	5.29
Ni (Total)	0.00	0.42	0.06	0.54	0.06	0.02	0.01	0.02	0.02	0.09	0.08	0.16
Pb (Total)	0.02	7.50	0.11	1.45	0.04	0.24	0.00	0.02	0.03	0.56	0.25	2.26
S (Total)	52.76	97.57	91.39	197.66	136.80	62.93	32.96	64.05	92.96	107.74	113.29	166.24
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.01
Si (Total)	13.13	110.03	12.47	27.97	12.54	9.25	8.93	9.63	1.67	13.08	11.05	20.23
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.29	0.74	0.90	0.59	0.75	0.35	0.80	1.33	1.29	0.49	1.03	1.08
Ti (Total)	0.00	0.09	0.00	0.00	0.01	0.04	0.00	0.00	0.01	0.19	0.01	0.03
V (Total)	0.00	0.35	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.06
Zn (Total)	0.16	58.15	2.07	72.60	0.31	4.29	0.13	0.26	0.35	3.56	1.46	16.68

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed												
Well Number	GWE6	GWE6P	GWE6P	GWE6P	GWE6P	GWE7	GWE7	GWE7	GWE7	GWE7P	GWE7P	GWE7P
Date of Collection	10/18/97	6/20/97	8/4/97	9/13/97	10/18/97	6/19/97	8/5/97	9/13/97	10/18/97	6/20/97	8/5/97	9/13/97
Field Measurements												
Eh (mV)	226.7	-65.5	1.4	198.6	103.2	322.9	413.4	327.8	356.9	-192.3	280.0	-98.3
pH	4.3	4.9	5.3	5.1	4.6	4.0	4.2	4.2	4.2	5.6	5.8	5.8
Temp (°C)	7.2	9.3	10.7	14.8	3.2	8.5	7.6	11.8	6.0	7.6	10.3	14.8
D.O. (mg/l)	2.9	2.9	3.4	2.9	3.2	4.4	2.8	3.8	3.7	4.5	2.4	2.4
Alkalinity in field (mg/l $CaCO_3$)	N/A	4.5	10.8	5.9	N/A	N/A	N/A	N/A	N/A	23.0	35.4	18.5
Field Eh to H_2 electrode (mV)	417.8	132.2	194.3	502.7	407.3	509.8	604.1	518.9	548.0	5.4	470.7	92.8
Calculated Eh (mV)	5.0	-16.1	-48.5	-40.8	3.2	93.2	25.4	26.2	24.9	-65.0	-76.2	-81.8
Anions												
Fluoride	1.39	2.25	0.84	1.92	1.64	4.41	2.48	5.03	4.12	1.24	0.24	0.18
Chloride	0.96	4.06	0.59	1.44	0.29	4.07	0.03	0.58	0.89	3.60	0.41	0.59
Nitrate	0.23	3.59	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.79	0.00
Phosphate	0.00	0.00	0.00	6.32	0.00	0.00	0.00	0.00	0.00	5.78	0.00	0.00
Sulfate	255.78	351.19	183.64	237.94	271.04	351.17	283.10	283.93	257.00	107.89	67.69	56.34
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	8.78	4.00	1.37	2.37	4.62	14.76	15.90	17.26	17.12	0.39	0.32	0.31
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00
B (Dissolved)	0.09	0.04	0.06	0.04	0.04	0.03	0.02	0.00	0.02	0.08	0.01	0.01
Ba (Dissolved)	0.03	0.05	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.16	0.14	0.16
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	48.46	49.82	41.53	45.52	44.78	43.09	40.80	45.07	42.82	34.93	22.32	20.54
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.17	0.20	0.23	0.08	0.00	0.00	0.00
Co (Dissolved)	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.27	0.37	0.50	0.47	0.00	0.00	0.00
Fe (Dissolved)	19.34	18.01	35.35	28.38	19.52	2.36	3.14	1.99	3.03	0.90	0.50	0.42
K (Dissolved)	37.64	1.73	0.97	0.78	0.64	2.21	2.64	2.85	2.48	2.01	2.31	2.33
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Mg (Dissolved)	17.44	17.07	16.03	17.21	17.29	17.19	16.53	18.48	18.06	11.69	8.20	7.79
Mn (Dissolved)	12.17	11.05	10.39	11.28	11.70	13.95	13.54	14.69	14.49	4.13	2.89	2.66
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	5.35	5.69	5.74	5.55	5.38	3.08	3.55	3.36	3.25	3.79	3.95	3.84
Ni (Dissolved)	0.07	0.03	0.04	0.34	0.03	0.12	0.13	0.17	0.14	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.04	0.02	0.00	0.00	0.00
S (Dissolved)	152.59	82.19	84.68	124.16	86.28	99.14	105.12	169.51	110.64	40.78	22.71	19.78
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Si (Dissolved)	10.06	8.33	8.10	8.81	9.36	11.79	11.51	12.73	13.78	10.10	10.56	10.54
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.92	0.43	1.41	1.22	0.93	0.40	0.49	0.46	0.46	0.30	0.21	0.22
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.23	0.16	0.03	0.05	0.10	16.07	16.89	18.72	17.78	0.02	0.01	0.03
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	15.45	4.29	2.49	4.83	4.57	34.84	21.67	40.65	17.36	1.19	0.79	3.37
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00
B (Total)	0.04	0.04	0.07	0.04	0.01	0.04	0.02	0.02	0.01	0.06	0.01	0.01
Ba (Total)	0.05	0.06	0.03	0.05	0.03	0.16	0.05	0.06	0.02	0.18	0.14	0.20
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Ca (Total)	50.19	52.43	42.46	45.35	45.66	44.83	44.84	45.80	42.66	35.94	22.66	22.58
Cd (Total)	0.02	0.01	0.01	0.01	0.00	0.38	0.24	0.61	0.08	0.00	0.00	0.02
Co (Total)	0.02	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Cr (Total)	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Total)	0.42	0.02	0.00	0.15	0.00	10.09	2.59	17.15	0.64	0.08	0.00	0.01
Fe (Total)	20.62	19.09	36.78	29.21	1.14	14.66	3.30	6.55	3.93	1.03	0.49	1.02
K (Total)	0.74	1.56	1.01	0.75	0.61	4.05	2.65	2.94	2.45	2.13	2.04	2.38
Li (Total)	0.01	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.01	0.00	0.00	0.00
Mg (Total)	18.77	17.90	16.40	17.22	17.72	20.61	18.32	19.63	18.07	12.37	8.32	8.48
Mn (Total)	12.85	11.60	10.65	11.15	11.93	13.95	14.85	14.78	14.46	4.23	2.87	2.93
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	5.54	5.56	5.71	5.62	5.68	3.52	3.39	3.62	3.35	3.85	3.89	3.96
Ni (Total)	0.07	0.04	0.04	0.04	0.02	0.16	0.14	0.20	0.13	0.00	0.00	0.02
Pb (Total)	0.55	0.05	0.07	0.44	0.01	0.25	0.09	0.29	0.02	0.01	0.00	0.05
S (Total)	103.81	86.33	86.71	128.31	90.95	102.20	115.47	137.45	110.50	43.55	23.70	23.37
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	11.81	8.89	8.43	9.23	9.01	22.18	13.52	17.70	13.29	10.55	10.07	11.69
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	1.01	0.45	1.37	1.29	0.43	0.42	0.47	0.64	0.56	0.32	0.17	0.24
Ti (Total)	0.01	0.00	0.00	0.00	0.00	0.11	0.00	0.02	0.00	0.01	0.00	0.00
V (Total)	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Total)	2.31	0.24	1.04	1.56	0.23	19.28	18.95	25.79	17.87	0.56	0.22	2.54

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed												
Well Number	GWE7P	GWE8	GWE8	GWE8	GWE8	GWE8P	GWE8P	GWE8P	GWE8P	GWE9	GWE9	GWE9
Date of Collection	10/18/97	6/19/97	8/4/97	9/13/97	10/18/97	6/20/97	8/5/97	9/13/97	10/18/97	6/19/97	8/4/97	9/13/97
Field Measurements												
Eh (mV)	-23.0	-26.7	44.8	-9.9	100.8	-116.8	190.5	157.9	188.0	143.7	40.3	62.2
pH	5.8	4.2	4.4	4.6	4.8	4.2	4.3	4.5	4.3	5.7	5.9	6.1
Temp (°C)	5.8	9.9	11.3	15.1	6.4	8.0	10.3	14.5	6.4	10.0	9.3	10.3
D.O. (mg/l)	3.3	3.3	3.2	3.6	3.1	3.9	2.3	2.8	2.8	3.6	4.3	5.7
Alkalinity in field (mg/l $CaCO_3$)	36.0	N/A	N/A	2.9	N/A	N/A	N/A	N/A	N/A	52.7	51.2	37.5
Field Eh to H_2 electrode (mV)	168.9	160.2	237.7	181.2	291.9	80.9	381.2	349.0	379.1	330.6	233.2	253.3
Calculated Eh (mV)	-76.7	24.3	10.5	-1.8	-9.3	30.3	16.0	3.8	21.7	-75.7	-86.3	-98.1
Anions												
Fluoride	1.85	3.63	2.32	1.23	1.66	3.77	1.96	1.35	0.96	1.68	0.30	0.59
Chloride	2.00	4.58	1.41	1.82	0.55	5.37	0.69	3.27	1.34	0.00	0.46	0.25
Nitrate	0.00	0.00	0.00	0.30	0.00	1.98	0.00	0.00	0.00	2.96	0.90	7.25
Phosphate	0.00	0.00	0.00	0.00	9.70	5.01	0.00	11.46	1.41	13.38	0.00	0.00
Sulfate	68.95	321.10	312.23	231.48	224.97	335.92	292.53	293.22	293.14	57.18	55.43	102.30
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.27	9.61	7.62	4.25	3.67	16.26	16.56	7.51	14.22	0.29	0.21	0.33
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.01	0.06	0.02	0.02	0.01	0.03	0.02	0.05	0.02	0.06	0.04	0.05
Ba (Dissolved)	0.17	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.14	0.15	0.15
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	24.89	42.07	42.10	38.89	36.92	38.38	40.56	39.61	38.87	15.91	15.18	14.62
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	1.80	7.40	7.12	6.18	5.64	6.46	11.94	27.01	9.61	23.85	25.31	27.21
K (Dissolved)	1.94	2.25	3.00	2.74	2.39	2.44	2.70	4.24	3.17	1.10	1.27	2.12
Li (Dissolved)	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00
Mg (Dissolved)	9.72	22.49	22.36	20.59	19.80	21.10	22.62	20.78	21.55	4.93	4.31	4.34
Mn (Dissolved)	3.63	16.72	16.45	14.84	14.48	15.56	17.01	14.71	15.80	2.22	1.66	1.61
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	3.70	3.69	4.10	3.86	3.63	4.00	3.94	4.56	3.53	3.79	4.19	4.79
Ni (Dissolved)	0.00	0.03	0.02	0.01	0.00	0.07	0.09	0.12	0.07	0.01	0.01	0.01
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	25.83	96.47	99.82	85.68	76.94	98.81	120.25	102.63	103.76	20.35	18.20	18.86
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Si (Dissolved)	10.99	11.49	10.70	10.68	10.91	11.27	11.44	10.49	11.14	12.00	11.65	12.87
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.28	0.38	0.56	0.56	0.50	0.33	0.64	1.17	0.67	0.14	0.74	0.95
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.01	0.02	0.02	0.01	0.03	0.02	0.02	0.02	0.09	0.05	0.02	0.18
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	0.55	17.68	13.27	7.70	4.74	16.86	17.80	20.54	13.98	15.61	3.28	5.72
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.00	0.05	0.02	0.02	0.01	0.03	0.02	0.06	0.02	0.07	0.04	0.07
Ba (Total)	0.16	0.07	0.03	0.03	0.04	0.01	0.02	0.04	0.02	0.33	0.19	0.19
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	24.79	46.38	42.50	39.26	37.03	39.77	40.70	40.52	37.32	16.65	15.98	14.72
Cd (Total)	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.17	0.01	0.02	0.01	0.01
Co (Total)	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.01	0.00	0.00
Cr (Total)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Cu (Total)	0.00	0.00	0.01	0.10	0.00	0.01	0.00	1.73	0.04	0.34	0.01	0.10
Fe (Total)	0.43	9.74	7.47	6.70	6.02	6.60	12.26	29.19	9.32	36.57	28.30	39.12
K (Total)	1.86	2.72	3.40	3.19	2.41	2.43	3.12	4.31	3.02	1.54	1.57	1.57
Li (Total)	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Mg (Total)	9.69	25.89	22.66	20.84	19.86	22.27	22.72	21.44	20.67	6.38	4.61	4.70
Mn (Total)	3.56	18.25	16.63	14.87	14.45	16.13	17.08	14.92	15.11	2.31	1.74	1.63
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	3.81	4.03	4.48	3.98	3.61	4.18	4.29	4.57	3.40	3.93	4.44	4.52
Ni (Total)	0.00	0.04	0.03	0.10	0.01	0.07	0.10	0.12	0.06	0.05	0.01	0.03
Pb (Total)	0.00	0.05	0.01	0.05	0.01	0.00	0.02	0.70	0.01	0.21	0.04	0.05
S (Total)	25.30	104.52	100.90	91.85	77.19	102.22	120.43	116.18	99.51	25.64	18.85	22.63
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Si (Total)	10.97	14.98	11.95	11.84	11.59	11.67	11.69	12.10	10.64	19.61	13.08	15.47
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.29	0.43	0.59	0.57	0.53	0.35	0.68	1.25	0.61	0.16	0.83	1.32
Ti (Total)	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.01
V (Total)	0.00	0.03	0.03	0.01	0.01	0.00	0.00	0.01	0.00	0.02	0.00	0.00
Zn (Total)	0.14	7.64	2.53	2.87	0.58	0.12	1.17	19.54	0.43	3.93	0.89	1.41

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Analysis Performed						
Well Number	GWE9	GWE9P	GWE9P	GWE9P	GWE9P	Surface Water
Date of Collection	10/18/97	6/20/97	8/5/97	9/13/97	10/18/97	8/4/97
Field Measurements						
Eh (mV)	116.8	60.7	23.1	49.4	249.7	466.7
pH	5.9	5.6	5.8	5.7	5.2	3.2
Temp (°C)	8.1	5.9	9.9	16.6	4.2	10.1
D.O. (mg/l)	2.6	4.8	3.1	4.3	4.6	5.7
Alkalinity in field (mg/l $CaCO_3$)	54.3	30.0	31.8	5.5	5.0	N/A
Field Eh to H_2 electrode (mV)	307.9	258.4	213.8	353.5	553.8	657.4
Calculated Eh (mV)	-83.0	-65.0	-81.1	-136.6	-33.4	NC
Anions						
Fluoride	0.12	1.48	0.71	NM	1.28	3.13
Chloride	2.46	3.42	0.27	NM	0.54	0.77
Nitrate	0.00	5.62	11.07	NM	6.64	0.00
Phosphate	0.00	0.00	0.00	NM	0.00	0.00
Sulfate	34.75	97.22	80.44	NM	199.29	4297.99
Dissolved Cations						
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.60	0.51	0.86	1.40	3.91	20.37
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.05	0.06	0.02	0.03	0.02	0.09
Ba (Dissolved)	0.15	0.16	0.17	0.19	0.12	0.01
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.01
Ca (Dissolved)	14.03	23.26	19.00	21.10	20.92	73.27
Cd (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.16
Co (Dissolved)	0.00	0.00	0.01	0.01	0.01	0.08
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.02	0.01	0.00	0.00	0.00	6.85
Fe (Dissolved)	29.04	15.42	14.89	14.92	8.52	52.37
K (Dissolved)	1.36	1.71	0.84	0.69	0.77	2.03
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.02
Mg (Dissolved)	4.15	7.01	6.09	7.81	9.70	27.26
Mn (Dissolved)	1.54	3.47	3.41	4.49	6.14	26.46
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	4.39	3.73	3.10	3.33	2.94	5.37
Ni (Dissolved)	0.01	0.02	0.02	0.03	0.04	0.16
Pb (Dissolved)	0.02	0.01	0.00	0.00	0.00	0.03
S (Dissolved)	13.49	30.78	27.14	36.77	44.28	218.14
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.03
Si (Dissolved)	15.51	10.36	10.62	10.82	10.19	9.16
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.89	0.22	0.52	0.64	0.43	2.30
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.17	0.26	0.02	0.17	3.51	36.56
Total Cations						
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	13.53	3.95	1.15	2.84	5.44	20.77
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.07	0.05	0.02	0.03	0.01	0.09
Ba (Total)	0.31	0.26	0.18	0.19	0.12	0.02
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.01
Ca (Total)	15.13	24.99	19.66	21.04	21.11	74.66
Cd (Total)	0.03	0.03	0.00	0.01	0.00	0.16
Co (Total)	0.01	0.00	0.01	0.01	0.01	0.08
Cr (Total)	0.01	0.00	0.00	0.00	0.00	0.00
Cu (Total)	0.51	0.23	0.00	0.01	0.00	6.99
Fe (Total)	41.33	18.66	15.58	15.84	8.62	54.86
K (Total)	1.51	1.58	1.07	0.76	0.72	1.52
Li (Total)	0.01	0.00	0.00	0.00	0.00	0.02
Mg (Total)	6.47	7.91	6.29	7.86	9.78	28.17
Mn (Total)	1.75	3.74	3.54	4.48	6.19	26.94
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	4.01	3.68	3.43	3.35	3.05	4.89
Ni (Total)	0.05	0.02	0.02	0.03	0.04	0.16
Pb (Total)	0.21	0.13	0.00	0.00	0.00	0.03
S (Total)	21.32	34.06	27.91	37.44	44.98	222.83
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.03
Si (Total)	21.22	12.42	10.97	11.23	10.49	9.60
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	1.24	0.24	0.55	0.69	0.45	2.39
Ti (Total)	0.04	0.07	0.00	0.01	0.00	0.00
V (Total)	0.02	0.00	0.00	0.00	0.00	0.00
Zn (Total)	3.71	2.19	0.05	0.43	3.67	37.21

Appendix A.1b Raw Water Data for Pennsylvania Mine Wetland

NM= Not Measured
NC= Not Calculated
N/A= Not Applicable

Sample ID	GWC1P		GWC2P		GWE10P	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	39.00	0.28	9.05	0.07	32.12	0.21
Al	7261.94	10.47	4346.56	44.10	9454.37	61.37
As	17.78	0.56	4.82	0.07	7.10	0.39
B	10.68	0.08	6.97	0.08	38.49	0.31
Ba	4.71	0.04	6.55	0.07	4.03	0.06
Be	0.32	0.00	0.17	0.00	0.44	0.00
Ca	315.48	1.02	230.26	2.19	1560.91	7.10
Cd	107.62	0.50	57.40	0.43	51.58	0.44
Co	1.62	0.06	3.52	0.04	5.26	0.03
Cr	2.13	0.05	nd	0.06	4.60	0.05
Cu	4551.38	8.61	3045.61	22.66	1873.12	11.03
Fe	7648.57	29.96	4839.17	23.55	35832.92	127.24
K	5952.34	15.10	2674.47	18.22	5578.32	42.55
Li	0.60	0.00	0.47	0.02	1.52	0.03
Mg	491.67	1.88	331.64	2.59	1544.21	15.68
Mn	68.54	0.29	58.00	0.56	115.53	0.55
Mo	nd	0.05	nd	0.11	nd	0.29
Na	409.35	1.08	290.27	2.41	401.50	6.87
Ni	6.22	0.05	9.28	0.14	17.28	0.22
Pb	5462.34	26.71	5540.08	39.48	5903.73	36.71
S	6298.38	39.90	1808.61	19.27	6682.98	48.70
Sb	nd	0.18	nd	0.05	nd	0.42
Se	nd	0.28	nd	0.28	nd	1.47
Si	69.06	0.65	44.93	0.95	37.78	0.27
Sn	1.24	0.20	0.08	0.15	1.95	0.05
Sr	278.70	2.53	188.33	1.84	1087.13	13.83
Ti	6.70	0.01	0.78	0.01	50.54	0.23
V	4.96	0.03	0.06	0.01	8.54	0.08
Zn	7455.75	20.92	11746.72	72.61	6428.23	22.97

nd= non-detect

Appendix A.1c Raw Data For Soils Collected at Pennsylvania Mine Wetland on 10-18-97.

Sample ID	GWE2P		GWE3P		GWE4P	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.21	1.64	0.04	0.14	0.02
Al	15599.72	43.66	17859.49	40.07	8013.01	37.88
As	75.76	1.68	nd	0.62	8.93	0.28
B	205.46	3.30	45.20	0.65	15.99	0.21
Ba	74.96	0.20	73.98	0.29	6.07	0.09
Be	1.31	0.02	0.91	0.00	0.43	0.00
Ca	327.40	4.73	585.84	0.67	1068.85	16.45
Cd	4.63	0.07	nd	0.02	190.99	2.82
Co	8.45	0.07	4.45	0.06	4.76	0.05
Cr	nd	0.14	18.27	0.16	nd	0.03
Cu	1749.94	3.08	828.22	1.19	9164.63	37.69
Fe	186038.11	3184.06	42703.16	121.01	15690.97	80.26
K	3333.77	6.28	4341.37	11.78	2478.63	11.62
Li	3.83	0.03	7.02	0.02	3.29	0.05
Mg	1470.21	21.95	3272.50	5.91	1493.55	14.06
Mn	124.85	1.85	204.96	0.30	173.91	2.66
Mo	nd	1.25	nd	0.15	nd	0.03
Na	258.17	3.51	377.93	4.39	255.57	2.05
Ni	45.03	1.50	18.06	0.16	14.27	0.12
Pb	825.48	13.18	719.74	0.52	335.84	2.75
S	1044.96	7.30	1496.70	7.23	7784.59	106.61
Sb	nd	9.49	nd	0.64	nd	0.36
Se	nd	9.22	nd	0.54	nd	0.45
Si	nd	0.13	6.53	8.51	17.34	0.35
Sn	4.34	0.11	1.23	0.21	nd	0.10
Sr	6130.19	62.14	1435.51	22.98	510.01	4.01
Ti	29.17	0.30	75.39	0.12	48.39	0.71
V	nd	0.11	11.14	0.07	7.93	0.05
Zn	405.84	6.36	397.10	0.30	14316.75	80.76

nd= non-detect

Appendix A.1c Raw Data For Soils Collected at Pennsylvania Mine Wetland on 10-18-97.

Sample ID	GWE5P		GWE6P		GWE7P	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.12	5.20	0.07	nd	0.01
Al	5016.56	79.96	5437.26	3.90	4559.39	34.52
As	nd	1.84	7.99	0.38	nd	0.24
B	136.18	1.76	29.58	0.09	8.38	0.18
Ba	32.23	0.13	6.55	0.01	4.58	0.04
Be	0.27	0.00	0.32	0.00	0.27	0.00
Ca	279.01	3.91	509.52	0.28	827.21	3.91
Cd	3.96	0.13	69.93	0.13	32.81	0.72
Co	5.35	0.15	4.99	0.12	6.95	0.15
Cr	nd	0.22	nd	0.08	nd	0.03
Cu	1576.82	8.80	7549.80	48.32	4860.88	33.80
Fe	123733.15	1834.35	30599.81	223.66	5853.69	19.27
K	1326.16	24.25	3092.87	2.20	902.18	6.64
Li	1.09	0.04	1.49	0.01	1.99	0.02
Mg	460.45	1.41	910.09	6.05	820.52	2.95
Mn	89.20	1.30	84.29	0.10	160.59	0.70
Mo	nd	0.89	nd	0.17	nd	0.09
Na	94.11	0.74	294.78	4.05	166.48	1.61
Ni	28.10	0.89	14.25	0.07	19.76	0.32
Pb	180.27	3.31	1668.49	1.06	226.08	3.42
S	741.91	21.10	5540.48	38.56	6066.08	41.67
Sb	nd	6.70	nd	0.46	nd	0.35
Se	nd	6.55	nd	0.33	nd	0.33
Si	nd	5.00	3.86	0.21	30.62	0.11
Sn	2.35	0.16	0.91	0.15	nd	0.03
Sr	3870.51	19.03	982.66	12.08	194.14	0.38
Ti	7.97	0.14	14.96	0.01	26.28	0.16
V	nd	0.10	1.00	0.02	4.84	0.07
Zn	264.36	5.90	5686.20	32.38	10997.27	53.52

nd= non-detect

Appendix A.1c Raw Data For Soils Collected at Pennsylvania Mine Wetland on 10-18-97.

Sample ID	GWE8P		GWE9P	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.03	5.12	0.03
Al	6557.32	18.31	7472.83	38.32
As	nd	0.25	nd	0.25
B	145.68	0.84	37.16	0.21
Ba	32.85	0.06	15.92	0.08
Be	0.37	0.00	0.42	0.00
Ca	357.85	2.66	420.39	1.85
Cd	175.86	1.12	73.53	0.21
Co	9.53	0.16	2.76	0.03
Cr	nd	0.18	nd	0.09
Cu	9471.06	25.60	4367.50	46.67
Fe	134061.23	763.02	37261.09	409.10
K	1730.03	4.45	3158.64	19.68
Li	1.96	0.02	0.89	0.01
Mg	689.11	4.16	669.82	7.26
Mn	99.30	0.65	91.77	0.43
Mo	nd	0.47	nd	0.17
Na	152.82	2.84	234.38	0.57
Ni	41.79	0.23	12.13	0.11
Pb	378.50	2.14	504.71	6.69
S	2562.15	20.61	2639.47	25.66
Sb	nd	3.45	nd	0.34
Se	nd	3.40	nd	1.28
Si	nd	2.24	2.37	0.30
Sn	1.54	0.07	1.23	0.12
Sr	4347.69	60.43	1161.01	14.85
Ti	21.71	0.06	3.24	0.03
V	nd	0.15	1.53	0.02
Zn	10636.11	31.84	4286.22	41.08

nd= non-detect

Appendix A.1c Raw Data For Soils Collected at Pennsylvania Mine Wetland on 10-18-97.

Sample ID	GWC1P		GWC2P		GWE10P	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Dev. (mg/kg)
Ag	1.61	0.21	0.93	0.14	1.14	0.14
Al	516.90	6.01	129.22	0.96	185.26	4.03
As	4.87	0.55	nd	nd	36.26	16.24
B	nd	nd	nd	nd	nd	nd
Ba	6.79	0.06	4.61	0.08	4.58	0.06
Be	0.08	0.01	0.03	0.01	0.04	0.01
Ca	3610.16	11.50	2701.56	15.14	2629.18	4.14
Cd	nd	nd	nd	nd	nd	nd
Co	0.20	0.57	nd	nd	0.29	0.17
Cr	0.52	0.26	nd	nd	nd	nd
Cu	28.93	0.34	7.43	0.09	6.31	0.32
Fe	654.48	5.27	180.91	0.84	190.97	2.39
K	10336.54	65.45	15531.35	89.06	14419.53	122.20
Li	1.78	0.10	1.78	0.19	1.79	0.46
Mg	843.62	1.45	669.32	3.10	1573.98	12.77
Mn	1320.16	2.85	672.96	3.73	881.10	2.12
Mo	2.07	0.32	0.22	0.13	10.41	3.23
Na	185.49	3.22	112.33	2.18	179.99	1.99
Ni	5.06	0.78	1.07	0.14	3.31	0.73
Pb	38.20	2.70	36.34	1.87	5.32	1.51
S	nd	nd	nd	nd	1366.32	287.92
Sb	nd	nd	2.24	1.01	0.40	2.48
Se	1.43	4.12	5.97	1.41	2.54	1.84
Si	136.16	1.24	142.11	0.63	96.88	6.11
Sn	1.96	1.05	1.82	2.58	1.77	1.36
Sr	49.76	11.26	20.82	20.08	17.47	16.84
Ti	0.17	0.05	nd	nd	0.67	0.07
V	0.10	0.11	0.20	0.29	0.16	0.26
Zn	507.78	4.10	44.28	0.31	210.21	2.94

nd=non-detect

Appendix A.1d Raw Data for Vegetation Collected at Pennsylvania Mine Wetland on 10-18-97. Reported as Average of Two Samples.

Sample ID	GWE2P		GWE3P		GWE4P	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.50	0.17	2.13	1.43	1.03	0.10
Al	313.57	8.42	982.50	7.16	236.69	3.94
As	nd	nd	nd	nd	nd	nd
B	nd	nd	231.13	204.92	nd	nd
Ba	7.49	0.10	8.02	0.06	6.65	0.09
Be	0.07	0.02	0.17	0.01	0.04	0.02
Ca	3311.69	40.74	2775.62	18.41	3085.65	28.13
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	1.21	0.72	nd	nd
Cr	0.05	0.27	nd	nd	nd	nd
Cu	138.19	1.78	199.36	1.42	34.52	0.22
Fe	277.00	5.28	139.22	1.59	641.17	5.64
K	4111.91	51.82	3654.40	21.75	11656.74	122.51
Li	1.43	0.52	2.88	0.43	2.07	0.55
Mg	886.08	7.27	1175.86	3.61	1736.49	6.04
Mn	525.91	4.95	732.37	3.69	934.99	7.74
Mo	0.04	0.65	0.16	0.25	nd	nd
Na	107.45	3.51	419.79	6.99	160.02	3.69
Ni	3.05	0.76	10.27	0.33	3.11	0.57
Pb	12.45	2.45	19.74	3.72	5.61	2.53
S	nd	nd	nd	nd	nd	nd
Sb	1.70	1.94	0.44	0.48	nd	nd
Se	3.52	1.67	4.10	1.05	3.55	5.14
Si	170.53	2.16	233.17	1.31	109.32	1.00
Sn	1.64	1.50	0.96	1.59	2.36	1.17
Sr	37.12	22.27	27.90	28.07	41.18	6.14
Ti	1.63	0.07	1.22	0.09	nd	nd
V	0.11	0.28	0.08	0.17	0.10	0.38
Zn	368.47	3.67	793.61	5.89	239.75	3.82

nd=non-detect

Appendix A.1d Raw Data for Vegetation Collected at Pennsylvania Mine Wetland on 10-18-97. Reported as Average of Two Samples.

Sample ID	GWE5P		GWE6P		GWE7P	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	1.24	0.24	0.49	0.11	3.09	0.32
Al	373.95	6.25	538.44	12.78	468.33	6.78
As	nd	nd	10.53	2.50	nd	nd
B	199.34	57.37	nd	nd	83.24	31.85
Ba	12.98	0.19	3.01	0.09	4.29	0.11
Be	0.08	0.01	0.10	0.01	0.13	0.02
Ca	2810.60	15.97	3315.73	68.01	3477.59	20.12
Cd	nd	nd	nd	nd	nd	nd
Co	0.26	0.12	0.48	0.30	0.27	0.42
Cr	nd	nd	0.00	0.32	0.06	0.18
Cu	52.47	1.02	66.67	1.43	32.79	0.55
Fe	139.81	1.60	306.20	6.60	92.76	1.09
K	12268.36	116.57	12277.37	286.27	16631.23	83.43
Li	1.89	0.30	1.87	0.35	3.36	0.40
Mg	1471.10	8.42	1426.64	14.34	2196.12	13.27
Mn	1005.96	5.09	987.70	21.62	1193.43	9.27
Mo	0.45	0.59	2.18	1.05	0.39	0.67
Na	84.49	3.41	255.63	6.34	185.61	3.65
Ni	4.03	0.65	4.79	0.42	5.88	0.79
Pb	2.02	2.72	2.68	1.98	0.55	1.47
S	nd	nd	nd	nd	1751.61	286.86
Sb	2.86	1.83	0.60	1.95	0.05	2.58
Se	0.17	2.84	3.64	1.34	0.65	3.44
Si	128.77	1.39	93.40	1.57	197.40	0.98
Sn	1.84	3.40	1.47	1.28	1.99	1.58
Sr	21.33	13.57	32.08	16.31	37.35	11.41
Ti	nd	nd	nd	nd	0.28	0.10
V	0.23	0.09	0.09	0.21	0.24	0.11
Zn	341.85	3.94	712.48	15.02	681.45	5.68

nd=non-detect

Appendix A.1d Raw Data for Vegetation Collected at Pennsylvania Mine Wetland on 10-18-97. Reported as Average of Two Samples.

Sample ID	GWE8P		GWE9P	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.62	0.24	1.07	0.18
Al	603.64	6.29	515.41	5.23
As	nd	nd	nd	nd
B	nd	nd	56.55	36.88
Ba	5.13	0.10	6.10	0.16
Be	0.10	0.01	0.09	0.01
Ca	2458.97	15.27	3880.14	88.69
Cd	nd	nd	nd	nd
Co	0.54	0.61	0.63	0.11
Cr	nd	nd	0.07	0.08
Cu	43.15	0.56	51.40	0.45
Fe	266.56	2.43	444.09	4.06
K	11396.49	40.21	12904.88	228.77
Li	1.95	0.32	2.86	0.35
Mg	1841.51	19.58	2269.82	15.17
Mn	989.58	6.17	1338.48	31.71
Mo	0.11	0.31	0.45	0.20
Na	238.93	3.21	195.05	2.21
Ni	4.78	0.44	5.81	0.86
Pb	1.48	1.41	4.76	2.31
S	2530.82	167.69	4766.74	148.68
Sb	nd	nd	nd	nd
Se	2.54	5.27	1.58	3.46
Si	62.11	1.62	266.51	2.10
Sn	1.62	1.95	2.40	2.53
Sr	18.89	16.62	55.43	12.04
Ti	0.87	0.04	10.56	0.36
V	0.26	0.14	0.20	0.19
Zn	308.95	1.40	524.68	12.76

nd=non-detect

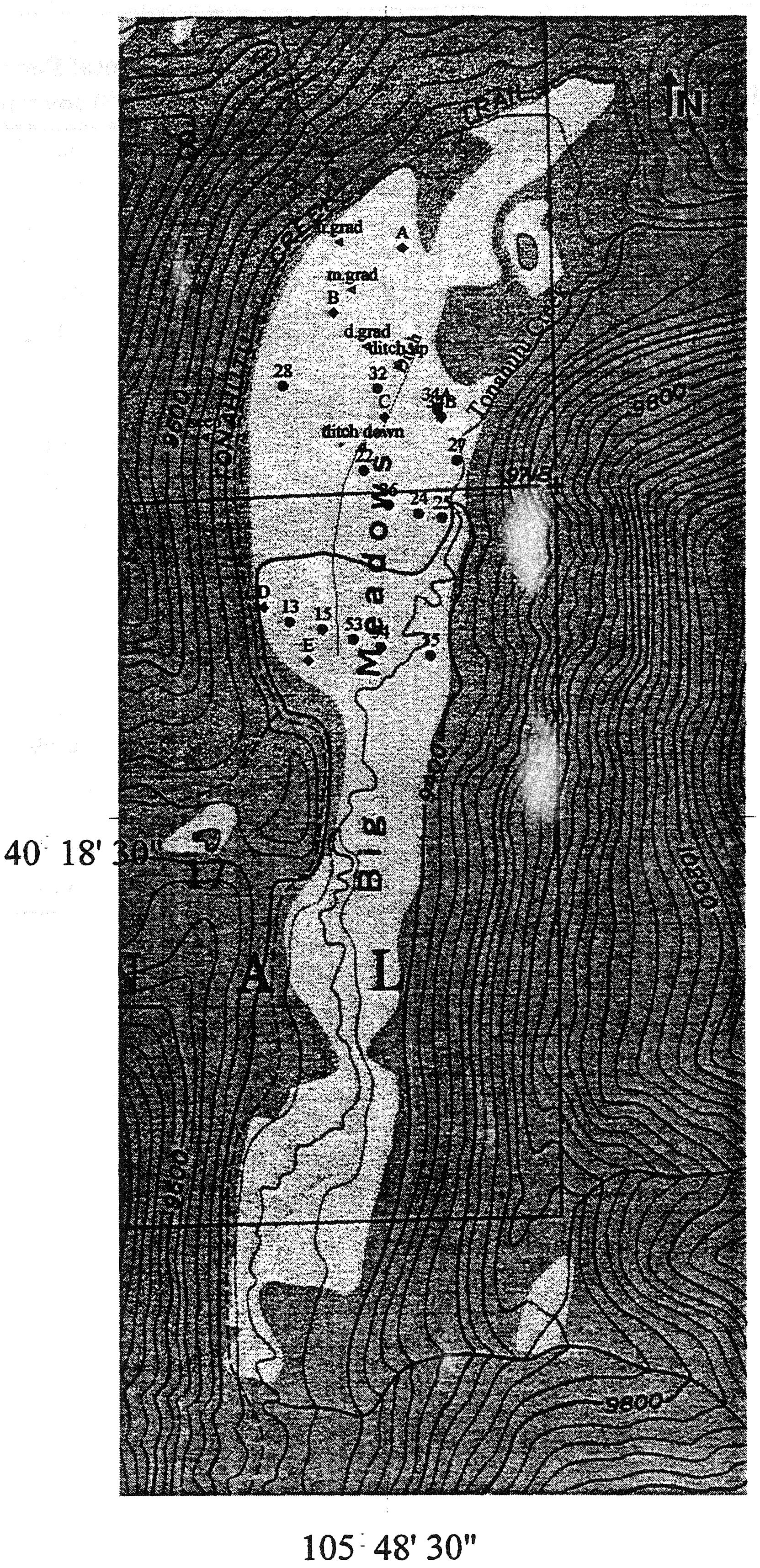
Appendix A.1d Raw Data for Vegetation Collected at Pennsylvania Mine Wetland on 10-18-97. Reported as Average of Two Samples.

Sample ID	Bulk Density (BD) (g/ml)	% Organic Matter (OM) (by weight)	% Carbonate (by weight)	% Total Pore Space (TPS) (by volume)
GWC2P	1.01	8.00	-	62.07
GWE10P	0.86	9.00	-	67.71
GWE3P	0.88	27.00	-	60.48
GWE2P	0.26	31.00	-	87.84
GWE8P	0.14	48.00	-	92.69
GWE4P	0.20	40.00	-	90.32
GWE5P	0.29	54.00	-	85.04
GWE9P	0.41	32.00	-	80.81
GWE7P	0.20	70.00	-	88.67
GWC1P	0.48	19.00	-	81.70
GWE6P	0.23	25.00	-	89.97
BMA	0.61	42.00	-	70.00
BMB	0.71	25.00	-	68.51
BMC	0.24	45.00	-	88.23
BMD	0.15	70.00	-	91.33
BME	0.24	60.00	-	87.28
BM13	0.16	68.00	-	90.99
BM54	0.37	42.00	-	81.69
BM22	0.37	12.00	-	85.86
BM28	0.34	19.00	-	87.32
BM32	0.21	40.00	-	89.96

GW= Pennsylvania Mine Wetland
BM= Big Meadows Wetland
- indicates carbonates were not present

Appendix A.1e Properties of Soils Collected from Slope Wetlands.

AppendixA.2a Sampling Locations at Big Meadows Wetland.



- ● Peat Wells
- ◆ Unconsolidated Wells
- ▲ Surface Water

Analysis Performed												
Well Number	BM13	BM13	BM13	BM13	BM15	BM15	BM15	BM15	BM22	BM22	BM28	BM28
Date of Collection	6/10/97	6/25/97	8/12/97	9/27/97	6/10/97	6/25/97	8/12/97	9/27/97	8/12/97	9/27/97	8/12/97	9/27/97
Field Measurements												
pH	6.2	6.0	5.7	6.0	5.9	6.3	5.9	5.8	5.7	6.6	6.4	6.1
Temp (°C)	9.8	13.4	12.3	8.7	9.6	11.8	14.3	8	9	10.1	10.2	11
D.O. (mg/l)	5.9	3.4	5.0	NM	4.3	7.0	5.4	NM	5.5	NM	6.1	NM
Alkalinity in field (mg/l $CaCO_3$)	10.2	72.5	30.0	28.5	17.6	15.0	16.0	12.0	34.0	39.0	32.0	22.0
Specific Cond. Field (*u* s)	27.6	173.2	61.8	53.87	889.7	84.9	80.4	59.4	206.1	79.670	133.6	58.0
Field Eh to H_2 electrode (mV)	455.6	377.9	325.8	377.3	458.1	389.7	426.1	414.4	263.3	294.5	329.8	394.5
Calculated Eh (mV)	-90.1	-104.1	NC	-84.5	-78.6	-96.5	NC	-83.6	-76.8	-128.0	-121.9	-93.7
Anions												
Fluoride	0.00	1.08	2.11	1.33	0.00	1.08	0.17	0.00	3.07	1.38	2.56	0.16
Chloride	2.17	3.54	0.39	2.58	2.32	5.61	1.75	0.00	0.38	0.02	3.56	0.83
Nitrate	1.21	0.00	0.00	0.00	5.58	3.47	0.00	0.00	0.00	0.00	0.00	11.02
Phosphate	0.00	0.00	10.06	1.08	0.00	0.00	0.00	15.91	0.00	14.14	0.00	0.00
Sulfate	3.10	0.00	0.00	0.00	2.70	0.00	0.00	2.01	2.48	1.66	8.22	3.12
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	2.47	1.11	0.41	0.42	0.16	5.73	0.10	0.23	0.17	0.38	1.84	0.16
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.00	0.03	0.01	0.01	0.00	0.04	0.05	0.01	0.09	0.07	0.06	0.04
Ba (Dissolved)	0.03	0.02	0.01	0.02	0.00	0.06	0.01	0.01	0.01	0.01	0.03	0.01
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	2.70	2.73	3.11	2.46	2.73	4.42	2.97	2.14	3.08	2.31	5.19	5.22
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.00	0.00	0.01
Cu (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01
Fe (Dissolved)	5.03	6.82	4.71	5.01	3.58	14.16	1.38	1.57	17.25	12.10	3.31	0.46
K (Dissolved)	0.68	0.81	1.04	1.02	1.19	0.72	0.97	2.44	1.08	0.85	1.62	1.38
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Dissolved)	1.43	1.25	1.06	0.91	0.92	2.95	0.98	0.77	1.26	1.05	1.91	1.58
Mn (Dissolved)	0.04	0.05	0.04	0.03	0.04	0.11	0.04	0.03	0.11	0.04	0.02	0.01
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	1.97	3.50	2.78	2.89	3.06	2.78	2.56	2.38	3.31	3.19	4.18	3.79
Ni (Dissolved)	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.03	0.01	0.01	0.00	0.02
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	0.40	0.31	0.00	0.25	0.35	0.33	0.00	0.25	0.27	0.40	0.14	0.51
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	4.35	7.32	5.84	6.21	4.45	10.27	3.36	2.85	8.83	7.73	10.00	7.70
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.02	0.02	0.16	0.13	0.02	0.03	0.03	0.01	0.36	0.30	0.10	0.02
Ti (Dissolved)	0.16	0.08	0.02	0.02	0.00	0.33	0.00	0.01	0.00	0.02	0.01	0.00
V (Dissolved)	0.01	0.01	0.00	0.00	0.01	0.07	0.00	0.00	0.01	0.01	0.01	0.00
Zn (Dissolved)	0.00	0.02	0.02	0.08	0.01	0.10	0.01	0.06	0.01	0.02	0.02	0.02
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	0.10	146.17	12.04	21.84	8.63	0.19	0.67	1.22	10.92	8.70	27.23	1.13
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.00	0.33	0.03	0.07	0.02	0.04	0.05	0.06	0.12	0.09	0.09	0.03
Ba (Total)	0.00	1.14	0.13	0.19	0.13	0.01	0.02	0.04	0.14	0.09	0.74	0.02
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	1.73	17.87	4.63	5.98	5.35	3.48	3.16	2.25	4.04	3.10	24.07	5.56
Cd (Total)	0.00	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
Co (Total)	0.00	0.11	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
Cr (Total)	0.00	0.33	0.02	0.03	0.03	0.00	0.00	0.00	0.07	0.06	0.03	0.00
Cu (Total)	0.00	0.28	0.02	0.05	0.04	0.00	0.00	0.00	0.08	0.09	0.05	0.00
Fe (Total)	1.33	256.43	24.74	42.60	15.62	5.82	5.41	3.42	45.44	33.87	29.40	1.16
K (Total)	0.35	26.52	2.71	3.89	0.72	0.42	0.58	0.80	2.49	2.61	2.57	0.36
Li (Total)	0.00	0.23	0.02	0.03	0.01	0.00	0.00	0.00	0.02	0.01	0.02	0.00
Mg (Total)	0.63	60.39	6.04	9.64	3.11	1.13	1.10	1.03	4.53	3.65	9.02	1.75
Mn (Total)	0.01	2.57	0.22	0.37	0.13	0.05	0.05	0.03	0.16	0.12	0.13	0.01
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	1.90	3.55	2.80	2.97	2.83	2.54	2.51	2.16	3.38	3.16	4.24	3.44
Ni (Total)	0.00	0.25	0.02	0.04	0.00	0.00	0.00	0.00	0.02	0.02	0.05	0.00
Pb (Total)	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00
S (Total)	0.36	1.10	0.00	0.17	0.35	0.28	0.00	0.13	0.10	0.43	0.16	0.49
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.14	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Si (Total)	2.24	143.47	19.75	30.86	10.40	4.31	3.77	4.26	18.15	17.36	34.85	8.89
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.01	0.15	0.73	1.24	0.04	0.02	0.13	0.06	1.25	0.90	0.91	0.00
Ti (Total)	0.00	13.80	0.72	0.91	0.27	0.01	0.01	0.02	0.08	0.19	0.00	0.00
V (Total)	0.00	0.46	0.04	0.09	0.16	0.01	0.01	0.01	0.22	0.12	0.09	0.00
Zn (Total)	0.00	0.73	0.07	0.12	0.02	0.02	0.02	0.02	0.06	0.04	0.13	0.00

Appendix A.2b Raw Water Data for Big Meadows Wetland.

NM= Not Measured
NC= Not Calculated

Analysis Performed												
Well Number	BM32	BM32	BM32	BM32	BM35	BM54	BM54	BM54	BM54	BM55	BM55	BM55
Date of Collection	6/10/97	6/25/97	8/12/97	9/27/97	8/12/97	6/10/97	6/25/97	8/12/97	9/27/97	6/10/97	6/25/97	8/12/97
Field Measurements												
pH	6.0	6.1	6.1	6.1	5.6	6.1	6.3	6.2	6.1	5.5	5.4	5.3
Temp (°C)	11.6	14.5	10.2	11.8	9.6	5.2	11.8	9.6	7.4	7.2	14.1	10.6
D.O. (mg/l)	6.0	7.6	5.8	NM	6.8	4.1	6.4	4.9	NM	8.6	7.4	5.0
Alkalinity in field (mg/l $CaCO_3$)	10.4	25.2	70.0	44.0	10.0	26.4	27.0	30.0	38.0	6.5	19.0	9.5
Specific Cond. Field (μs)	26.7	90.8	293.6	104.7	66.2	60.6	71.9	93.6	64.6	24.4	38.1	345.7
Field Eh to H_2 electrode (mV)	471.8	391.9	298.4	352.9	329.6	345.9	401.0	249.6	263.2	600.3	509.2	468.2
Calculated Eh (mV)	-88.3	-99.6	-87.4	-106.2	-76.6	-87.0	-111.6	-110.3	-97.7	-52.8	-59.4	-39.6
Anions												
Fluoride	0.00	1.15	NM	0.23	NM	0.00	1.09	0.00	0.00	0.00	1.06	0.12
Chloride	2.17	5.42	NM	0.02	NM	2.29	3.43	0.40	0.03	2.14	3.34	0.30
Nitrate	2.00	0.00	NM	0.00	NM	0.00	0.00	0.00	0.00	3.39	3.68	5.72
Phosphate	0.00	0.00	NM	0.00	NM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	3.10	2.47	NM	0.35	NM	2.76	2.58	6.75	6.89	2.70	5.85	0.91
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.21	0.43	0.74	0.55	0.60	0.05	0.08	0.10	0.06	0.52	1.51	0.47
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.01	0.05	0.06	0.06	0.00	0.00	0.11	0.06	0.04	0.00	0.08	0.07
Ba (Dissolved)	0.00	0.01	0.02	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.07	0.02
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	1.80	5.18	9.00	5.93	3.03	2.97	2.97	3.32	3.28	2.63	3.49	2.44
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00
Cu (Dissolved)	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01
Fe (Dissolved)	1.17	10.89	27.49	16.00	5.77	6.45	5.74	5.42	6.45	0.55	3.04	0.38
K (Dissolved)	0.41	0.44	0.78	0.59	0.55	0.29	0.54	0.83	1.44	0.42	0.51	0.53
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Mg (Dissolved)	0.65	1.99	3.84	2.40	1.13	1.06	1.03	1.20	1.16	0.56	1.60	0.53
Mn (Dissolved)	0.01	0.07	0.05	0.02	0.10	0.06	0.08	0.10	0.06	0.13	0.24	0.07
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	1.83	2.50	3.75	3.05	2.09	2.88	3.26	3.33	3.29	1.06	1.33	1.51
Ni (Dissolved)	0.00	0.02	0.02	0.01	0.00	0.00	0.02	0.00	0.03	0.00	0.01	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	0.44	0.48	0.29	0.46	0.09	0.36	0.40	0.00	0.06	0.39	0.98	0.00
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	3.80	7.85	11.32	12.22	4.86	6.49	6.36	6.97	7.11	3.77	4.78	3.67
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.01	0.03	0.74	0.43	0.17	0.02	0.02	0.11	0.15	0.01	0.02	0.00
Ti (Dissolved)	0.00	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.01	0.00
V (Dissolved)	0.00	0.01	0.03	0.02	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.00
Zn (Dissolved)	0.00	0.05	0.03	0.01	0.01	0.00	0.03	0.01	0.01	0.00	0.07	0.02
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	2.03	8.61	14.63	7.69	12.16	0.99	1.67	9.13	3.70	4.39	1.68	2.82
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.00	0.05	0.15	0.07	0.03	0.00	0.09	0.07	0.04	0.00	0.06	0.06
Ba (Total)	0.04	0.10	0.17	0.09	0.14	0.01	0.02	0.09	0.04	0.05	0.03	0.04
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	2.65	6.89	11.00	7.01	4.41	3.66	3.41	5.98	4.15	3.53	3.25	2.67
Cd (Total)	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Total)	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Total)	0.00	0.03	0.04	0.02	0.03	0.01	0.01	0.02	0.01	0.01	0.00	0.00
Cu (Total)	0.02	0.06	0.07	0.04	0.03	0.02	0.02	0.05	0.02	0.03	0.01	0.01
Fe (Total)	2.63	24.22	48.96	25.86	21.82	7.70	7.99	17.93	10.74	2.80	2.69	2.50
K (Total)	0.35	0.89	1.19	0.88	2.09	0.17	0.43	1.71	0.76	0.74	0.44	0.55
Li (Total)	0.00	0.01	0.02	0.01	0.02	0.00	0.01	0.01	0.00	0.00	0.01	0.00
Mg (Total)	0.98	4.21	7.84	4.15	5.04	1.30	1.40	3.42	1.97	1.28	0.94	1.13
Mn (Total)	0.01	0.08	0.13	0.06	0.19	0.07	0.07	0.16	0.09	0.22	0.21	0.06
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	1.80	3.04	3.89	3.00	2.19	2.87	3.21	3.40	3.24	1.08	1.26	1.47
Ni (Total)	0.00	0.02	0.03	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Pb (Total)	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
S (Total)	0.43	0.61	0.18	0.39	0.22	0.41	0.51	0.00	0.12	0.41	0.32	0.11
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Si (Total)	4.90	16.76	24.88	19.01	16.88	7.11	7.61	13.93	10.47	5.78	4.76	5.39
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.02	0.05	1.40	0.76	0.67	0.02	0.02	0.48	0.28	0.02	0.02	0.04
Ti (Total)	0.02	0.34	0.20	0.10	0.31	0.07	0.08	0.05	0.03	0.15	0.07	0.07
V (Total)	0.01	0.08	0.16	0.07	0.07	0.04	0.04	0.20	0.07	0.02	0.01	0.01
Zn (Total)	0.00	0.54	0.11	0.04	0.07	0.01	0.06	0.04	0.03	0.02	0.09	0.03

Appendix A.2b Raw Water Data for Big Meadows Wetland.

NM= Not Measured
NC= Not Calculated

Analysis Performed												
Well Number	BMA	BMA	BMA	BMB	BMB	BMB	BMC	BMC	BMC	BMD	BMD	BMD
Date of Collection	6/25/97	8/12/97	9/27/97	6/25/97	8/13/97	9/27/97	6/25/97	8/13/97	9/27/97	6/25/97	8/13/97	9/27/97
Field Measurements												
pH	5.9	5.9	5.9	6.0	5.7	6.3	5.1	6.9	6.7	6.2	7.4	6.8
Temp (°C)	12.1	11	12.8	14	12.5	14.9	13.2	11.9	11.2	17.8	11.4	11.9
D.O. (mg/l)	6.2	5.8	NM	4.0	4.5	NM	7.2	6.8	NM	6.2	5.8	NM
Alkalinity in field (mg/l $CaCO_3$)	11.0	10.0	17.0	19.0	18.5	15.0	14.0	70.0	17.0	20.0	29.0	14.5
Specific Cond. Field (u s)	25.1	30.3	26.3	52.7	109.6	32.7	81.3	168.3	52.8	84.9	97.3	87.5
Field Eh to H_2 electrode (mV)	562.7	385.0	438.4	551.8	499.3	393.9	530.7	272.3	372.1	515.0	451.9	313.5
Calculated Eh (mV)	-85.8	-89.8	-93.7	-92.6	-83.7	-105.0	-39.3	-153.7	-140.3	-114.6	-151.9	-154.3
Anions												
Fluoride	0.00	0.21	3.31	1.22	NM	1.68	1.21	0.30	0.30	1.48	0.90	1.45
Chloride	8.96	1.24	1.51	6.00	NM	2.39	5.58	0.51	2.20	6.30	3.07	1.97
Nitrate	8.27	0.56	0.32	1.91	NM	0.00	0.00	7.72	1.20	3.44	9.89	0.09
Phosphate	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	3.59	12.96	0.32	3.25	NM	8.44	4.36	1.00	0.56	6.27	1.63	5.52
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	31.13	4.83	3.28	13.98	0.95	1.84	0.25	0.33	0.31	0.18	0.09	0.27
As (Dissolved)	0.00	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00
B (Dissolved)	0.09	0.00	0.01	0.06	0.00	0.03	0.05	0.00	0.04	0.07	0.00	0.03
Ba (Dissolved)	0.35	0.05	0.05	0.82	0.02	0.03	0.01	0.03	0.01	0.01	0.01	0.02
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	8.18	2.21	1.61	27.36	2.99	2.01	2.15	7.82	4.10	4.25	8.76	7.16
Cd (Dissolved)	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.04	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Cu (Dissolved)	0.05	0.01	0.01	0.05	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Fe (Dissolved)	27.37	4.06	2.56	9.59	1.22	1.55	0.55	10.33	7.30	0.40	1.16	2.85
K (Dissolved)	3.64	1.40	4.68	3.35	1.54	3.66	1.10	30.35	1.65	1.81	1.92	2.67
Li (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Mg (Dissolved)	5.56	1.21	0.82	6.63	0.98	0.81	0.53	2.25	1.45	0.68	1.25	1.15
Mn (Dissolved)	0.19	0.02	0.03	0.94	0.06	0.03	0.04	0.09	0.04	0.06	0.05	0.04
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	3.41	2.61	4.54	3.68	2.83	3.40	2.80	3.83	3.57	4.83	7.29	6.38
Ni (Dissolved)	0.03	0.00	0.03	0.02	0.00	0.01	0.00	0.02	0.01	0.01	0.00	0.01
Pb (Dissolved)	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	0.79	0.13	0.44	0.89	0.35	1.02	1.22	0.97	0.45	1.58	0.60	0.25
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	45.88	12.15	10.50	9.82	4.22	7.36	5.31	9.45	9.10	10.24	16.98	19.75
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.07	0.13	0.10	0.18	0.02	0.04	0.01	0.32	0.18	0.02	0.06	0.07
Ti (Dissolved)	0.18	0.03	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
V (Dissolved)	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.14	0.02	0.04	0.67	0.02	0.01	0.02	0.06	0.03	0.03	0.03	0.04
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	75.23	25.22	77.93	101.61	12.63	71.17	111.89	3.10	6.56	53.88	1.35	0.34
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.10	0.01	0.06	0.14	0.00	0.08	0.24	0.04	0.07	0.12	0.00	0.03
Ba (Total)	1.40	0.62	1.29	1.56	0.47	1.59	1.19	0.10	0.09	0.68	0.04	0.02
Be (Total)	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00
Ca (Total)	28.67	13.72	23.58	42.48	14.24	38.53	42.34	10.92	7.42	73.99	10.55	7.65
Cd (Total)	0.02	0.01	0.02	0.03	0.00	0.02	0.03	0.00	0.01	0.01	0.00	0.00
Co (Total)	0.02	0.01	0.02	0.03	0.01	0.02	0.03	0.01	0.00	0.01	0.00	0.00
Cr (Total)	0.07	0.02	0.07	0.09	0.00	0.04	0.17	0.00	0.00	0.04	0.00	0.00
Cu (Total)	0.14	0.05	0.13	0.12	0.02	0.08	0.39	0.03	0.04	0.18	0.02	0.01
Fe (Total)	51.63	13.43	38.04	74.90	6.93	36.34	150.13	31.79	33.16	52.97	7.53	7.32
K (Total)	4.95	1.54	4.91	6.72	0.67	2.87	5.57	52.18	1.71	5.23	2.11	2.70
Li (Total)	0.03	0.01	0.04	0.04	0.01	0.02	0.02	0.00	0.00	0.01	0.00	0.00
Mg (Total)	14.53	6.18	13.91	18.72	4.41	14.21	10.66	2.73	2.39	7.42	1.61	1.19
Mn (Total)	0.41	0.13	0.37	1.71	0.27	0.50	0.77	0.13	0.09	0.27	0.08	0.04
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	2.85	2.70	3.44	3.07	2.67	3.46	4.80	3.77	3.47	6.49	7.40	6.54
Ni (Total)	0.06	0.02	0.06	0.07	0.01	0.05	0.11	0.04	0.03	0.08	0.01	0.01
Pb (Total)	0.04	0.00	0.02	0.08	0.00	0.03	0.15	0.00	0.02	0.11	0.00	0.00
S (Total)	0.64	0.09	0.40	1.44	0.33	1.10	5.71	1.04	0.52	5.56	0.68	0.28
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Si (Total)	77.10	28.74	84.77	105.49	12.70	61.67	69.36	10.76	13.64	32.19	18.47	20.47
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.23	0.50	1.17	0.29	0.30	1.25	0.33	0.99	0.95	0.37	0.25	0.22
Ti (Total)	0.03	0.00	0.01	0.09	0.00	0.00	0.43	0.00	0.00	0.35	0.05	0.01
V (Total)	0.05	0.01	0.03	0.11	0.01	0.07	0.34	0.02	0.03	0.12	0.00	0.00
Zn (Total)	0.18	0.05	0.17	0.28	0.05	0.12	0.41	0.12	0.04	0.58	0.11	0.05

Appendix A.2b Raw Water Data for Big Meadows Wetland.

NM= Not Measured
NC= Not Calculated

Analysis Performed									
Well Number	BME	BME	BME	BMSEEP	Ditch Down	Ditch Up	Downgradient	Midgradient	Upgradient
Date of Collection	6/25/97	8/13/97	9/27/97	9/27/97	6/25/97	6/25/97	6/10/97	6/10/97	6/10/97
Field Measurements									
pH	6.3	5.9	5.7	6.9	6.3	6.0	6.7	6.2	6.5
Temp (°C)	13.8	10.2	10.5	9	16	15.7	15.9	16.2	10.5
D.O. (mg/l)	7.0	4.5	NM	NM	5.2	7.5	7.8	8.5	7.4
Alkalinity in field (mg/l $CaCO_3$)	NM	35.0	9.0	22.0	9.0	4.3	8.6	7.6	7.9
Specific Cond. Field (u s)	230.9	154.6	43.3	56.740	33.6	35.4	26.7	27.6	25.4
Field Eh to H_2 electrode (mV)	402.3	392.6	417.8	672.9	540.2	546.9	545.7	533.6	507.0
Calculated Eh (mV)	-111.4	-80.9	-75.5	NC	NC	NC	NC	NC	NC
Anions									
Fluoride	1.15	3.51	2.61	0.27	1.03	NM	0.00	0.00	0.00
Chloride	30.58	3.64	0.26	0.46	4.06	NM	2.19	2.15	2.18
Nitrate	0.00	0.74	0.00	0.00	2.20	NM	5.23	5.89	1.55
Phosphate	0.00	9.41	0.00	10.74	0.00	NM	0.00	0.00	0.00
Sulfate	6.09	0.39	3.48	2.69	3.04	NM	3.02	0.00	3.50
Dissolved Cations									
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.77	0.12	0.49	0.13	0.06	0.08	0.26	0.37	0.17
As (Dissolved)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.07	0.00	0.02	0.01	0.05	0.06	0.00	0.00	0.01
Ba (Dissolved)	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.00
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	4.16	5.45	3.08	4.73	2.60	2.26	2.29	3.23	2.18
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	1.39	7.31	2.03	0.29	0.30	0.31	0.49	0.62	0.17
K (Dissolved)	34.38	0.52	0.49	1.01	0.60	0.52	0.48	0.48	0.47
Li (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Dissolved)	1.19	1.88	1.19	1.55	0.98	0.88	1.00	0.90	0.72
Mn (Dissolved)	0.04	0.06	0.04	0.00	0.01	0.00	0.01	0.01	0.00
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	3.07	3.31	2.72	3.15	2.08	1.82	1.68	2.27	1.59
Ni (Dissolved)	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	0.79	0.08	0.00	0.74	0.40	0.38	0.47	0.39	0.45
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	4.23	7.95	6.67	5.93	2.08	1.95	2.68	0.89	3.30
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.02	0.23	0.04	0.00	0.02	0.01	0.01	0.02	0.01
Ti (Dissolved)	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.09	0.05	0.01	0.01	0.01	0.02	0.00	0.00	0.00
Total Cations									
Ag (Total)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	49.23	1.33	1.34	0.29	0.07	0.09	0.08	0.41	0.19
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.10	0.00	0.02	0.00	0.01	0.05	0.00	0.00	0.00
Ba (Total)	0.53	0.03	0.03	0.01	0.01	0.01	0.00	0.01	0.00
Be (Total)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	17.52	6.05	3.45	4.76	2.45	2.52	2.14	3.28	2.26
Cd (Total)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Total)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Total)	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Total)	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Total)	47.84	9.90	5.56	0.37	0.37	0.40	0.29	0.75	0.17
K (Total)	39.54	0.38	0.27	0.90	0.38	0.53	0.42	0.51	0.42
Li (Total)	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Total)	11.12	2.17	1.36	1.60	0.91	0.96	0.77	0.90	0.77
Mn (Total)	0.42	0.06	0.04	0.00	0.00	0.01	0.00	0.01	0.00
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	4.31	3.35	2.56	3.12	1.95	2.06	1.62	0.00	1.63
Ni (Total)	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Total)	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Total)	2.30	0.06	0.04	0.67	0.39	0.39	0.49	0.41	0.48
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	48.30	8.85	7.24	6.28	2.04	2.08	2.28	0.94	3.50
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.13	0.30	0.13	0.00	0.01	0.01	0.01	0.02	0.01
Ti (Total)	1.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00
V (Total)	0.24	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Total)	9.58	0.15	0.00	0.00	0.03	0.27	0.00	0.00	0.00

Appendix A.2b Raw Water Data for Big Meadows Wetland.

NM= Not Measured
NC= Not Calculated

Sample ID	BM13		BM22		BM28	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.00	nd	0.02	nd	0.01
Al	7676.64	9.11	21295.61	56.17	28414.89	107.28
As	nd	0.06	nd	0.30	nd	0.51
B	6.83	0.16	26.86	0.28	22.38	0.04
Ba	28.79	0.03	87.57	0.27	134.73	0.50
Be	0.36	0.01	0.83	0.01	1.16	0.00
Ca	2661.35	11.02	1364.14	3.48	4111.47	8.82
Cd	nd	0.02	nd	0.01	nd	0.01
Co	1.37	0.02	5.22	0.04	7.06	0.07
Cr	6.28	0.02	34.91	0.15	18.43	0.03
Cu	11.11	0.21	15.13	0.16	11.41	0.05
Fe	6668.10	19.73	19100.76	51.07	21562.57	45.01
K	1094.05	0.41	2379.81	6.91	3794.83	15.55
Li	4.13	0.07	12.53	0.12	14.85	0.04
Mg	1220.39	9.05	3551.74	30.29	4541.43	11.16
Mn	27.67	0.53	75.40	0.72	275.96	0.76
Mo	nd	0.03	nd	0.08	nd	0.06
Na	176.07	1.03	309.10	0.62	352.90	0.32
Ni	4.83	0.03	14.20	0.08	15.75	0.05
Pb	13.51	0.09	4.05	0.17	6.93	0.01
S	1735.08	36.53	175.26	0.59	455.78	4.50
Sb	nd	0.11	nd	0.21	nd	0.24
Se	nd	0.11	nd	0.21	nd	0.14
Si	7.88	0.04	177.55	1.95	0.65	0.06
Sn	nd	0.03	0.41	0.14	0.37	0.20
Sr	244.42	0.53	638.42	6.81	767.92	3.90
Ti	44.54	0.86	426.06	0.99	164.98	0.53
V	10.32	0.04	55.57	0.50	36.11	0.10
Zn	21.02	0.34	34.52	0.36	65.05	0.26

nd= non-detect

Appendix A.2c Raw Data for Soils Collected at Big Meadows Wetland on 9-27-97.

Sample ID Analyte	BM32 Conc. (mg/kg)	 Std. Dev. (mg/kg)	BM54 Conc. (mg/kg)	 Std. Dev. (mg/kg)	BMA Conc. (mg/kg)	 Std. Dev. (mg/kg)
Ag	nd	0.02	nd	0.01	nd	0.01
Al	8548.80	26.03	12492.78	179.71	26267.23	46.93
As	nd	0.37	nd	0.92	nd	0.72
B	9.70	0.06	29.53	0.24	10.37	0.00
Ba	42.31	0.07	54.75	0.80	112.14	0.18
Be	0.60	0.01	1.37	0.00	0.98	0.00
Ca	1693.95	4.68	1470.77	8.54	1863.93	3.33
Cd	nd	0.00	nd	0.02	nd	0.02
Co	1.58	0.02	2.20	0.04	4.16	0.04
Cr	8.36	0.02	22.52	0.31	14.50	0.12
Cu	18.73	0.30	8.62	0.02	13.89	0.02
Fe	8924.36	21.75	28622.75	416.18	9723.82	18.09
K	986.63	2.15	1276.99	2.67	2475.63	3.22
Li	4.19	0.08	5.28	0.01	14.28	0.01
Mg	1145.99	2.09	1756.51	27.64	3375.91	15.23
Mn	18.46	0.27	25.81	0.13	161.50	0.33
Mo	nd	0.03	nd	0.19	nd	0.03
Na	179.87	0.89	253.89	2.32	276.23	0.97
Ni	6.88	0.07	9.13	0.12	9.47	0.06
Pb	5.95	0.05	5.11	0.24	4.65	0.20
S	703.40	7.18	1577.18	29.60	nd	3.36
Sb	nd	0.20	nd	0.28	nd	0.20
Se	nd	0.13	nd	1.46	nd	0.44
Si	25.39	0.15	1.83	0.14	26.80	0.16
Sn	nd	0.15	0.00	0.06	0.30	0.09
Sr	306.57	3.83	988.44	8.02	357.39	2.80
Ti	60.10	0.95	30.33	0.12	9.12	0.03
V	13.29	0.08	43.06	0.25	3.48	0.02
Zn	17.23	0.08	15.78	0.21	53.01	0.09

nd= non-detect

Appendix A.2c Raw Data for Soils Collected at Big Meadows Wetland on 9-27-97.

Sample ID	BMB		BMC		BMD	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.03	nd	0.01	nd	0.01
Al	27811.46	161.91	5757.67	4.47	7772.51	26.77
As	nd	1.09	nd	0.34	nd	0.31
B	18.52	0.23	6.69	0.07	4.76	0.06
Ba	114.99	0.59	32.49	0.04	32.05	0.10
Be	1.06	0.01	0.31	0.00	0.38	0.00
Ca	2915.47	14.98	1345.04	0.57	3157.63	10.20
Cd	nd	0.03	nd	0.01	nd	0.01
Co	3.68	0.02	1.09	0.02	1.14	0.01
Cr	14.56	0.09	14.27	0.14	5.30	0.03
Cu	11.06	0.14	9.92	0.07	10.59	0.09
Fe	15172.51	83.53	5266.21	4.98	4496.60	12.36
K	2715.06	16.25	723.46	8.31	920.73	3.01
Li	15.91	0.17	3.25	0.04	3.65	0.03
Mg	3850.00	35.18	737.54	9.00	1130.50	1.54
Mn	72.52	0.70	14.60	0.16	16.65	0.13
Mo	nd	0.07	nd	0.05	nd	0.01
Na	314.14	1.34	193.16	1.28	158.74	0.17
Ni	9.88	0.14	4.37	0.05	4.56	0.01
Pb	6.51	0.15	6.10	0.07	11.38	0.15
S	159.57	4.52	424.58	6.66	1347.79	12.06
Sb	nd	0.41	nd	0.15	nd	0.05
Se	nd	0.47	nd	0.28	nd	0.17
Si	70.20	0.89	90.20	0.82	4.57	0.02
Sn	1.03	0.12	nd	0.03	nd	0.06
Sr	531.55	4.39	183.48	1.37	172.13	1.00
Ti	73.01	0.82	59.70	0.60	39.47	0.32
V	26.74	0.35	9.98	0.08	9.04	0.05
Zn	53.45	0.38	15.89	0.14	15.96	0.11

nd= non-detect

Appendix A.2c Raw Data for Soils Collected at Big Meadows Wetland on 9-27-97.

Sample ID	BME	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.00
Al	5378.47	6.45
As	nd	0.04
B	5.98	0.03
Ba	41.46	0.05
Be	0.38	0.00
Ca	2556.19	2.99
Cd	nd	0.01
Co	1.25	0.01
Cr	6.01	0.02
Cu	11.75	0.11
Fe	6020.20	3.92
K	841.00	0.70
Li	1.99	0.02
Mg	948.78	8.75
Mn	32.19	0.28
Mo	nd	0.01
Na	170.08	0.35
Ni	4.39	0.02
Pb	7.34	0.14
S	633.12	3.68
Sb	nd	0.04
Se	nd	0.04
Si	13.64	0.00
Sn	nd	0.07
Sr	223.84	1.99
Ti	56.95	0.50
V	8.64	0.03
Zn	13.63	0.03

nd= non-detect

Appendix A.2c Raw Data for Soils Collected at Big Meadows Wetland on 9-27-97.

Sample ID	BM13		BM15		BM22	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	1.03	0.34	0.33	0.24	3.01	0.11
Al	39.18	11.70	92.95	2.41	9.75	2.30
As	0.77	1.58	nd	nd	nd	nd
B	nd	nd	nd	nd	2.46	3.02
Ba	39.76	0.73	75.18	0.61	47.66	0.60
Be	0.12	0.08	0.04	0.01	0.03	0.01
Ca	2619.46	45.65	5838.12	36.66	4538.94	49.52
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	nd	nd	0.07	0.49
Cr	nd	nd	0.32	0.25	nd	nd
Cu	11.84	1.35	9.27	0.10	4.59	0.14
Fe	306.22	5.23	525.08	5.39	62.96	0.82
K	12617.91	171.65	14549.22	135.07	3937.78	67.68
Li	1.34	3.18	0.82	0.38	0.77	0.48
Mg	1371.85	16.79	2258.18	7.31	1549.47	7.55
Mn	90.47	1.65	138.85	1.02	375.61	5.72
Mo	5.87	1.65	1.55	0.45	1.80	0.77
Na	144.21	8.95	132.61	3.80	92.57	3.81
Ni	2.12	2.32	1.12	0.29	0.65	0.68
Pb	0.00	0.31	10.90	1.70	nd	nd
S	nd	nd	nd	nd	nd	nd
Sb	nd	nd	nd	nd	nd	nd
Se	7.95	13.16	1.31	4.63	2.17	2.42
Si	287.12	5.57	118.00	0.67	44.82	0.56
Sn	8.03	4.26	1.10	2.16	0.90	1.85
Sr	10.52	13.80	33.27	41.84	14.79	16.25
Ti	6.91	0.35	10.34	0.07	2.40	0.06
V	1.64	1.72	0.82	0.19	0.46	0.36
Zn	88.79	0.90	41.94	0.48	16.23	0.16

nd= non-detect

Appendix A.2d Raw Data for Vegetation Collected at Big Meadows Wetland on 9-27-97. Reported as Average of Two Samples.

Sample ID	BM28		BM32		BM35	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.44	0.36	0.35	0.07	0.64	0.19
Al	22.16	2.19	21.65	1.41	21.67	0.91
As	nd	nd	nd	nd	nd	nd
B	nd	nd	nd	nd	nd	nd
Ba	50.16	0.64	53.16	0.70	48.55	0.56
Be	0.03	0.02	0.04	0.01	0.03	0.02
Ca	7315.84	95.95	5343.24	64.94	5695.42	68.75
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	0.00	0.23	0.32	0.63
Cr	0.76	0.34	nd	nd	0.01	0.04
Cu	6.81	0.33	4.79	0.22	6.34	0.23
Fe	106.61	2.08	247.74	3.33	85.39	0.90
K	13806.98	163.17	8213.40	140.80	9881.16	118.47
Li	0.64	0.49	0.60	0.26	0.68	0.31
Mg	2085.21	12.82	3576.11	8.34	2560.47	12.57
Mn	212.69	2.81	58.69	0.58	823.83	11.45
Mo	1.58	0.75	1.66	0.34	1.34	0.20
Na	70.76	2.07	178.42	3.13	35.29	1.02
Ni	1.83	0.94	1.40	0.43	1.28	0.33
Pb	1.32	1.34	2.25	1.87	nd	nd
S	nd	nd	nd	nd	nd	nd
Sb	nd	nd	nd	nd	nd	nd
Se	1.58	4.67	2.78	4.86	0.93	2.54
Si	131.23	1.70	114.86	0.99	142.47	1.26
Sn	2.42	2.53	1.63	1.62	0.81	1.04
Sr	28.85	20.04	25.73	16.28	20.45	9.81
Ti	0.80	0.02	0.87	0.03	nd	nd
V	0.28	0.53	0.50	0.25	0.35	0.40
Zn	101.66	1.83	22.14	0.43	33.60	0.38

nd= non-detect

Appendix A.2d Raw Data for Vegetation Collected at Big Meadows Wetland on 9-27-97. Reported as Average of Two Samples.

Sample ID	BM53		BM55		BMA	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.56	0.29	0.56	0.21	0.29	0.37
Al	16.05	1.09	28.90	1.57	9.51	2.13
As	nd	nd	7.31	1.44	nd	nd
B	7.08	3.58	15.81	5.17	nd	nd
Ba	43.00	0.17	38.57	0.17	28.70	0.22
Be	0.06	0.03	0.05	0.00	0.03	0.00
Ca	3926.48	36.91	3399.63	18.66	3193.31	42.73
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	0.17	1.05	0.25	0.29
Cr	0.34	0.32	nd	nd	nd	nd
Cu	4.79	0.21	6.92	0.29	4.36	0.20
Fe	191.86	3.14	119.02	0.89	52.38	0.56
K	6239.22	48.40	14070.49	130.96	7824.99	78.58
Li	0.59	0.21	0.84	0.33	0.52	0.09
Mg	1662.33	11.66	1240.34	9.19	1255.90	6.83
Mn	130.12	2.24	325.44	2.47	269.31	3.59
Mo	1.23	0.56	5.08	1.38	0.62	0.57
Na	234.86	4.14	30.17	2.51	62.89	4.87
Ni	0.63	0.50	0.83	0.51	0.77	0.31
Pb	nd	nd	1.74	2.65	nd	nd
S	nd	nd	nd	nd	nd	nd
Sb	nd	nd	nd	nd	nd	nd
Se	3.47	1.65	1.30	7.87	1.32	4.13
Si	27.78	1.38	72.90	1.13	86.33	0.29
Sn	1.38	0.88	1.79	1.02	0.94	1.25
Sr	19.77	26.11	11.87	27.85	13.71	18.42
Ti	nd	nd	1.35	0.03	nd	nd
V	0.46	0.29	0.27	0.42	0.19	0.14
Zn	20.47	0.31	37.16	0.46	18.17	0.21

nd= non-detect

Appendix A.2d Raw Data for Vegetation Collected at Big Meadows Wetland on 9-27-97. Reported as Average of Two Samples.

Sample ID	BMB		BMC		BMD	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.45	0.13	0.26	0.22	0.29	0.11
Al	90.19	2.82	10.00	1.19	12.75	2.79
As	nd	nd	nd	nd	0.52	0.56
B	nd	nd	nd	nd	nd	nd
Ba	36.73	0.46	47.18	0.71	38.67	0.57
Be	0.07	0.01	0.03	0.01	0.05	0.02
Ca	4028.34	40.87	3851.07	45.88	3399.54	58.70
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	0.20	0.25	0.03	0.39
Cr	0.25	0.27	nd	nd	0.02	0.34
Cu	7.11	0.20	4.56	0.20	4.05	0.32
Fe	178.34	3.90	115.50	1.59	174.84	5.66
K	5944.10	71.97	8557.39	150.25	10262.83	160.09
Li	0.50	0.23	0.71	0.30	0.53	0.45
Mg	1412.67	8.14	2513.83	9.32	1653.41	17.58
Mn	581.39	5.09	214.75	2.83	61.73	1.15
Mo	1.03	0.41	1.56	0.53	0.96	0.28
Na	40.81	1.98	14.84	1.88	67.04	4.58
Ni	0.68	0.48	1.07	0.26	1.15	0.60
Pb	1.22	2.78	nd	nd	1.00	1.62
S	nd	nd	nd	nd	nd	nd
Sb	nd	nd	nd	nd	0.19	0.71
Se	1.44	2.98	2.45	0.85	2.43	6.06
Si	99.77	1.03	88.05	1.15	56.00	0.57
Sn	1.51	1.71	1.39	1.21	1.75	1.42
Sr	12.99	17.53	19.96	28.16	14.89	20.93
Ti	0.54	0.06	nd	nd	nd	nd
V	0.60	0.19	0.28	0.29	0.26	0.36
Zn	35.25	0.57	37.45	0.55	62.92	0.87

nd= non-detect

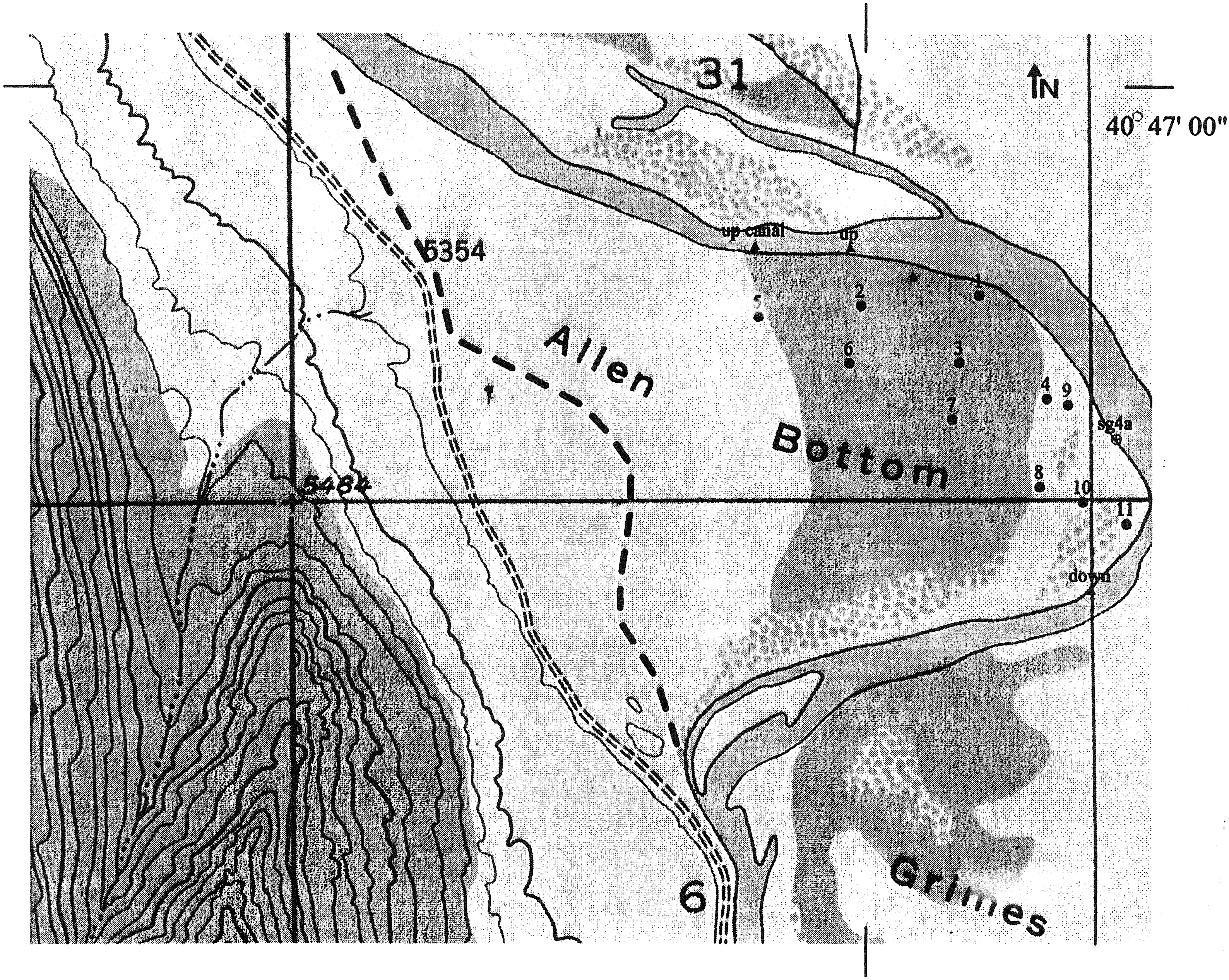
Appendix A.2d Raw Data for Vegetation Collected at Big Meadows Wetland on 9-27-97. Reported as Average of Two Samples.

Sample ID	BME	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.17	0.32
Al	17.83	2.43
As	66.20	13.76
B	30.12	9.45
Ba	57.22	0.88
Be	0.04	0.00
Ca	3128.29	57.09
Cd	nd	nd
Co	0.31	0.18
Cr	0.23	0.44
Cu	5.59	0.16
Fe	153.58	2.49
K	9023.54	117.00
Li	0.86	0.37
Mg	1317.45	9.13
Mn	86.17	1.48
Mo	6.03	2.66
Na	84.66	2.47
Ni	0.63	0.57
Pb	1.86	1.97
S	nd	nd
Sb	nd	nd
Se	1.62	2.09
Si	83.03	4.83
Sn	1.48	1.12
Sr	12.75	15.39
Ti	0.60	0.04
V	0.22	0.16
Zn	35.32	1.35

nd= non-detect

Appendix A.2d Raw Data for Vegetation Collected at Big Meadows Wetland on 9-27-97. Reported as Average of Two Samples.

Appendix A.3a Sampling Locations at Allen Bottom Wetland.



- ● Ground-Water Wells
- ▲ Surface Water

Analysis Performed												
Well Number	BP1	BP1	BP1	BP1	BP10	BP10	BP10	BP10	BP11	BP11	BP2	BP2
Date of Collection	5/21/97	6/5/97	7/22/97	11/1/97	5/22/97	6/5/97	7/22/97	10/31/97	7/22/97	10/31/97	5/22/97	6/6/97
Field Measurements												
pH	7.0	7.5	7.5	7.8	7.3	7.7	7.2	7.2	7.2	7.4	7.4	8.0
Temp (°C)	11.2	13.3	17.5	12.3	11.9	13.8	20.5	10.8	18.3	10.8	13.8	18.4
D.O. (mg/l)	3.0	3.8	6.3	6.7	2.6	3.6	5.0	3.1	4.2	3.2	3.3	3.2
Alkalinity in field (mg/l $CaCO_3$)	259.9	408.0	199.0	300.0	400.1	206.0	623.0	620.0	313.0	370.0	340.3	438.0
Specific Cond. Field (*u* s)	759.1	764.9	955.9	748.6	1459.1	712.4	1914.6	1473.7	2501.1	2098.0	751.8	746.0
Field Eh to H_2 electrode (mV)	411.0	519.7	236.6	587.4	149.3	480.4	101.4	470.7	106.6	552.9	445.8	477.9
Calculated Eh (mV)	-155.7	-194.6	-194.2	-209.0	-108.6	-207.5	-181.3	-175.7	-181.9	-185.2	-190.1	-226.1
Anions												
Fluoride	0.58	1.60	0.24	0.26	0.33	1.20	0.24	0.11	0.28	0.31	0.45	1.65
Chloride	16.23	25.97	17.99	24.46	39.50	17.55	41.29	35.13	156.43	109.06	15.23	22.69
Nitrate	10.37	0.00	2.19	0.00	3.44	3.40	0.00	9.71	0.14	2.01	0.00	0.00
Phosphate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Sulfate	181.46	200.40	197.72	244.32	380.21	188.82	355.99	289.36	743.51	765.09	182.04	226.89
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.01	0.00	0.09	0.38	0.00	0.09	0.02	0.02	0.04	0.02	0.00	0.61
As (Dissolved)	0.00	0.00	0.02	0.02	0.00	0.00	0.02	0.02	0.00	0.03	0.00	0.00
B (Dissolved)	0.11	0.10	0.14	0.11	0.10	0.09	0.18	0.15	0.03	0.16	0.11	0.09
Ba (Dissolved)	0.10	0.09	0.11	0.12	0.06	0.05	0.10	0.10	0.01	0.04	0.09	0.09
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	67.82	63.65	63.10	72.54	155.27	62.25	151.18	153.59	29.98	207.06	60.33	62.87
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	0.02	0.01	0.06	0.37	5.47	0.18	6.33	7.06	0.90	2.98	0.01	1.18
K (Dissolved)	2.65	3.12	3.42	4.80	3.19	2.51	4.70	4.81	0.79	6.73	2.25	3.50
Li (Dissolved)	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.01	0.07	0.03	0.02
Mg (Dissolved)	25.10	23.63	23.33	26.80	46.52	23.41	49.16	50.12	13.50	89.78	23.65	24.51
Mn (Dissolved)	1.41	1.55	1.86	1.54	1.67	0.13	1.70	2.44	0.79	5.91	1.10	1.30
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	55.05	57.52	59.11	65.12	96.06	47.99	145.93	103.85	24.39	129.35	53.98	57.79
Ni (Dissolved)	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	68.04	63.42	66.88	77.35	135.04	58.52	113.67	95.78	38.87	254.78	62.55	65.93
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	5.69	5.42	5.58	7.07	7.50	2.83	9.41	10.43	1.31	9.50	5.78	6.82
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.55	0.52	0.42	0.59	1.00	0.57	1.27	1.27	0.21	1.59	0.48	0.52
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
V (Dissolved)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Zn (Dissolved)	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.01	0.00	0.04	0.00	0.00
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.01	0.00	0.01	0.00	0.00
Al (Total)	7.95	5.62	7.50	4.90	2.25	4.33	3.72	23.22	12.45	0.04	16.12	16.40
As (Total)	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.05	0.02	0.07	0.00	0.00
B (Total)	0.11	0.11	0.15	0.12	0.10	0.10	0.20	0.17	0.20	0.18	0.12	0.13
Ba (Total)	0.29	0.37	0.37	0.13	0.12	0.34	0.24	0.13	0.26	0.11	0.32	0.67
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	105.98	93.72	106.42	506.62	176.02	101.66	171.49	768.16	281.76	1075.23	204.16	239.67
Cd (Total)	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Co (Total)	0.01	0.01	0.01	0.05	0.00	0.01	0.01	0.10	0.02	0.02	0.04	0.04
Cr (Total)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.03	0.01	0.03	0.03
Cu (Total)	0.02	0.01	0.02	0.01	0.00	0.01	0.00	0.05	0.02	0.00	0.03	0.04
Fe (Total)	10.48	7.90	10.11	0.04	11.89	11.10	13.24	8.41	28.10	0.03	32.56	35.29
K (Total)	4.33	4.46	5.54	6.06	4.00	3.30	5.76	7.46	8.78	8.45	5.76	6.66
Li (Total)	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.07	0.10	0.10	0.05	0.05
Mg (Total)	33.82	30.54	33.76	80.50	51.68	32.24	54.54	132.58	107.94	183.52	50.73	55.19
Mn (Total)	2.16	2.13	2.75	8.48	1.89	0.47	1.89	8.23	6.81	16.23	4.74	5.40
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	60.43	57.69	60.50	69.97	101.06	53.76	149.44	112.31	163.20	138.35	60.05	61.48
Ni (Total)	0.01	0.01	0.02	0.05	0.00	0.01	0.01	0.10	0.03	0.02	0.04	0.05
Pb (Total)	0.00	0.01	0.01	0.00	0.00	0.02	0.00	0.02	0.01	0.00	0.02	0.03
S (Total)	63.34	62.96	67.52	78.38	142.89	60.48	116.27	98.40	297.72	273.30	70.66	70.24
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	22.97	17.79	21.57	21.49	12.62	10.77	18.65	46.70	39.44	11.63	37.93	35.82
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.72	0.65	0.88	1.93	1.14	0.73	1.56	3.03	2.78	4.13	1.10	1.25
Ti (Total)	0.05	0.07	0.08	0.00	0.03	0.08	0.06	0.00	0.15	0.00	0.13	0.20
V (Total)	0.02	0.02	0.02	0.00	0.01	0.02	0.01	0.01	0.04	0.01	0.06	0.07
Zn (Total)	0.05	0.04	0.06	0.10	0.01	0.03	0.20	0.26	0.13	0.03	0.10	0.13

Appendix A.3b Raw Water Data for Allen Bottom Wetland

NM= Not Measured
NC= Not Calculated

Analysis Performed												
Well Number	BP2	BP2	BP3	BP3	BP3	BP3	BP4	BP4	BP5	BP5	BP5	BP6
Date of Collection	7/22/97	11/1/97	5/22/97	6/6/97	7/22/97	11/1/97	7/22/97	10/31/97	5/22/97	6/6/97	7/22/97	5/21/97
Field Measurements												
pH	7.6	7.3	7.5	7.6	7.4	7.3	6.9	7.0	7.4	7.7	7.5	7.0
Temp (°C)	16.3	12.8	10.2	13.7	20.6	13.3	17.8	8.4	11.6	15.3	16.9	14.3
D.O. (mg/l)	5.2	4.4	4.0	2.3	5.0	4.1	1.4	1.2	4.0	2.7	7.4	3.0
Alkalinity in field (mg/l $CaCO_3$)	229.0	256.0	279.9	308.0	227.0	284.0	660.0	676.0	360.0	388.0	314.0	400.1
Specific Cond. Field (μs)	1252.1	649.3	1094.4	1047.0	1019.7	1047.0	1234.8	1001.6	883.0	854.3	938.1	1124.9
Field Eh to H_2 electrode (mV)	255.2	410.9	310.9	352.0	221.3	523.4	74.0	120.2	449.2	408.8	285.4	499.2
Calculated Eh (mV)	-202.6	-180.0	-189.9	-198.7	-195.1	-180.0	-157.0	-171.1	-186.5	-207.9	-196.8	-167.4
Anions												
Fluoride	0.26	0.01	0.40	1.28	0.25	0.13	0.25	0.16	0.42	1.52	0.81	0.41
Chloride	17.39	13.67	25.33	27.61	23.80	28.89	22.77	22.42	16.53	26.43	17.39	24.99
Nitrate	2.31	0.00	3.34	10.62	2.12	0.00	1.01	1.19	6.12	0.00	2.93	1.80
Phosphate	0.00	0.00	0.00	0.00	7.46	1.39	0.00	0.00	0.00	0.00	4.03	0.00
Sulfate	207.23	181.56	289.37	311.42	281.43	333.92	25.70	9.03	203.78	243.78	232.27	284.86
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.47	0.08	0.00	0.00	0.03	0.35	9.32	1.14	0.00	0.04	2.13	0.00
As (Dissolved)	0.02	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.03	0.00	0.04	0.00
B (Dissolved)	0.12	0.10	0.11	0.11	0.14	0.13	0.23	0.22	0.11	0.12	0.16	0.10
Ba (Dissolved)	0.11	0.09	0.06	0.05	0.05	0.09	0.81	0.73	0.11	0.06	0.12	0.09
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	64.35	56.43	100.06	93.02	80.84	117.83	131.27	111.81	77.74	82.68	79.32	119.78
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00
Fe (Dissolved)	0.66	0.11	0.19	0.19	0.11	0.36	27.96	26.19	0.03	0.05	2.74	0.02
K (Dissolved)	3.16	4.37	3.15	2.96	3.31	5.02	10.75	8.23	3.74	3.69	6.65	3.62
Li (Dissolved)	0.02	0.02	0.01	0.02	0.02	0.02	0.04	0.03	0.01	0.02	0.02	0.01
Mg (Dissolved)	24.80	21.51	34.99	33.06	28.96	41.12	48.70	45.95	28.29	25.99	27.70	33.95
Mn (Dissolved)	1.44	1.05	3.26	3.29	3.55	3.32	1.35	1.22	1.93	0.82	1.69	1.96
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Na (Dissolved)	55.08	58.55	79.95	82.32	69.19	87.39	72.22	80.43	59.25	63.52	63.12	73.76
Ni (Dissolved)	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.00	0.01	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	67.73	60.80	104.95	98.70	91.92	124.10	11.10	4.55	70.03	69.64	68.67	106.25
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	6.07	6.75	6.85	6.60	6.59	8.47	39.48	19.83	6.42	6.60	11.52	7.75
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.43	0.41	0.74	0.68	0.52	0.81	1.80	1.95	0.66	0.62	0.52	0.89
Ti (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.23	0.02	0.00	0.00	0.05	0.00
V (Dissolved)	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00
Zn (Dissolved)	0.01	0.01	0.00	0.00	0.01	0.01	0.08	0.06	0.00	0.00	0.03	0.00
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Al (Total)	8.73	12.33	8.88	9.37	8.44	0.08	27.48	0.02	13.14	13.70	25.78	5.87
As (Total)	0.02	0.02	0.00	0.00	0.00	0.04	0.00	0.09	0.00	0.00	0.00	0.00
B (Total)	0.14	0.15	0.13	0.14	0.17	0.15	0.29	0.14	0.13	0.12	0.21	0.11
Ba (Total)	0.84	0.09	0.13	0.29	0.85	0.16	1.68	1.90	0.21	0.53	0.90	0.13
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	120.64	265.83	166.40	163.38	120.23	467.94	313.84	1443.99	214.06	193.32	288.89	154.13
Cd (Total)	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.00	0.01	0.01	0.02	0.00
Co (Total)	0.02	0.04	0.02	0.01	0.01	0.02	0.03	0.00	0.03	0.02	0.03	0.01
Cr (Total)	0.02	0.02	0.02	0.02	0.02	0.01	0.05	0.01	0.02	0.02	0.05	0.01
Cu (Total)	0.02	0.03	0.01	0.02	0.02	0.00	0.08	0.00	0.03	0.03	0.06	0.01
Fe (Total)	15.81	29.09	16.65	16.26	13.01	0.00	76.87	0.06	23.79	23.56	41.17	9.55
K (Total)	5.16	4.96	5.03	5.46	5.66	5.23	11.80	15.84	6.29	6.15	9.89	4.84
Li (Total)	0.04	0.04	0.03	0.04	0.03	0.03	0.09	0.08	0.04	0.04	0.07	0.02
Mg (Total)	36.91	56.56	50.89	50.26	38.83	82.52	85.73	133.78	52.46	47.50	65.94	40.83
Mn (Total)	3.47	6.55	5.12	5.05	4.63	10.19	3.03	0.00	6.16	4.78	9.14	2.50
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Na (Total)	57.53	61.22	81.24	76.31	68.17	89.15	77.46	101.87	66.08	64.49	66.58	76.25
Ni (Total)	0.02	0.05	0.02	0.02	0.02	0.02	0.07	0.00	0.04	0.04	0.07	0.01
Pb (Total)	0.03	0.01	0.00	0.01	0.00	0.00	0.10	0.00	0.02	0.04	0.05	0.00
S (Total)	71.64	70.16	103.73	101.52	92.85	142.08	13.34	70.23	71.56	69.91	71.85	105.37
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	24.77	28.92	25.74	26.20	27.63	13.27	72.40	5.66	34.34	37.16	63.36	21.33
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	1.06	1.85	1.02	0.98	1.04	1.79	3.81	7.06	1.13	1.00	2.40	1.04
Ti (Total)	0.16	0.00	0.06	0.10	0.15	0.00	0.15	0.00	0.04	0.14	0.15	0.04
V (Total)	0.03	0.06	0.03	0.03	0.02	0.01	0.08	0.00	0.04	0.04	0.07	0.02
Zn (Total)	0.07	0.13	0.06	0.09	0.06	0.03	0.30	0.02	0.09	0.11	0.19	0.03

Appendix A.3b Raw Water Data for Allen Bottom Wetland

NM= Not Measured
NC= Not Calculated

Analysis Performed												
Well Number	BP6	BP6	BP6	BP7	BP7	BP7	BP7	BP8	BP8	BP8	BP8	BP9
Date of Collection	6/6/97	7/22/97	11/1/97	5/22/97	6/6/97	7/22/97	11/1/97	5/21/97	6/6/97	7/22/97	10/31/97	5/22/97
Field Measurements												
pH	7.5	7.3	7.4	7.2	7.5	7.3	7.3	7.1	7.6	7.1	7.2	6.7
Temp (°C)	14.6	17.5	13.2	10.7	13.7	15.1	14.1	10.3	12.0	15.4	10.6	12.9
D.O. (mg/l)	2.8	5.4	5.2	3.4	1.6	3.8	2.4	2.5	1.5	4.2	3.9	3.7
Alkalinity in field (mg/l $CaCO_3$)	360.0	271.0	196.0	280.4	290.0	249.0	200.0	379.6	420.0	481.0	517.0	360.8
Specific Cond. Field (*u* s)	1128.1	1040.0	775.9	837.8	817.4	887.9	718.6	1238.8	1265.1	3270.7	621.0	897.4
Field Eh to H_2 electrode (mV)	450.8	223.3	405.0	236.6	200.8	139.2	439.4	207.2	375.5	99.8	591.4	221.7
Calculated Eh (mV)	-194.6	-183.1	-185.8	-173.8	-192.3	-184.2	-183.7	-165.8	-200.0	-172.5	-175.4	-141.0
Anions												
Fluoride	1.16	0.36	0.17	0.35	1.19	0.12	0.23	0.35	1.18	0.14	0.18	0.38
Chloride	26.77	23.35	21.39	16.30	19.87	17.33	16.84	25.58	28.88	139.61	24.99	17.17
Nitrate	5.85	5.91	1.06	1.41	4.99	0.30	0.00	3.77	2.44	4.41	10.06	6.92
Phosphate	8.42	0.00	6.82	0.00	7.71	0.00	15.05	0.00	0.00	0.00	0.00	0.00
Sulfate	367.68	213.59	236.90	180.39	211.23	163.12	202.19	320.27	334.69	1245.33	273.89	135.06
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.02	0.05	0.01	0.00	0.03	0.65	0.41	0.01	0.48	0.61	0.07	0.00
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.03	0.02	0.00
B (Dissolved)	0.11	0.11	0.11	0.10	0.09	0.11	0.11	0.10	0.09	0.22	0.11	0.12
Ba (Dissolved)	0.08	0.08	0.06	0.05	0.05	0.05	0.08	0.09	0.09	0.15	0.06	0.07
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	119.93	78.77	83.66	79.79	76.78	76.14	74.14	128.40	125.83	273.07	89.13	84.73
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	0.04	0.08	0.03	0.97	0.68	1.70	0.54	2.01	3.61	8.87	0.47	4.32
K (Dissolved)	3.80	3.41	4.56	2.18	2.58	2.75	5.11	3.78	3.95	9.09	5.11	2.78
Li (Dissolved)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.01	0.02
Mg (Dissolved)	34.09	22.88	24.40	24.67	24.20	23.74	23.47	39.08	41.16	97.31	36.67	22.93
Mn (Dissolved)	2.25	2.35	1.37	2.98	2.74	2.91	2.49	4.32	4.34	8.80	2.64	1.18
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	76.34	62.22	68.10	58.21	59.51	58.86	62.01	85.16	75.76	287.21	84.89	60.43
Ni (Dissolved)	0.00	-0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	100.80	73.52	77.38	63.69	67.20	60.36	67.25	119.81	114.81	415.94	95.02	43.41
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	7.74	7.25	7.83	8.96	9.02	9.75	10.27	9.07	9.56	9.91	9.63	8.83
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.86	0.57	0.58	0.53	0.52	0.52	0.49	0.91	0.87	2.09	0.68	0.62
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.00	0.01	0.00	0.00	0.01	0.05	0.01	0.00	0.00	0.02	0.00	0.00
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Al (Total)	23.76	11.59	0.03	7.63	9.49	8.71	0.00	7.51	11.91	9.37	0.09	1.69
As (Total)	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
B (Total)	0.16	0.14	0.11	0.11	0.12	0.13	0.11	0.13	0.13	0.24	0.14	0.11
Ba (Total)	0.35	0.93	0.17	0.20	0.85	0.63	0.29	0.13	0.15	0.20	0.18	0.14
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	346.38	149.29	356.79	131.61	147.91	120.48	499.36	175.50	250.38	324.00	760.88	102.82
Cd (Total)	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00
Co (Total)	0.03	0.02	0.00	0.01	0.02	0.01	0.00	0.01	0.02	0.01	0.03	0.00
Cr (Total)	0.05	0.02	0.01	0.02	0.02	0.01	0.00	0.01	0.02	0.02	0.01	0.00
Cu (Total)	0.04	0.02	0.00	0.01	0.03	0.01	0.00	0.03	0.04	0.02	0.00	0.00
Fe (Total)	38.73	17.51	0.00	14.65	17.56	13.28	0.00	17.11	29.13	26.03	0.01	8.46
K (Total)	8.85	6.50	4.68	3.73	4.70	5.32	4.10	6.47	6.19	9.99	6.55	3.38
Li (Total)	0.06	0.03	0.01	0.03	0.03	0.02	0.02	0.04	0.04	0.06	0.03	0.02
Mg (Total)	77.38	38.77	50.75	35.67	42.44	34.40	48.21	49.36	66.06	104.87	109.46	27.51
Mn (Total)	5.38	3.78	1.93	3.75	4.02	3.54	2.73	5.27	6.37	9.30	10.68	1.42
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	78.62	64.02	67.77	61.25	59.09	63.58	64.37	83.61	84.37	314.22	90.27	64.04
Ni (Total)	0.06	0.03	0.01	0.01	0.02	0.02	0.01	0.01	0.03	0.02	0.03	0.00
Pb (Total)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.00	0.00
S (Total)	100.78	76.21	87.36	61.63	70.04	63.15	74.02	122.73	125.98	399.38	122.69	47.51
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	53.08	35.17	9.70	24.80	28.20	31.84	7.04	27.36	30.05	30.74	14.08	13.06
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	1.68	1.38	1.21	0.74	0.86	1.08	1.88	1.07	1.36	3.05	2.50	0.72
Ti (Total)	0.18	0.12	0.00	0.06	0.12	0.18	0.00	0.04	0.02	0.13	0.00	0.03
V (Total)	0.06	0.03	0.00	0.03	0.03	0.02	0.00	0.02	0.04	0.03	0.00	0.01
Zn (Total)	0.19	0.22	0.01	0.05	0.11	0.18	0.08	0.06	0.10	0.08	0.05	0.01

Appendix A.3b Raw Water Data for Allen Bottom Wetland

NM= Not Measured
NC= Not Calculated

Analysis Performed											
Well Number	BP9	BP9	Down River	Down River	Down River	Down River	Up canal	Up canal	Up River	Up River	Up River
Date of Collection	6/6/97	7/22/97	5/22/97	6/5/97	7/22/97	10/31/97	6/6/97	11/1/97	5/22/97	6/6/97	7/22/97
Field Measurements											
pH	7.5	7.2	7.9	8.0	8.4	7.5	8.9	7.5	8.2	8.4	8.5
Temp (°C)	16.4	21.6	12.8	18.0	25.1	8.2	26.0	10.9	16.7	19.3	26.8
D.O. (mg/l)	4.9	5.0	5.8	7.3	8.7	6.8	5.2	6.6	7.2	5.4	6.8
Alkalinity in field (mg/l $CaCO_3$)	360.0	417.0	259.9	146.0	152.0	138.0	140.0	164.0	259.9	124.0	147.0
Specific Cond. Field (u s)	1014.7	1455.5	633.7	632.6	765.5	572.7	609.4	569.9	654.8	609.3	640.0
Field Eh to H_2 electrode (mV)	273.3	109.4	475.1	465.8	233.3	394.4	381.4	487.9	423.6	318.9	240.7
Calculated Eh (mV)	-192.7	-182.3	NC	NC	NC	NC	NC	NC	NC	NC	NC
Anions											
Fluoride	1.23	0.10	0.44	1.18	0.09	0.52	1.09	0.50	0.44	1.09	0.23
Chloride	23.61	25.21	11.90	16.88	14.34	12.72	12.57	12.15	11.32	13.14	12.00
Nitrate	2.38	0.48	0.00	0.00	1.03	1.31	2.59	0.00	2.94	2.26	0.00
Phosphate	13.81	0.00	0.00	0.00	0.50	0.00	9.26	15.84	0.00	0.00	6.31
Sulfate	146.50	246.68	148.58	178.37	172.48	160.88	166.04	135.53	153.57	179.22	162.64
Dissolved Cations											
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.00	0.03	0.00	0.02	0.08	0.04	0.00	0.00	0.01	0.04	0.09
As (Dissolved)	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.02
B (Dissolved)	0.10	0.16	0.08	0.07	0.15	0.07	0.06	0.07	0.08	0.07	0.13
Ba (Dissolved)	0.08	0.13	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	90.78	134.73	56.94	55.90	55.07	56.94	54.52	58.24	58.56	56.29	53.37
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.01
Fe (Dissolved)	4.27	5.29	0.02	0.02	0.05	0.04	0.01	0.01	0.01	0.07	0.19
K (Dissolved)	3.18	4.80	2.15	3.28	2.70	3.62	2.23	3.89	2.51	2.31	2.59
Li (Dissolved)	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.02
Mg (Dissolved)	24.52	35.29	20.72	20.55	20.64	20.86	20.72	21.34	21.52	20.76	20.04
Mn (Dissolved)	1.23	2.27	0.00	0.00	0.02	0.01	0.01	0.01	0.00	0.00	0.00
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	60.57	94.44	44.04	42.54	45.85	45.54	42.12	47.19	43.39	42.27	44.12
Ni (Dissolved)	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	44.63	98.45	51.61	52.29	55.87	52.01	51.03	52.97	56.07	51.52	54.06
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	9.41	9.59	1.77	1.85	2.46	2.47	1.79	2.27	1.97	1.87	1.94
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.65	1.07	0.52	0.50	0.44	0.50	0.50	0.53	0.55	0.51	0.40
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.00	0.05	0.00	0.05	0.01	0.02	0.00	0.01	0.00	0.00	0.01
Total Cations											
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	2.81	2.77	0.12	0.04	0.14	0.51	0.25	0.04	0.06	0.23	0.12
As (Total)	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
B (Total)	0.11	0.16	0.08	0.07	0.13	0.07	0.07	0.07	0.07	0.07	0.12
Ba (Total)	0.19	0.20	0.06	0.06	0.06	0.08	0.06	0.07	0.06	0.08	0.06
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	109.66	141.12	57.55	55.91	56.88	63.27	53.65	58.44	54.65	54.64	55.97
Cd (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Total)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Total)	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Total)	9.72	10.68	0.15	0.07	0.15	0.73	0.63	0.06	0.06	0.97	0.16
K (Total)	3.82	5.40	2.31	3.15	2.57	3.40	2.32	3.75	2.21	2.20	2.35
Li (Total)	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02
Mg (Total)	28.23	36.61	21.00	20.64	21.12	22.42	20.43	21.41	20.04	20.16	20.87
Mn (Total)	1.41	2.31	0.01	0.01	0.02	0.05	0.02	0.01	0.01	0.74	0.02
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	62.63	92.18	45.21	44.27	48.78	45.50	42.04	47.03	45.24	41.93	46.29
Ni (Total)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Total)	45.28	93.82	52.93	49.70	56.99	52.33	50.84	53.24	51.08	49.72	55.26
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	14.34	16.00	2.18	1.90	2.14	3.49	2.20	2.36	1.94	2.04	2.00
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.74	1.21	0.54	0.50	0.46	0.55	0.49	0.49	0.51	0.49	0.45
Ti (Total)	0.06	0.06	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
V (Total)	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Total)	0.02	0.03	0.00	0.05	0.02	0.01	0.00	0.00	0.00	0.01	0.01

Appendix A.3b Raw Water Data for Allen Bottom Wetland

NM= Not Measured
NC= Not Calculated

Sample ID	BP1		BP10		BP11	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.02	nd	0.02	nd	0.03
Al	9041.71	33.99	2727.62	16.16	3996.89	64.32
As	nd	0.96	nd	0.53	nd	0.70
B	28.02	0.38	11.20	0.21	13.52	0.21
Ba	329.89	2.06	225.41	1.06	140.56	0.49
Be	0.34	0.00	0.09	0.00	0.42	0.01
Ca	40980.99	243.00	19221.75	89.48	24506.96	103.12
Cd	nd	0.09	nd	0.03	nd	0.06
Co	6.51	0.13	3.07	0.11	3.62	0.12
Cr	15.94	0.08	7.68	0.11	7.88	0.10
Cu	10.48	0.12	2.41	0.03	5.44	0.03
Fe	11892.53	72.26	5494.08	27.23	6271.01	29.08
K	3319.50	16.30	666.98	2.69	972.75	15.43
Li	13.42	0.10	3.61	0.07	5.59	0.07
Mg	9053.14	113.52	2916.13	15.20	4494.73	40.32
Mn	390.61	1.26	178.22	0.77	169.19	2.75
Mo	nd	0.18	nd	0.07	nd	0.05
Na	919.36	8.24	632.50	5.44	706.59	7.68
Ni	14.35	0.19	5.51	0.02	7.28	0.06
Pb	6.52	0.38	4.10	0.07	4.83	0.14
S	nd	13.91	nd	12.67	nd	10.79
Sb	nd	0.50	nd	0.40	nd	0.06
Se	nd	0.60	nd	0.22	nd	0.84
Si	109.02	0.85	134.99	0.64	139.27	0.91
Sn	nd	0.11	1.02	0.16	0.26	0.08
Sr	437.21	1.18	193.42	3.94	225.94	2.94
Ti	282.84	0.71	153.45	0.80	154.18	2.24
V	21.61	0.26	11.28	0.08	12.49	0.14
Zn	40.84	0.34	13.79	0.09	20.23	0.15

nd= non-detect
NM= Not Measured

Appendix A.3c Raw Data For Soils Collected at Allen Bottom Wetland on 10-31-97.

Sample ID	BP2		BP3		BP4	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.01	nd	0.03	nd	0.03
Al	9613.31	80.32	16133.52	39.19	5616.72	70.08
As	nd	0.48	nd	0.19	nd	0.33
B	27.88	0.26	43.82	0.54	26.35	0.27
Ba	265.82	0.61	331.87	0.81	203.40	0.15
Be	0.37	0.01	0.59	0.01	0.21	0.00
Ca	43019.17	102.33	46656.87	118.95	27985.92	14.64
Cd	nd	0.03	5.12	17.72	nd	0.03
Co	6.77	0.03	9.48	0.14	4.38	0.18
Cr	15.58	0.02	24.10	0.25	10.19	0.09
Cu	11.11	0.04	16.67	0.14	7.08	0.05
Fe	12367.06	28.84	17814.51	48.04	8093.66	8.93
K	3632.18	9.56	5570.66	12.20	1700.32	22.91
Li	14.01	0.07	23.38	0.25	8.08	0.04
Mg	9682.29	120.85	12604.57	139.79	5855.03	95.22
Mn	380.49	3.53	477.78	6.26	252.11	3.30
Mo	nd	0.08	nd	0.08	nd	0.11
Na	810.66	6.95	1416.96	12.65	872.63	9.05
Ni	14.48	0.06	20.94	0.22	9.35	0.15
Pb	6.78	0.32	9.14	0.33	5.53	0.29
S	nd	10.18	847.27	24.11	nd	10.58
Sb	nd	0.26	nd	0.76	nd	0.50
Se	nd	0.30	nd	1.40	nd	0.20
Si	120.64	0.89	104.09	1.17	204.29	2.75
Sn	2.53	0.38	nd	0.13	0.39	0.13
Sr	451.37	1.98	633.36	2.77	293.90	7.40
Ti	290.83	2.27	401.27	0.92	193.79	2.72
V	22.08	0.23	31.05	0.29	15.32	0.11
Zn	42.75	0.32	61.97	0.53	28.81	0.24

nd= non-detect
NM= Not Measured

Appendix A.3c Raw Data For Soils Collected at Allen Bottom Wetland on 10-31-97.

Sample ID	BP6		BP7		BP8	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.03	nd	0.08	nd	0.04
Al	12199.92	75.56	29789.73	33.31	14272.49	58.64
As	nd	0.22	nd	1.81	nd	1.09
B	37.60	0.35	60.87	1.10	39.47	0.57
Ba	323.30	2.20	606.48	956.35	305.27	1.23
Be	0.48	0.00	0.54	0.01	0.51	0.01
Ca	44842.08	301.51	3377.85	7.29	46443.35	180.28
Cd	nd	0.06	nd	0.04	nd	0.03
Co	8.32	0.07	13.11	0.28	8.31	0.16
Cr	19.59	0.14	42.03	0.51	21.45	0.20
Cu	13.76	0.22	19.78	0.41	13.67	0.14
Fe	15116.27	97.20	23859.79	48.68	15869.93	68.52
K	5080.07	31.24	10634.30	18.49	4672.50	18.02
Li	18.91	0.25	32.31	0.58	20.76	0.33
Mg	11247.89	88.68	14896.96	149.63	12217.83	51.02
Mn	457.60	7.53	437.42	7.64	450.29	8.39
Mo	nd	0.09	nd	0.15	nd	0.13
Na	1222.10	6.59	824.24	20.08	1778.55	17.32
Ni	18.27	0.20	27.34	0.16	18.46	0.23
Pb	8.43	0.18	2.76	2.55	8.31	0.65
S	685.56	18.83	NM	NM	nd	11.72
Sb	nd	0.69	nd	0.63	nd	0.07
Se	nd	0.58	nd	0.25	nd	0.65
Si	189.24	3.60	26.49	5.93	125.00	1.30
Sn	nd	0.39	nd	17.96	1.92	0.18
Sr	556.85	1.06	583.49	7.82	580.85	9.71
Ti	326.82	5.51	2023.90	4.86	374.77	6.96
V	26.31	0.24	60.11	0.54	28.95	0.30
Zn	54.59	0.48	80.60	2.18	52.31	0.50

nd= non-detect
NM= Not Measured

Appendix A.3c Raw Data For Soils Collected at Allen Bottom Wetland on 10-31-97.

Sample ID	BP1		BP11		BP2	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.28	0.21	0.38	0.14	0.40	0.16
Al	13.61	2.02	20.16	1.92	9.08	1.27
As	3.27	2.14	2.47	2.72	nd	nd
B	nd	nd	nd	nd	nd	nd
Ba	31.81	0.95	29.78	0.66	18.92	0.65
Be	0.00	0.01	0.00	0.01	0.02	0.00
Ca	4310.50	101.19	7724.06	173.57	3333.66	68.23
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	0.88	0.25	nd	nd
Cr	0.13	0.28	0.09	0.40	nd	nd
Cu	5.28	0.11	7.32	1.32	13.08	2.67
Fe	35.76	0.87	346.31	2.29	41.52	1.05
K	11148.63	259.48	9909.97	82.21	15336.88	235.29
Li	1.09	0.28	22.65	0.82	1.36	0.24
Mg	1319.25	10.81	1689.48	9.27	1513.71	13.65
Mn	41.05	0.79	662.65	12.93	41.74	0.88
Mo	2.60	0.94	0.97	0.49	1.18	0.50
Na	1344.86	12.29	596.89	13.11	916.90	13.18
Ni	0.51	0.73	0.94	0.40	0.58	0.34
Pb	nd	nd	nd	nd	nd	nd
S	nd	nd	137.41	138.48	nd	nd
Sb	1.18	0.81	1.91	0.50	2.47	2.62
Se	2.88	1.63	1.87	3.59	2.61	4.84
Si	92.19	0.67	185.31	1.14	83.07	0.92
Sn	3.27	1.06	2.40	1.21	2.52	0.81
Sr	41.77	10.97	90.88	4.45	36.42	25.37
Ti	nd	nd	nd	nd	0.19	0.02
V	0.16	0.29	0.33	0.13	0.08	0.27
Zn	17.87	0.40	28.21	0.27	25.78	0.57

nd= non-detect

Appendix A.3d Raw Data for Vegetation Collected at Allen Bottom Wetland on 10-31-97. Reported as Average of Two Samples.

Sample ID	BP3		BP4		BP5	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.45	0.14	0.32	0.09	0.25	0.18
Al	12.15	2.05	7.09	2.24	13.46	1.45
As	nd	nd	nd	nd	84.35	49.44
B	nd	nd	nd	nd	nd	nd
Ba	13.19	0.16	17.38	0.31	19.09	0.28
Be	0.00	0.00	0.01	0.01	0.00	0.01
Ca	3438.23	38.75	10524.31	103.96	2632.99	48.51
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	nd	nd	0.03	0.15
Cr	nd	nd	nd	nd	nd	nd
Cu	3.31	0.19	3.81	0.18	6.61	0.55
Fe	31.23	0.47	59.07	0.94	44.74	0.79
K	4672.15	56.79	6037.68	104.24	6791.31	74.22
Li	1.21	0.44	1.20	0.40	1.80	0.18
Mg	846.22	8.45	2457.51	22.03	1347.71	2.32
Mn	26.00	0.15	33.63	0.60	19.84	0.14
Mo	1.12	0.34	0.76	0.54	11.00	4.08
Na	100.88	3.13	2691.14	44.44	1015.27	10.39
Ni	0.74	0.33	0.24	0.67	0.82	0.53
Pb	0.32	1.00	nd	nd	2.50	2.12
S	nd	nd	2262.95	206.29	nd	nd
Sb	0.97	1.59	1.66	2.87	0.52	2.42
Se	2.94	2.67	1.10	1.98	10.05	1.20
Si	46.95	1.34	84.43	7.91	42.61	3.57
Sn	1.88	1.56	1.86	1.07	3.25	2.51
Sr	20.97	18.77	83.42	15.01	14.27	15.21
Ti	0.04	0.06	0.02	0.04	0.89	0.07
V	0.16	0.26	0.06	0.20	0.20	0.30
Zn	95.61	0.84	25.13	0.31	63.29	1.00

nd= non-detect

Appendix A.3d Raw Data for Vegetation Collected at Allen Bottom Wetland on 10-31-97. Reported as Average of Two Samples.

Sample ID	BP54		BP6		BP7	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.80	0.14	0.20	0.20	0.27	0.12
Al	13.63	1.96	16.35	9.59	12.50	2.53
As	nd	nd	5.35	1.50	3.90	2.63
B	nd	nd	nd	nd	nd	nd
Ba	68.95	1.44	17.11	9.20	14.13	0.10
Be	0.01	0.02	0.00	0.01	0.00	0.01
Ca	8118.92	169.89	2764.96	2036.43	8513.94	82.65
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	nd	nd	nd	nd
Cr	0.11	0.32	nd	nd	nd	nd
Cu	5.29	0.38	4.83	3.12	3.78	0.20
Fe	203.79	2.16	39.35	29.31	25.01	0.35
K	4631.57	92.30	8134.32	4297.84	3184.50	35.73
Li	1.19	0.29	1.16	1.25	1.22	0.33
Mg	3756.15	26.14	925.42	616.95	1825.04	13.96
Mn	104.46	2.02	36.66	30.56	44.89	0.72
Mo	2.96	0.37	3.25	7.45	3.05	0.38
Na	90.27	2.63	387.48	310.71	1370.33	18.72
Ni	0.50	0.74	0.71	0.50	0.24	0.29
Pb	0.28	0.34	0.07	1.00	nd	nd
S	nd	nd	nd	nd	nd	nd
Sb	nd	nd	1.50	3.75	0.95	2.86
Se	2.01	7.57	2.58	6.65	2.33	4.55
Si	41.24	1.73	104.27	34.84	69.07	1.23
Sn	1.90	0.69	1.79	2.38	1.29	2.29
Sr	40.19	12.24	21.71	41.37	70.12	22.83
Ti	nd	nd	0.89	0.01	nd	nd
V	0.24	0.32	0.21	0.22	0.18	0.22
Zn	17.83	0.32	59.00	22.97	17.05	0.19

nd= non-detect

Appendix A.3d Raw Data for Vegetation Collected at Allen Bottom Wetland on 10-31-97. Reported as Average of Two Samples.

Sample ID	BP9	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.38	0.18
Al	11.06	1.63
As	nd	nd
B	nd	nd
Ba	26.67	0.45
Be	nd	nd
Ca	15317.53	112.04
Cd	nd	nd
Co	nd	nd
Cr	nd	nd
Cu	2.14	0.10
Fe	40.60	0.80
K	4043.62	67.42
Li	2.51	0.53
Mg	2831.99	20.87
Mn	45.72	0.81
Mo	1.50	0.74
Na	2441.20	18.87
Ni	0.07	0.14
Pb	nd	nd
S	nd	nd
Sb	0.91	2.48
Se	2.74	4.47
Si	124.22	1.92
Sn	1.61	1.55
Sr	101.90	19.04
Ti	0.48	0.07
V	0.26	0.42
Zn	50.20	1.24

nd= non-detect

Appendix A.3d Raw Data for Vegetation Collected at Allen Bottom Wetland on 10-31-97. Reported as Average of Two Samples.

Sample ID	Bulk Density (BD) (g/ml)	% Organic Matter (OM) (by weight)	% Carbonate (by weight)	% Total Pore Space (TPS) (by volume)
DL9	1.69	5.86	1.14	36.11
DL8	0.99	4.10	1.37	62.47
DL5	0.83	8.04	4.98	68.65
DL14	1.58	3.99	2.11	40.35
DL3A	1.20	6.61	1.93	54.72
DL12	1.83	6.99	1.71	30.94
DL4	1.18	3.80	2.03	55.51
DL13	1.29	2.17	2.35	51.21
DL2	1.35	3.26	1.85	49.09
DL27	1.62	5.19	3.25	38.86
DL26	1.38	8.03	1.04	47.89
BP4	1.07	2.96	0.52	59.65
BP6	1.02	5.95	5.88	61.43
BP1	1.56	4.63	0.74	41.25
BP10	1.14	0.88	0.98	57.07
BP2	2.20	5.44	0.65	16.94
BP3	1.52	9.06	1.53	42.75
BP11	0.35	3.85	0.27	86.96
BP8	1.24	6.76	0.19	53.02
BP7	1.27	7.84	1.23	52.08

DL= Deerlodge Wetland
BP= Allen Bottom Wetland

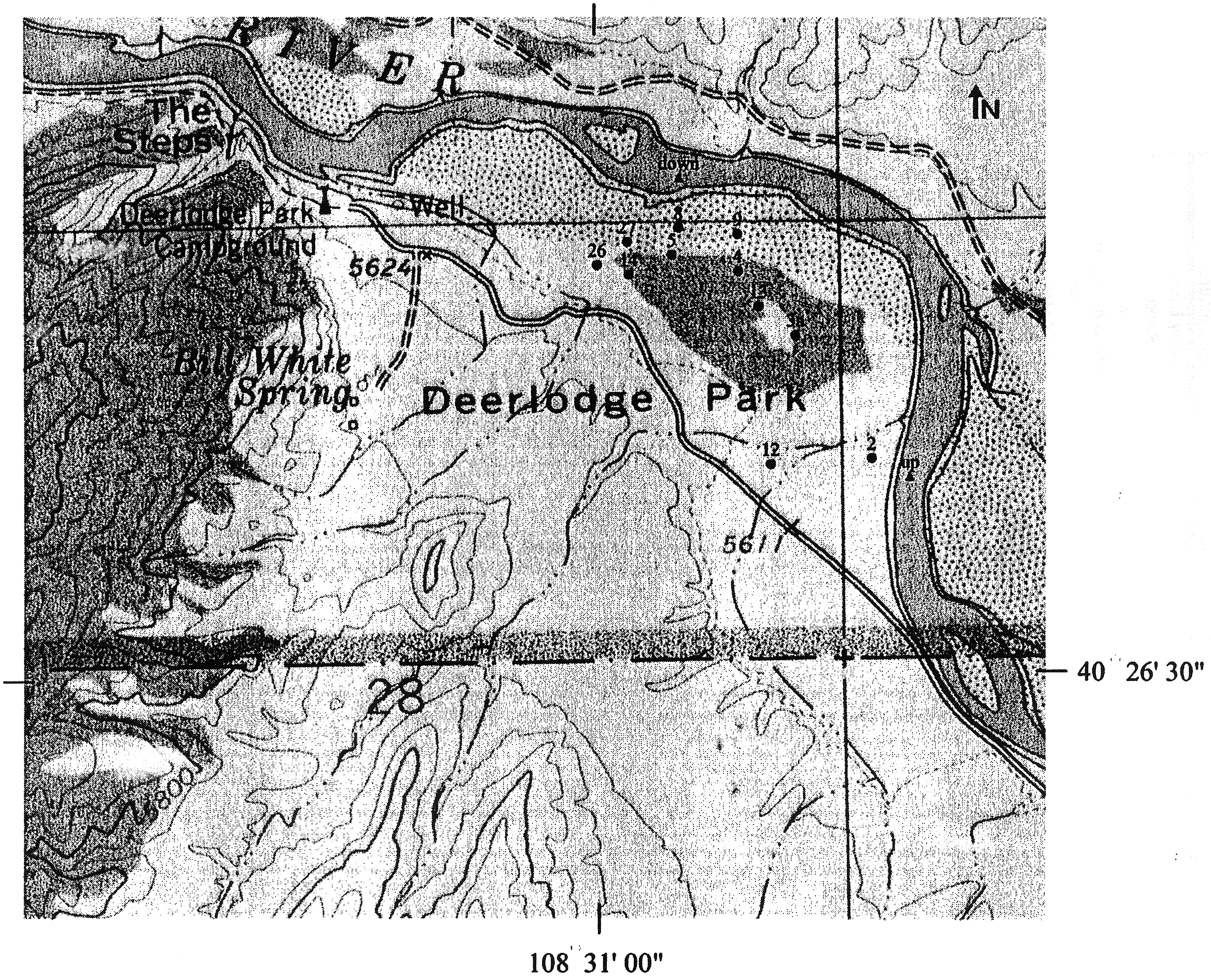
Appendix A.3e Properties of Soils Collected from Riverine Wetlands.

Sample ID	Sand %	Clay %	Silt %	Soil Texture
BP1	61	5	34	Sandy Loam
BP10	95	2	2	Sand
BP11	89	0	11	Sand
BP2	56	15	29	Sandy Clay Loam
BP3	36	28	36	Clay Loam
BP4	63	8	29	Sandy Loam
BP6	37	20	43	Loam
BP7	29	30	41	Clay Loam
BP8	29	24	47	Loam
DL12	18	50	32	Clay
DL13	74	8	18	Sandy Loam
DL14	29	30	42	Clay Loam
DL2	59	12	29	Sandy Loam
DL26	29	27	44	Clay Loam
DL27	49	15	36	Loam
DL3A	40	26	34	Loam/Clay Loam
DL4	62	23	15	Sandy Loam
DL5	15	41	44	Silty Clay
DL8	45	15	41	Loam
DL9	59	21	21	Sandy Clay Loam

BP= Allen Bottom Wetland
DL= Deerlodge Wetland

Appendix A.3f Particle Size Analysis of Soils Collected From Riverine Wetlands.

Appendix A.4a Sampling Locations at Deerlodge Wetland.



- ● Ground-Water Wells
- ▲ Surface Water

Analysis Performed												
Well Number	DL12	DL12	DL12	DL13	DL13	DL13	DL14	DL14	DL14	DL2	DL2	DL2
Date of Collection	5/20/97	7/9/97	11/2/97	5/20/97	7/9/97	11/2/97	5/20/97	7/9/97	11/2/97	5/20/97	7/9/97	11/2/97
Field Measurements												
pH	7.0	7.4	6.9	7.8	7.6	7.6	7.4	7.3	7.4	7.8	7.6	7.5
Temp (°C)	7.8	13.7	13.0	9.7	14.2	11.3	9.2	18.4	12.6	8.4	13.6	12.0
D.O. (mg/l)	4.1	2.8	3.0	3.1	3.2	3.8	2.6	6.4	3.4	3.2	2.5	2.9
Alkalinity in field (mg/l $CaCO_3$)	420.7	442.0	516.0	134.9	171.0	160.0	421.0	450.0	359.0	200.1	190.0	166.0
Specific Cond. Field (us)	1332.9	886.3	1054.8	736.1	629.9	569.0	5312.1	5973.0	3731.9	721.9	339.3	612.0
Field Eh to H_2 electrode (mV)	275.1	252.7	180.4	430.2	190.9	221.4	295.4	167.8	239.1	430.2	142.7	424.6
Calculated Eh (mV)	-159.7	-185.8	-153.8	-208.0	-199.4	-199.8	-184.4	-173.6	-167.9	-205.4	-196.3	-191.4
Anions												
Fluoride	0.67	2.22	0.34	0.44	1.65	0.46	0.46	1.18	2.31	0.43	1.27	0.15
Chloride	7.19	9.16	5.06	9.71	16.89	17.09	290.59	230.37	90.04	4.99	12.49	14.14
Nitrate	5.09	5.52	0.00	0.00	5.03	1.14	7.95	6.04	3.37	0.75	2.87	0.00
Phosphate	0.00	0.00	0.00	0.00	0.00	9.96		0.00	0.00	0.00	0.00	15.13
Sulfate	158.22	95.95	197.64	84.64	82.10	112.36	2076.27	7173.32	14164.10	83.61	161.10	210.13
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.01	0.36	0.00	0.00	0.05	0.00	0.02	0.19	0.02	0.00	0.03	0.03
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.00	0.00	0.00
B (Dissolved)	0.07	0.10	0.20	0.05	0.07	0.06	1.30	1.46	1.21	0.05	0.09	0.05
Ba (Dissolved)	0.08	0.09	0.12	0.04	0.04	0.05	0.02	0.02	0.02	0.06	0.07	0.08
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	102.40	86.83	154.43	50.61	46.08	59.66	244.30	245.76	221.24	42.92	55.15	60.12
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	4.02	3.71	8.68	0.01	0.17	0.06	1.06	1.01	0.56	0.06	0.27	0.20
K (Dissolved)	5.39	4.94	5.60	2.22	3.05	3.50	6.63	8.25	8.95	2.01	2.90	3.76
Li (Dissolved)	0.03	0.03	0.04	0.02	0.01	0.02	0.48	0.47	0.43	0.02	0.02	0.02
Mg (Dissolved)	27.59	27.67	43.76	10.11	9.64	12.12	128.47	121.59	118.95	15.36	20.44	22.40
Mn (Dissolved)	1.43	1.44	2.64	1.96	2.11	2.26	2.36	2.36	1.93	0.73	1.18	1.20
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	44.40	37.86	58.18	43.03	45.65	54.58	848.25	1037.19	780.82	35.33	48.55	46.12
Ni (Dissolved)	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	55.35	29.39	63.02	32.83	28.40	40.90	878.06	835.94	791.40	31.94	39.19	54.01
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	6.85	7.19	9.50	7.24	6.76	7.72	7.69	7.70	8.13	4.94	5.00	5.59
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.75	0.61	1.32	0.29	0.27	0.35	4.68	4.91	3.98	0.25	0.33	0.32
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.00	0.01	0.03	0.00	0.02	0.00	0.00	0.03	0.02	0.00	0.01	0.06
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	1.40	2.12	2.79	2.60	0.65	0.17	1.07	0.86	0.38	3.90	1.19	1.18
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.00
B (Total)	0.08	0.11	0.21	0.06	0.05	0.06	1.27	1.49	1.21	0.06	0.09	0.05
Ba (Total)	0.13	0.17	0.14	0.27	0.10	0.05	0.03	0.06	0.02	0.20	0.12	0.10
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	101.26	96.75	161.52	63.27	47.95	60.27	258.76	246.51	221.47	64.46	63.10	63.95
Cd (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Total)	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00
Cr (Total)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Cu (Total)	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Fe (Total)	7.58	9.10	13.97	4.48	1.48	0.44	3.12	2.96	1.33	9.40	3.13	3.06
K (Total)	5.37	5.38	5.90	2.83	2.83	3.32	7.03	8.48	8.17	2.95	2.94	3.58
Li (Total)	0.04	0.03	0.05	0.02	0.02	0.02	0.49	0.48	0.43	0.02	0.03	0.02
Mg (Total)	28.14	30.13	45.61	12.41	9.98	12.26	132.18	125.42	118.23	20.03	22.45	23.41
Mn (Total)	1.45	1.49	2.76	3.15	2.21	2.28	2.55	2.48	1.93	1.15	1.31	1.29
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	48.52	41.12	58.11	41.67	47.28	54.31	876.07	1073.61	805.18	36.55	50.67	45.27
Ni (Total)	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
Pb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
S (Total)	55.25	31.91	63.77	33.85	28.08	41.01	885.51	856.51	787.29	32.32	41.03	54.70
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	9.52	10.87	14.82	12.93	7.69	8.16	10.53	9.47	8.99	13.42	7.41	8.45
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.75	0.67	1.49	0.35	0.28	0.35	4.98	5.06	4.10	0.33	0.38	0.43
Ti (Total)	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.00	0.02	0.02	0.00
V (Total)	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.00
Zn (Total)	0.01	0.04	0.06	0.02	0.27	0.01	0.01	0.08	0.02	0.05	0.03	0.05

Appendix A.4b Raw Water Data for Deerlodge Wetland

NM= Not Measured
NC= Not Calculated

Analysis Performed												
Well Number	DL26	DL26	DL27	DL27	DL3A	DL3A	DL3A	DL4	DL4	DL4	DL5	DL5
Date of Collection	7/9/97	11/2/97	7/9/97	11/2/97	5/20/97	7/9/97	11/2/97	5/20/97	7/9/97	11/2/97	5/20/97	7/9/97
Field Measurements												
pH	7.5	7.5	7.3	7.2	6.8	7.4	7.9	7.3	7.1	7.2	7.6	7.4
Temp (°C)	16.2	14.1	17.3	14.6	9.9	12.2	12.5	10.3	16.4	13.5	9.1	12.4
D.O. (mg/l)	4.0	3.3	3.6	3.8	2.3	2.6	1.8	3.0	2.8	3.5	3.0	4.1
Alkalinity in field (mg/l $CaCO_3$)	313.5	282.0	408.0	626.0	0.0	334.5	401.0	360.0	409.0	408.0	259.9	278.0
Specific Cond. Field (μs)	1340.3	794.4	2838.5	2593.1	1009.0	1342.1	902.5	1293.0	3907.9	1997.8	1212.1	1206.3
Field Eh to H_2 electrode (mV)	72.5	439.9	181.4	251.1	567.5	370.0	534.2	265.0	126.0	217.1	290.7	114.7
Calculated Eh (mV)	-192.3	-194.5	-185.0	-178.1	-140.4	-183.5	-215.0	-180.8	-152.2	-176.7	-197.0	-187.9
Anions												
Fluoride	1.19	0.26	2.38	0.42	0.38	1.19	0.00	0.39	6.74	0.00	0.33	1.23
Chloride	34.24	27.20	195.16	191.79	13.00	27.52	15.79	62.19	364.86	115.03	36.70	51.99
Nitrate	8.97	0.00	2.33	0.00	0.00	2.02	0.00	0.00	3.83	0.00	7.31	2.42
Phosphate	0.00	5.92	0.00	3.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	384.56	170.40	1106.20	1248.06	101.87	306.40	195.77	296.63	7247.06	760.38	304.50	360.11
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Al (Dissolved)	0.08	0.00	0.30	0.03	0.00	1.29	0.14	0.42	0.11	0.00	0.03	1.32
As (Dissolved)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.02	0.00	0.00
B (Dissolved)	0.25	0.17	0.28	0.39	0.06	0.13	0.09	0.06	0.16	0.11	0.11	0.17
Ba (Dissolved)	0.17	0.10	0.16	0.08	0.06	0.14	0.07	0.11	0.12	0.07	0.07	0.33
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	99.34	62.40	208.35	269.25	75.57	145.28	100.85	160.71	431.97	227.89	118.08	215.06
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Co (Dissolved)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.05
Cr (Dissolved)	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.94
Fe (Dissolved)	1.88	0.08	0.78	0.35	0.96	4.56	2.89	2.11	1.47	1.47	0.23	1.78
K (Dissolved)	4.92	5.27	6.82	8.18	3.15	5.46	6.06	2.69	8.38	6.76	3.89	57.66
Li (Dissolved)	0.04	0.03	0.07	0.11	0.02	0.03	0.02	0.03	0.07	0.05	0.03	0.10
Mg (Dissolved)	36.47	25.91	56.18	64.53	12.53	27.55	17.99	29.10	95.61	58.98	24.89	46.33
Mn (Dissolved)	1.23	0.39	3.31	4.71	1.39	1.65	1.73	3.56	5.31	1.65	4.19	7.27
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Na (Dissolved)	125.41	72.87	243.66	373.58	59.76	98.54	75.53	80.25	335.62	218.92	97.09	252.47
Ni (Dissolved)	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.11
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
S (Dissolved)	109.34	56.15	241.63	342.84	38.39	86.89	50.48	105.33	502.39	247.59	110.99	180.12
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21
Si (Dissolved)	7.95	7.72	7.76	8.11	7.81	10.31	9.21	8.36	10.53	11.42	6.98	14.55
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.84	0.49	1.17	1.62	0.40	0.83	0.59	0.84	2.31	1.24	0.71	1.23
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
Zn (Dissolved)	0.01	0.00	0.05	0.01	0.00	0.04	0.05	0.01	0.05	0.02	0.00	1.05
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	2.30	2.18	2.68	1.49	4.72	8.29	8.04	3.02	5.23	5.49	4.35	2.61
As (Total)	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
B (Total)	0.26	0.18	0.29	0.40	0.07	0.15	0.11	0.07	0.16	0.13	0.12	0.13
Ba (Total)	0.27	0.13	0.22	0.05	0.27	0.44	0.20	0.12	0.15	0.04	0.10	[illegible]
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	117.43	70.83	232.47	273.63	89.84	197.55	121.99	168.25	458.08	244.08	139.36	[illegible]
Cd (Total)	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00
Co (Total)	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Cr (Total)	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00
Cu (Total)	0.01	0.00	0.01	0.00	0.02	0.05	0.02	0.00	0.01	0.01	0.01	0.01
Fe (Total)	9.74	6.04	5.32	3.37	13.55	24.96	17.65	6.05	9.08	10.16	8.52	5.82
K (Total)	5.31	4.45	6.55	7.60	4.08	6.63	7.30	3.36	9.40	7.58	4.84	5.72
Li (Total)	0.05	0.03	0.08	0.12	0.03	0.05	0.04	0.03	0.08	0.06	0.04	0.03
Mg (Total)	40.55	28.17	59.29	65.68	15.37	36.93	23.22	32.04	97.02	62.38	27.62	27.46
Mn (Total)	1.43	0.54	3.62	4.79	1.93	2.81	2.31	3.74	5.39	1.90	4.82	4.48
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	132.40	75.13	265.97	372.27	59.86	104.97	81.05	84.76	324.56	220.67	100.42	102.22
Ni (Total)	0.01	0.00	0.01	0.01	0.01	0.03	0.02	0.01	0.02	0.02	0.01	0.01
Pb (Total)	0.00	0.00	0.00	0.00	0.02	0.05	0.03	0.01	0.00	0.00	0.00	0.00
S (Total)	111.91	57.22	254.80	343.33	38.40	92.72	54.24	110.49	538.80	246.43	106.80	100.01
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	12.82	13.37	12.55	11.33	18.64	23.45	29.82	15.18	23.52	24.01	15.88	11.93
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.92	0.68	1.29	1.69	0.45	1.04	1.09	0.88	2.57	1.56	0.79	0.77
Ti (Total)	0.03	0.00	0.03	0.00	0.01	0.02	0.00	0.00	0.03	0.00	0.01	0.02
V (Total)	0.01	0.01	0.01	0.01	0.02	0.05	0.02	0.01	0.01	0.02	0.02	0.01
Zn (Total)	0.50	0.03	0.18	0.03	0.06	0.19	0.09	0.03	0.13	0.08	0.04	0.37

Appendix A.4b Raw Water Data for Deerlodge Wetland

NM= Not Measured
NC= Not Calculated

Analysis Performed								
Well Number	DL5	DL8	DL8	DL8	DL9	DL9	Down River	Up River
Date of Collection	11/2/97	5/20/97	7/9/97	11/2/97	7/9/97	11/2/97	11/2/97	11/2/97
Field Measurements								
pH	7.4	7.4	7.4	7.3	7.5	7.7	8.2	8.2
Temp (°C)	12.4	11.2	16.6	15.7	14.4	12.9	9.0	8.7
D.O. (mg/l)	3.1	2.4	2.9	4.1	2.5	4.2	8.2	8.8
Alkalinity in field (mg/l $CaCO_3$)	318.0	279.9	300.0	308.0	350.0	282.0	126.0	148.0
Specific Cond. Field (*u* s)	1259.0	1324.0	695.6	1387.5	1702.7	889.6	567.3	553.1
Field Eh to H_2 electrode (mV)	209.4	492.8	280.7	329.3	293.7	393.9	407.1	511.0
Calculated Eh (mV)	-184.1	-183.9	-186.6	-185.6	-191.1	-204.8	NC	NC
Anions								
Fluoride	0.00	0.35	1.43	0.15	1.31	0.20	0.11	0.00
Chloride	48.87	42.65	44.63	59.96	23.79	20.51	10.60	9.81
Nitrate	0.00	3.61	2.68	0.04	4.38	0.00	0.00	0.00
Phosphate	0.00	0.00	14.84	0.00	4.29	0.00	0.00	0.00
Sulfate	388.54	362.06	430.05	425.32	316.83	228.29	150.89	NM
Dissolved Cations								
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.01	0.04	0.10	0.03	0.29	0.00	0.08	0.02
As (Dissolved)	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.12	0.09	0.10	0.09	0.00	0.10	0.04	0.04
Ba (Dissolved)	0.15	0.12	0.11	0.15	0.15	0.10	0.05	0.05
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	146.36	146.99	133.26	165.77	195.81	96.29	42.30	43.09
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe (Dissolved)	0.19	0.05	0.21	0.06	0.72	0.00	0.08	0.03
K (Dissolved)	8.36	5.36	6.36	8.05	5.98	5.10	5.01	3.83
Li (Dissolved)	0.04	0.04	0.03	0.03	0.12	0.03	0.02	0.03
Mg (Dissolved)	30.75	37.51	33.08	40.38	46.89	22.88	26.85	27.81
Mn (Dissolved)	5.26	3.61	3.29	5.24	0.61	0.92	0.01	0.01
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	122.35	92.25	101.81	115.73	160.38	84.53	44.66	45.37
Ni (Dissolved)	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	128.43	136.67	115.78	152.80	140.21	71.31	55.04	56.86
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00
Si (Dissolved)	8.56	7.50	7.35	8.38	13.21	8.61	3.00	2.88
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.93	0.90	0.82	0.98	1.01	0.56	0.34	0.33
Ti (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn (Dissolved)	0.01	0.02	0.05	0.02	0.00	0.02	0.00	0.00
Total Cations								
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	2.69	3.83	2.00	1.10	4.19	2.58	1.08	1.00
As (Total)	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
B (Total)	0.13	0.09	0.11	0.10	0.13	0.11	0.05	0.05
Ba (Total)	0.09	0.13	0.38	0.08	0.39	0.16	0.07	0.06
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	151.41	167.09	152.01	169.94	141.35	104.58	45.10	44.45
Cd (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Total)	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00
Cr (Total)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Total)	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Fe (Total)	2.32	8.23	5.59	2.89	7.56	3.80	1.12	1.03
K (Total)	6.99	5.44	6.27	7.55	4.57	4.87	3.07	2.95
Li (Total)	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03
Mg (Total)	32.13	38.26	35.58	41.12	33.65	24.77	28.82	28.83
Mn (Total)	5.48	4.50	4.98	5.70	2.45	1.93	0.04	0.03
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	123.35	96.01	104.26	116.37	97.52	85.61	45.96	45.60
Ni (Total)	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00
Pb (Total)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
S (Total)	129.24	130.84	121.65	153.36	89.85	71.80	57.36	57.53
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	14.78	14.52	11.64	11.11	16.59	14.75	6.04	5.75
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	1.03	0.96	0.90	1.10	0.78	0.69	0.39	0.39
Ti (Total)	0.00	0.02	0.02	0.00	0.05	0.00	0.00	0.00
V (Total)	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00
Zn (Total)	0.02	0.02	0.31	0.03	0.27	0.03	0.01	0.01

Appendix A.4b Raw Water Data for Deerlodge Wetland

NM= Not Measured
NC= Not Calculated

Sample ID	DL12		DL13		DL14	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.03	nd	0.06	nd	0.03
Al	20413.50	105.08	17589.14	83.14	13328.67	21.76
As	nd	1.02	nd	1.59	nd	0.70
B	34.23	0.55	30.16	0.17	27.97	0.24
Ba	179.59	0.92	29.36	1.33	174.33	0.09
Be	1.10	0.01	0.35	0.00	0.77	0.00
Ca	23495.46	121.61	3736.22	26.21	33968.19	16.04
Cd	nd	0.03	nd	0.06	nd	0.09
Co	7.56	0.15	4.28	0.03	5.35	0.13
Cr	13.68	0.25	12.18	0.12	7.00	0.11
Cu	16.64	0.23	12.06	0.48	12.04	0.05
Fe	17026.89	88.85	7983.57	42.23	9776.22	10.52
K	5126.36	25.87	5523.21	50.30	3955.34	6.35
Li	17.27	0.22	9.82	0.11	10.68	0.07
Mg	7159.89	87.64	4474.20	10.90	6218.92	34.58
Mn	318.42	5.51	182.87	2.40	444.56	1.47
Mo	nd	0.22	nd	0.02	nd	0.10
Na	192.75	1.81	262.96	28.68	499.40	4.51
Ni	19.25	0.22	7.58	0.21	10.33	0.15
Pb	13.00	0.42	nd	0.59	7.25	0.72
S	nd	11.04	NM	NM	nd	14.74
Sb	nd	0.49	nd	0.26	nd	0.22
Se	nd	0.62	nd	0.22	nd	1.05
Si	234.78	2.48	37.24	0.82	122.85	0.50
Sn	1.95	0.05	nd	5.37	1.05	0.37
Sr	549.64	5.93	213.15	3.97	353.50	2.21
Ti	70.18	1.25	890.87	4.43	41.13	0.11
V	27.13	0.25	21.24	0.12	14.44	0.12
Zn	75.67	0.87	38.28	0.62	40.52	0.12

nd= non-detect
NM= Not Measured

Appendix A.4c Raw Data For Soil Collected at Deerlodge Wetland on 11-01-97.

Sample ID	DL2		DL26		DL27	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.01	nd	0.01	nd	0.01
Al	7369.20	78.85	13616.43	9.96	7965.63	86.11
As	nd	0.92	nd	0.39	nd	0.79
B	20.78	0.26	30.27	0.47	22.80	0.31
Ba	170.29	0.18	207.59	0.59	175.23	0.42
Be	0.44	0.00	0.89	0.00	0.62	0.00
Ca	20579.00	12.51	22236.86	48.47	19632.53	43.76
Cd	nd	0.02	nd	0.07	nd	0.05
Co	5.82	0.07	8.88	0.10	7.26	0.02
Cr	8.71	0.07	13.10	0.09	9.27	0.20
Cu	9.14	0.05	18.86	0.23	15.12	0.11
Fe	10826.71	7.27	17708.89	30.07	13480.07	30.87
K	2215.45	24.56	3115.79	5.42	1826.55	18.93
Li	9.50	0.12	15.05	0.15	10.25	0.09
Mg	5527.12	30.93	7098.74	77.30	5914.28	69.20
Mn	249.51	2.93	429.54	5.03	308.96	3.16
Mo	nd	0.16	nd	0.02	nd	0.08
Na	546.17	2.98	242.41	4.05	179.15	0.76
Ni	13.07	0.13	21.74	0.08	17.58	0.23
Pb	7.37	0.40	13.20	0.47	10.50	0.29
S	nd	13.73	nd	9.88	nd	12.54
Sb	nd	0.36	nd	0.02	nd	0.15
Se	nd	0.52	nd	0.48	nd	0.48
Si	126.75	0.70	88.57	0.62	89.98	0.80
Sn	0.50	0.19	0.83	0.14	0.74	0.21
Sr	352.09	1.25	538.56	2.11	411.34	2.97
Ti	148.14	1.61	106.41	1.24	116.47	1.33
V	20.82	0.08	29.02	0.13	22.68	0.14
Zn	41.67	0.37	73.00	0.80	56.03	0.37

nd= non-detect
NM= Not Measured

Appendix A.4c Raw Data For Soil Collected at Deerlodge Wetland on 11-01-97.

Sample ID	DL3A		DL4		DL5	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.14	nd	0.02	nd	0.04
Al	15277.00	3.14	8865.20	104.09	20540.52	10.21
As	nd	0.99	nd	0.74	nd	0.39
B	29.55	1.30	20.92	0.33	29.78	0.40
Ba	161.00	0.57	138.10	0.44	161.53	0.25
Be	0.85	0.01	0.47	0.00	1.27	0.01
Ca	30419.88	51.57	17569.39	52.73	27192.82	39.16
Cd	nd	0.43	nd	0.11	nd	0.05
Co	5.08	0.05	3.16	0.12	6.29	0.15
Cr	8.63	0.11	5.91	0.07	9.48	0.09
Cu	10.56	0.12	6.43	0.08	14.23	0.10
Fe	10744.80	16.68	6597.18	17.35	13550.07	11.69
K	4421.43	5.43	2941.49	30.88	4966.92	6.21
Li	11.16	0.16	6.82	0.07	14.39	0.19
Mg	6707.24	30.85	3762.40	26.82	7907.17	50.84
Mn	348.42	2.60	214.31	2.63	330.67	4.35
Mo	nd	0.16	nd	0.12	nd	0.06
Na	192.52	2.33	112.02	0.80	303.43	2.60
Ni	10.83	0.17	6.95	0.17	13.52	0.03
Pb	8.14	0.47	4.97	0.09	10.11	0.54
S	nd	17.07	nd	16.01	nd	13.62
Sb	nd	0.31	nd	0.21	nd	0.28
Se	nd	0.52	nd	0.16	nd	1.60
Si	113.31	0.38	111.50	0.85	114.23	0.30
Sn	1.67	0.45	2.11	0.11	1.64	0.33
Sr	358.48	7.01	221.12	6.28	488.27	0.83
Ti	53.08	0.34	51.12	0.64	52.39	0.80
V	16.76	0.10	11.86	0.18	19.60	0.09
Zn	44.30	0.78	29.06	0.34	84.06	1.16

nd= non-detect
NM= Not Measured

Appendix A.4c Raw Data For Soil Collected at Deerlodge Wetland on 11-01-97.

Sample ID	DL8		DL9	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.01	nd	0.03
Al	8583.56	104.29	26458.89	174.78
As	nd	0.34	nd	0.91
B	23.12	0.07	44.99	0.47
Ba	146.64	0.08	302.13	479.75
Be	0.55	0.01	0.56	0.01
Ca	18764.30	18.29	3478.55	11.10
Cd	nd	0.07	nd	0.08
Co	6.04	0.08	7.57	0.14
Cr	8.76	0.14	21.77	0.21
Cu	10.85	0.04	10.07	0.12
Fe	11659.87	18.13	14475.88	41.58
K	2134.91	26.26	7166.67	34.83
Li	9.31	0.16	17.13	0.15
Mg	5506.46	84.12	7118.89	48.93
Mn	284.57	3.30	282.20	4.12
Mo	nd	0.20	nd	0.07
Na	225.06	3.22	277.33	3.75
Ni	13.92	0.22	14.33	0.16
Pb	8.73	0.29	nd	4.80
S	nd	8.44	NM	NM
Sb	nd	0.65	nd	0.25
Se	nd	0.28	nd	0.83
Si	127.25	1.07	150.46	216.61
Sn	1.21	0.19	nd	13.68
Sr	341.87	5.65	356.68	5.24
Ti	125.42	1.56	1395.27	4.76
V	20.58	0.17	44.55	0.21
Zn	51.31	0.23	54.67	0.69

nd= non-detect
NM= Not Measured

Appendix A.4c Raw Data For Soil Collected at Deerlodge Wetland on 11-01-97.

Sample ID	DL13		DL14		DL2	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.54	0.20	0.39	0.21	0.561	0.146
Al	12.82	3.22	25.89	2.46	49.335	2.437
As	0.20	0.49	nd	nd	nd	nd
B	nd	nd	nd	nd	nd	nd
Ba	28.07	0.29	34.41	0.41	26.099	0.479
Be	0.04	0.02	0.04	0.01	0.058	0.009
Ca	5188.75	97.76	4532.71	43.32	4493.560	143.590
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	nd	nd	0.099	0.361
Cr	0.16	0.46	0.09	0.20	nd	nd
Cu	6.37	0.36	9.55	0.19	7.145	0.220
Fe	65.92	2.35	102.74	1.72	179.156	4.797
K	6817.08	137.20	17266.11	172.49	7442.818	308.223
Li	0.52	0.45	2.00	0.39	1.607	0.258
Mg	851.15	13.11	1476.93	7.89	1743.253	22.850
Mn	327.42	1.87	60.62	0.78	90.361	2.306
Mo	1.37	0.52	1.17	0.86	0.679	0.325
Na	164.49	6.88	2250.02	68.12	244.098	5.784
Ni	0.74	0.44	0.51	0.56	1.166	0.386
Pb	nd	nd	nd	nd	0.022	3.042
S	nd	nd	nd	nd	nd	nd
Sb	1.01	2.96	1.06	2.95	0.412	1.224
Se	3.81	2.77	0.59	1.94	3.480	5.839
Si	102.14	2.61	123.58	2.33	170.438	2.375
Sn	2.53	1.94	1.19	0.21	2.588	1.826
Sr	56.23	30.44	66.41	7.14	32.972	28.672
Ti	0.45	0.06	0.42	0.05	0.426	0.123
V	0.26	0.18	0.19	0.34	0.347	0.385
Zn	38.21	1.67	35.31	0.85	58.928	1.453

nd= non-detect

Appendix A.4d Raw Data for Vegetation Collected at Deerlodge Wetland on 11-01-97. Reported as Average of Two Samples.

Sample ID	DL26		DL27		DL3A	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	1.47	0.33	0.58	0.17	0.565	0.319
Al	50.10	2.35	23.37	1.65	35.061	2.776
As	nd	nd	0.25	1.31	0.269	2.145
B	nd	nd	nd	nd	nd	nd
Ba	31.20	0.62	10.90	0.23	50.975	1.834
Be	0.05	0.02	0.02	0.01	0.037	0.010
Ca	4457.99	102.97	9360.00	113.11	9203.629	268.641
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	nd	nd	nd	nd
Cr	0.06	0.05	nd	nd	0.011	0.158
Cu	6.07	0.29	6.78	0.13	6.110	0.323
Fe	97.60	2.25	98.36	1.82	69.159	2.192
K	8331.31	166.02	7922.95	152.77	10273.217	172.281
Li	1.72	0.50	1.24	0.29	1.607	0.306
Mg	1117.61	11.24	2077.45	21.98	1759.957	17.519
Mn	105.83	1.10	35.02	0.55	79.132	2.661
Mo	1.11	0.84	1.47	0.69	1.375	0.532
Na	222.13	5.99	402.53	10.82	1243.651	25.483
Ni	0.90	0.73	0.77	0.14	2.021	0.686
Pb	nd	nd	nd	nd	0.519	2.306
S	nd	nd	nd	nd	nd	nd
Sb	0.67	1.02	nd	nd	0.556	1.538
Se	3.25	7.12	1.76	3.57	3.217	5.419
Si	100.33	1.98	174.82	2.12	164.229	4.249
Sn	1.93	1.73	0.78	0.81	1.934	0.798
Sr	39.61	22.30	59.88	7.53	97.403	15.776
Ti	0.23	0.09	0.37	0.09	nd	nd
V	0.18	0.27	0.26	0.47	0.262	0.331
Zn	26.51	0.44	61.79	1.07	29.257	0.790

nd=non-detect

Appendix A.4d Raw Data for Vegetation Collected at Deerlodge Wetland on 11-01-97. Reported as Average of Two Samples.

Sample ID	DL4		DL9	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.42	0.10	0.38	0.19
Al	19.90	2.27	48.49	1.01
As	0.56	3.84	1.00	2.65
B	nd	nd	nd	nd
Ba	60.46	0.79	32.21	0.17
Be	0.01	0.01	0.04	0.00
Ca	4887.90	58.41	3374.58	13.09
Cd	nd	nd	nd	nd
Co	nd	nd	nd	nd
Cr	nd	nd	0.19	0.18
Cu	8.30	1.53	4.16	0.16
Fe	98.03	3.24	153.15	1.68
K	12725.07	208.51	9937.70	34.91
Li	0.63	0.18	0.61	0.17
Mg	1312.67	15.59	1024.78	2.57
Mn	59.77	1.93	46.37	0.39
Mo	2.00	0.55	1.60	0.38
Na	136.64	5.52	164.65	3.55
Ni	1.14	0.44	0.90	0.79
Pb	nd	nd	nd	nd
S	nd	nd	nd	nd
Sb	1.90	0.63	0.77	2.51
Se	2.84	3.02	0.86	3.53
Si	145.78	1.85	96.19	0.53
Sn	2.21	1.42	1.56	2.13
Sr	53.71	5.70	29.64	21.58
Ti	0.02	0.05	4.87	0.10
V	0.26	0.14	0.53	0.12
Zn	37.70	1.18	17.20	0.27

nd=non-detect

Appendix A.4d Raw Data for Vegetation Collected at Deerlodge Wetland on 11-01-97. Reported as Average of Two Samples.

Analysis Performed											
Well Number	Creek	Down River	Up River	W21	W21	W21	W23	W23	W24	W24	W24
Date of Collection	7/24/97	7/25/97	7/25/97	5/31/97	7/24/97	8/14/97	7/24/97	8/14/97	6/1/97	7/25/97	8/14/97
Field Measurements											
pH	7.3	7.2	7.9	6.4	7.0	6.8	6.2	6.1	4.9	6.5	5.9
Temp (°C)	13.4	14.5	9.8	13.2	15.5	12.0	12.6	10.4	14.4	16.0	10.6
D.O. (mg/l)	6.2	6.0	6.2	4.7	5.2	5.8	6.0	3.3	4.8	3.8	3.5
Alkalinity in field (mg/l $CaCO_3$)	35.0	21.0	23.0	<10	57.0	55.0	53.0	63.0	loq	80.0	54.0
Specific Cond. Field (μs)	176.1	121.0	100.3	65.5	108.6	119.2	113.5	115.5	104.8	160.9	145.8
Field Eh to H_2 (mV)	246.9	427.9	612.6	673.5	302.0	314.7	253.9	368.0	520.3	218.2	448.8
Calculated Eh (mV)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Anions											
Fluoride	0.98	0.39	0.94	0.00	2.18	0.81	2.18	1.92	0.00	1.56	1.32
Chloride	0.18	0.22	0.45	2.43	0.80	1.57	3.00	0.87	2.23	3.31	0.35
Nitrate	9.92	0.00	0.00	46.01	3.15	0.05	1.96	0.00	9.84	0.00	0.00
Phosphate	0.00	0.00	11.59	0.00	11.68	0.00	8.59	0.00	0.00	9.56	0.00
Sulfate	3.68	3.58	5.65	4.35	1.10	6.76	0.21	3.22	14.77	5.53	23.62
Dissolved Cations											
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.03	0.03	0.53	0.04	0.07	0.15	1.16	0.10	0.44	0.55	1.08
As (Dissolved)	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
B (Dissolved)	0.02	0.02	0.02	0.01	0.00	0.05	0.06	0.04	0.01	0.06	0.03
Ba (Dissolved)	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.02	0.01	0.02	0.03
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	11.30	6.27	6.56	12.58	11.86	13.21	12.52	12.28	7.88	11.23	8.58
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.04	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.02	0.00	0.02
Fe (Dissolved)	0.04	0.16	0.76	0.13	0.32	0.34	3.19	0.65	1.95	11.25	10.79
K (Dissolved)	1.83	0.77	0.92	1.97	1.42	2.10	1.59	1.27	0.66	1.78	3.71
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Mg (Dissolved)	2.61	1.64	1.84	2.83	3.18	3.37	3.42	3.32	2.17	3.23	2.43
Mn (Dissolved)	0.01	0.02	0.04	0.04	0.54	0.59	0.09	0.06	0.54	0.72	0.58
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	2.60	1.76	1.84	2.69	2.82	3.89	3.29	3.86	1.54	1.86	3.76
Ni (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	0.33	0.41	0.53	1.18	0.00	0.22	0.00	0.15	6.68	0.00	8.00
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	5.33	3.53	3.85	5.87	5.75	8.31	9.29	9.57	9.96	8.89	15.09
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.00	0.00	0.00	0.06	0.02	0.03	0.08	0.03	0.05	0.26	0.27
Ti (Dissolved)	0.00	0.00	0.01	0.00	0.00	0.01	0.03	0.00	0.01	0.01	0.02
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Zn (Dissolved)	0.03	0.03	0.03	0.01	0.01	0.03	0.05	0.01	0.03	0.03	0.05
Total Cations											
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM
Al (Total)	0.03	0.39	0.06	4.07	7.28	24.86	6.49	4.99	1.51	31.45	NM
As (Total)	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM
B (Total)	0.02	0.02	0.02	0.02	0.02	0.14	0.06	0.04	0.00	0.10	NM
Ba (Total)	0.01	0.01	0.01	0.09	0.11	0.51	0.10	0.10	0.02	0.41	NM
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	NM
Ca (Total)	11.18	6.38	6.70	17.07	15.90	27.09	19.84	21.03	8.39	23.35	NM
Cd (Total)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.02	NM
Co (Total)	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.01	0.02	NM
Cr (Total)	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.01	0.00	0.04	NM
Cu (Total)	0.00	0.00	0.00	0.01	0.01	0.05	0.03	0.01	0.01	0.07	NM
Fe (Total)	0.09	0.82	0.29	7.87	7.39	72.77	7.34	7.14	2.97	45.47	NM
K (Total)	1.33	0.91	0.86	1.85	2.62	4.93	1.69	1.49	1.04	10.45	NM
Li (Total)	0.00	0.00	0.00	0.00	0.01	0.07	0.01	0.01	0.00	0.03	NM
Mg (Total)	2.62	1.76	1.72	3.58	4.71	14.91	4.98	5.13	2.54	12.59	NM
Mn (Total)	0.01	0.02	0.02	1.01	0.89	2.25	0.17	0.16	0.57	1.35	NM
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM
Na (Total)	2.64	1.76	1.83	2.32	3.27	4.17	3.62	3.54	1.52	3.59	NM
Ni (Total)	0.00	0.01	0.00	0.00	0.01	0.05	0.01	0.03	0.00	0.04	NM
Pb (Total)	0.00	0.00	0.00	0.00	0.01	0.10	0.03	0.01	0.00	0.06	NM
S (Total)	0.28	0.60	0.50	1.87	1.34	0.26	0.20	0.04	6.90	0.00	NM
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	NM
Si (Total)	5.30	3.80	3.72	9.41	18.51	33.89	14.56	13.20	11.36	52.48	NM
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM
Sr (Total)	0.00	0.00	0.00	0.09	0.23	2.12	0.23	0.27	0.05	1.24	NM
Ti (Total)	0.00	0.00	0.00	0.11	0.13	0.02	0.20	0.01	0.06	0.74	NM
V (Total)	0.00	0.00	0.00	0.01	0.01	0.10	0.02	0.02	0.01	0.08	NM
Zn (Total)	0.01	0.02	0.01	0.09	0.08	0.38	0.15	0.09	0.04	0.28	NM

Appendix A.5a Raw Water Data for Kawuneeche Valley Wetland

NM= Not Measured
NC=Not Calculated

Analysis Performed												
Well Number	W24	W26	W26	W26	W27	W27	W27	W28	W29	W29	W4	W41
Date of Collection	9/28/97	5/31/97	7/24/97	8/14/97	6/1/97	8/14/97	9/28/97	6/1/97	8/14/97	9/28/97	6/1/97	6/1/97
Field Measurement												
pH	5.4	6.3	6.1	6.1	5.7	5.5	5.5	5.6	6.3	5.8	5.5	5.8
Temp (°C)	9.6	15.4	17.1	10.6	17.6	10.7	9.2	12.7	11.0	11.8	7.9	10.2
D.O. (mg/l)	NM	2.8	4.3	4.3	2.4	6.2	NM	4.2	5.2	NM	3.0	2.2
Alkalinity in field (mg/l $CaCO_3$)	24.0	see sheet	51.0	48.0	22.0	28.0	18.0	2.0	41.0	20.0	26.0	94.0
Specific Cond. Field (μs)	107.5	73.0	180.4	163.2	121.8	168.4	189.8	39.3	89.7	81.0	105.4	189.3
Field Eh to H_2 (mV)	411.1	611.8	261.6	434.5	381.6	455.1	569.1	685.6	238.5	348.2	391.7	237.2
Calculated Eh (mV)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Anions												
Fluoride	0.32	0.00	0.08	0.27	0.00	0.39	0.79	0.00	0.66	1.15	0.00	0.00
Chloride	0.59	2.44	1.72	1.29	2.27	0.41	0.65	2.14	0.32	0.58	2.71	2.25
Nitrate	0.00	0.00	0.91	0.00	9.26	0.97	0.00	3.17	0.00	0.00	4.65	3.31
Phosphate	0.57	0.00	0.00	7.62	0.00	0.00	10.88	0.00	0.00	10.29	0.00	0.00
Sulfate	19.41	2.98	7.98	1.26	7.97	39.32	51.91	4.67	4.90	16.47	16.33	3.04
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.19	0.15	0.40	0.12	1.26	0.71	1.35	0.68	0.73	0.91	0.38	0.52
As (Dissolved)	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.02	0.00	0.04	0.03	0.01	0.07	0.01	0.00	0.05	0.02	0.02	0.02
Ba (Dissolved)	0.01	0.01	0.02	0.02	0.01	0.04	0.04	0.01	0.02	0.02	0.01	0.02
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	7.44	7.39	11.91	12.65	12.95	22.08	23.68	2.60	3.80	5.13	13.17	13.93
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Cu (Dissolved)	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00
Fe (Dissolved)	7.57	0.33	1.50	0.77	2.02	0.56	0.69	0.44	2.50	4.42	5.31	21.20
K (Dissolved)	1.50	5.24	1.44	2.13	3.02	2.21	2.50	0.50	0.84	1.51	0.95	0.63
Li (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Dissolved)	2.08	2.23	3.59	3.86	2.50	4.25	4.74	0.52	1.08	1.47	2.68	4.68
Mn (Dissolved)	0.51	0.02	0.04	0.04	0.20	0.10	0.15	0.02	0.03	0.04	0.08	0.42
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	1.91	2.73	3.02	3.45	2.31	4.08	4.12	1.91	4.52	4.98	2.54	3.38
Ni (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.00	0.00	0.00	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	6.95	0.47	0.00	0.10	3.57	16.85	18.72	1.20	2.31	5.79	6.03	0.50
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	12.72	6.15	7.88	8.29	6.71	5.55	5.21	9.87	14.24	15.67	7.31	7.57
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.23	0.04	0.04	0.05	0.06	0.09	0.10	0.02	0.07	0.15	0.04	0.09
Ti (Dissolved)	0.00	0.00	0.01	0.00	0.03	0.01	0.01	0.00	0.02	0.02	0.01	0.01
V (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Zn (Dissolved)	0.02	0.00	0.02	0.04	0.03	0.04	1.32	0.00	0.02	0.15	0.05	0.02
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00
Al (Total)	21.41	12.22	6.98	3.68	16.42	14.97	21.82	2.07	NM	56.34	0.85	18.74
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00
B (Total)	0.06	0.02	0.04	0.04	0.01	0.06	0.02	0.00	NM	0.07	0.01	0.05
Ba (Total)	0.28	0.18	0.10	0.07	0.24	0.28	0.25	0.02	NM	0.63	0.01	0.31
Be (Total)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.02	0.00	0.00
Ca (Total)	19.43	34.18	23.91	20.70	29.30	47.30	40.33	2.83	NM	19.86	13.02	19.22
Cd (Total)	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	NM	0.03	0.00	0.01
Co (Total)	0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.00	NM	0.02	0.00	0.01
Cr (Total)	0.02	0.01	0.01	0.00	0.01	0.04	0.02	0.00	NM	0.06	0.00	0.03
Cu (Total)	0.06	0.02	0.02	0.00	0.02	0.01	0.00	0.00	NM	0.08	[illegible]	0.05
Fe (Total)	30.88	5.98	5.31	4.97	6.14	6.93	6.63	1.27	NM	42.10	[illegible]	47.87
K (Total)	6.29	5.70	1.65	2.24	3.88	2.34	3.40	0.66	NM	3.69	0.56	4.67
Li (Total)	0.03	0.00	0.01	0.00	0.00	0.01	0.02	0.00	NM	0.04	0.00	0.01
Mg (Total)	9.94	6.01	5.69	5.23	4.99	7.79	7.98	0.66	NM	10.28	2.84	10.91
Mn (Total)	1.14	0.12	0.09	0.08	0.45	0.42	0.22	0.03	NM	0.25	0.08	0.66
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00
Na (Total)	2.80	2.74	3.43	3.49	2.25	3.48	4.22	1.93	NM	5.84	2.07	3.71
Ni (Total)	0.03	0.01	0.01	0.00	0.01	0.30	0.02	0.00	NM	0.05	0.00	0.03
Pb (Total)	0.02	0.04	0.02	0.00	0.01	0.00	0.01	0.00	NM	0.05	0.00	0.06
S (Total)	7.44	0.85	0.00	0.14	3.51	17.52	19.81	1.21	NM	6.04	6.14	0.81
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00
Si (Total)	40.39	12.55	12.23	10.64	16.44	14.04	26.60	11.51	NM	72.45	7.83	27.49
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NM	0.00	0.00	0.00
Sr (Total)	0.95	0.19	0.16	0.23	0.15	0.39	0.34	0.02	NM	1.28	0.04	0.13
Ti (Total)	0.02	0.08	0.07	0.00	0.01	0.00	0.00	0.02	NM	0.03	0.03	0.66
V (Total)	0.07	0.03	0.02	0.01	0.03	0.03	0.03	0.01	NM	0.15	0.01	0.07
Zn (Total)	0.29	0.10	0.08	0.06	0.09	0.15	0.11	0.00	NM	0.71	0.07	0.18

Appendix A.5a Raw Water Data for Kawuneeche Valley Wetland

NM= Not Measured
NC=Not Calculated

Analysis Performed												
Well Number	W41	W41	W41	W42	W43	W43	W43	W56	W59	W59	W59	W6
Date of Collection	7/25/97	8/14/97	9/28/97	6/1/97	7/25/97	8/14/97	9/28/97	6/1/97	6/1/97	7/25/97	9/28/97	5/31/97
Field Measurements												
pH	6.3	6.4	6.0	5.4	6.3	6.3	5.9	5.9	5.5	6.8	6.2	5.1
Temp (°C)	15.8	15.0	12.9	12.4	16.3	13.8	12.3	12.8	12.4	15.4	13.9	13.0
D.O. (mg/l)	4.4	4.2	NM	3.0	4.8	5.8	NM	2.6	2.8	4.6	NM	4.6
Alkalinity in field (mg/l $CaCO_3$)	89.0	75.0	120.5	16.7	34.0	21.0	40.0	15.1	11.5	<53	49.0	13.9
Specific Cond. Field (*u* s)	157.1	131.9	167.8	59.5	107.6	79.8	101.5	152.5	119.1	479.6	109.3	111.2
Field Eh to H_2 (mV)	261.7	458.7	406.2	408.1	270.5	514.3	366.4	408.8	546.7	249.3	314.3	527.6
Calculated Eh (mV)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Anions												
Fluoride	0.90	0.35	0.03	0.00	2.61	0.72	1.02	0.00	0.00	2.44	1.27	0.00
Chloride	0.00	0.27	0.61	3.00	2.51	0.44	0.55	2.74	2.28	1.47	0.95	3.04
Nitrate	3.99	0.01	0.00	649.13	1.89	0.00	0.00	4.25	0.00	2.06	2.21	3.36
Phosphate	0.00	0.00	4.01	0.00	6.28	0.00	0.00	0.00	0.00	0.00	8.26	0.00
Sulfate	0.43	6.69	1.32	2.88	3.66	4.14	1.97	30.42	29.48	10.25	1.54	12.10
Dissolved Cations												
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	2.53	1.94	3.23	0.78	0.50	0.28	0.42	1.53	0.50	1.03	1.65	1.05
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.06	0.04	0.03	0.01	0.04	0.04	0.01	0.02	0.00	0.03	0.01	0.01
Ba (Dissolved)	0.06	0.17	0.07	0.03	0.03	0.05	0.03	0.02	0.03	0.04	0.04	0.01
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	11.12	12.07	12.05	6.07	5.93	6.70	8.15	11.38	11.59	9.81	10.53	16.26
Cd (Dissolved)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02
Cu (Dissolved)	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.06
Fe (Dissolved)	13.34	10.47	14.68	3.68	6.12	3.04	7.47	1.24	0.53	2.64	1.87	5.85
K (Dissolved)	1.94	39.12	2.62	0.33	2.00	20.78	1.13	1.02	0.59	1.43	3.07	1.88
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg (Dissolved)	4.35	4.26	4.94	1.35	1.44	1.58	2.02	1.81	2.76	2.57	2.94	3.39
Mn (Dissolved)	0.34	0.38	0.37	0.04	0.15	0.14	0.20	0.05	0.02	0.04	0.05	0.03
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	3.50	5.52	4.67	2.73	4.35	5.11	4.67	8.99	4.30	4.00	5.17	2.64
Ni (Dissolved)	0.01	0.01	0.02	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.02
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	0.00	5.98	0.35	1.32	1.04	4.37	1.03	12.32	11.66	0.47	0.53	6.97
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	9.08	8.88	11.67	8.56	12.04	13.16	13.42	9.94	8.85	10.67	12.54	5.28
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.32	0.32	0.46	0.04	0.11	0.13	0.26	0.07	0.07	0.07	0.11	0.08
Ti (Dissolved)	0.09	0.09	0.12	0.01	0.01	0.00	0.00	0.03	0.01	0.04	0.03	0.02
V (Dissolved)	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00
Zn (Dissolved)	0.04	0.10	0.04	0.02	0.03	0.04	0.05	0.03	0.01	0.03	0.02	0.06
Total Cations												
Ag (Total)	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	79.17	35.56	69.60	2.18	32.95	20.14	16.81	21.24	3.51	0.00	35.06	3.18
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
B (Total)	0.16	0.24	0.16	0.00	0.15	0.12	0.05	0.02	0.00	0.01	0.04	0.02
Ba (Total)	1.15	2.38	1.35	0.04	0.89	0.69	0.26	0.43	0.07	0.01	0.59	0.05
Be (Total)	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.02	0.01	0.00
Ca (Total)	24.49	56.82	27.92	6.37	25.18	19.70	11.63	20.79	11.77	0.03	23.91	20.06
Cd (Total)	0.03	0.03	0.03	0.00	0.02	0.02	0.01	0.01	0.00	0.04	0.01	0.00
Co (Total)	0.05	0.08	0.05	0.00	0.01	0.01	0.00	0.01	0.00	0.06	0.01	0.00
Cr (Total)	0.14	0.02	0.10	0.00	0.07	0.03	0.02	0.05	0.01	0.08	0.06	0.06
Cu (Total)	0.15	0.13	0.15	0.01	0.10	0.07	0.02	0.06	0.01	0.08	0.06	0.39
Fe (Total)	110.98	153.69	105.90	4.58	104.56	62.32	30.23	17.73	2.50	0.11	24.86	11.64
K (Total)	15.07	15.46	11.16	0.30	4.97	22.22	2.50	3.04	0.75	0.15	5.29	1.98
Li (Total)	0.06	0.04	0.07	0.00	0.02	0.01	0.01	0.01	0.00	0.35	0.02	0.00
Mg (Total)	26.86	23.09	26.20	1.49	8.67	4.74	3.85	6.02	3.19	0.40	9.08	4.08
Mn (Total)	1.09	1.71	1.17	0.04	0.56	0.37	0.28	0.15	0.03	0.46	0.17	0.07
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.00	0.00
Na (Total)	4.26	5.44	4.70	2.79	5.53	5.16	4.75	9.56	4.21	3.58	5.82	2.54
Ni (Total)	0.09	0.09	0.09	0.00	0.05	0.07	0.02	0.03	0.00	4.46	0.03	0.06
Pb (Total)	0.20	0.09	0.18	0.00	0.06	0.02	0.00	0.03	0.00	5.82	0.02	0.02
S (Total)	0.00	2.55	0.62	1.26	0.99	3.78	1.01	12.20	11.11	16.41	0.70	6.84
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.99	0.00	0.00
Se (Total)	0.04	0.08	0.05	0.00	0.07	0.04	0.00	0.00	0.00	20.43	0.00	0.00
Si (Total)	88.76	47.35	80.46	10.06	43.16	32.60	33.77	29.18	12.12	32.66	53.95	6.92
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	2.97	4.33	3.06	0.04	3.04	1.86	0.90	0.16	0.07	0.00	0.87	0.10
Ti (Total)	1.70	0.00	0.02	0.02	0.02	0.00	0.01	0.28	0.09	0.00	0.04	0.06
V (Total)	0.26	0.39	0.27	0.01	0.20	0.16	0.06	0.07	0.01	0.00	0.11	0.01
Zn (Total)	0.53	0.75	0.56	0.01	0.44	0.27	0.12	0.23	0.02	0.00	0.18	0.09

Appendix A.5a Raw Water Data for Kawuneeche Valley Wetland

NM= Not Measured
NC=Not Calculated

Analysis Performed										
Well Number	W6	W6	W7	WAA	WAA	WBB	WBB	WCC	WCC	WDD
Date of Collection	7/24/97	8/14/97	5/31/97	8/14/97	9/28/97	8/14/97	9/28/97	8/14/97	9/28/97	8/14/97
Field Measurements										
pH	6.1	5.7	5.3	5.7	5.4	5.8	5.9	5.6	5.4	5.9
Temp (°C)	15.5	10.9	14.5	11.1	11.5	12.2	11.3	11.0	11.7	11.5
D.O. (mg/l)	5.8	6.0	2.8	5.4	NM	6.0	NM	5.4	NM	5.1
Alkalinity in field (mg/l $CaCO_3$)	<36	9.5	15.9	32.0	14.0	32.5	24.5	17.5	21.0	12.0
Specific Cond. Field (u s)	51.2	72.8	166.9	151.7	136.0	278.9	218.1	259.6	198.4	193.1
Field Eh to H_2 (mV)	380.5	477.2	512.1	463.1	417.2	556.7	505.6	534.9	532.7	510.5
Calculated Eh (mV)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Anions										
Fluoride	1.49	2.52	0.00	1.03	0.13	0.29	1.59	0.62	0.35	0.47
Chloride	0.92	0.20	0.00	0.14	0.15	0.68	0.88	0.16	4.13	0.29
Nitrate	0.55	0.00	1.47	0.00	0.00	0.10	1.39	2.16	0.23	7.27
Phosphate	7.17	0.00	0.00	0.00	0.00	0.00	0.00	8.50	0.00	0.00
Sulfate	12.08	12.96	37.56	32.12	29.09	29.49	56.61	49.82	52.85	90.55
Dissolved Cations										
Ag (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Dissolved)	0.63	0.68	0.93	0.46	0.48	0.41	0.87	0.98	0.92	0.44
As (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Dissolved)	0.00	0.02	0.00	0.03	0.00	0.03	0.01	0.03	0.00	0.02
Ba (Dissolved)	0.01	0.02	0.02	0.03	0.02	0.02	0.03	0.03	0.03	0.05
Be (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Dissolved)	6.86	11.08	20.23	17.08	15.41	20.50	27.80	28.70	28.00	30.52
Cd (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Cu (Dissolved)	0.01	0.04	0.01	0.00	0.00	0.00	0.02	0.01	0.00	0.01
Fe (Dissolved)	1.29	1.12	1.31	1.84	2.01	0.62	0.66	0.82	0.55	0.16
K (Dissolved)	1.36	2.22	0.29	0.71	0.52	0.67	2.11	1.05	0.80	0.86
Li (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Mg (Dissolved)	1.66	2.48	4.17	4.16	3.86	3.33	4.83	5.36	5.33	6.75
Mn (Dissolved)	0.03	0.01	0.54	0.10	0.03	0.15	0.20	0.15	0.03	0.06
Mo (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Dissolved)	1.79	3.44	4.05	3.38	3.07	3.86	5.32	3.83	3.95	5.03
Ni (Dissolved)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Pb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S (Dissolved)	3.28	6.00	16.83	12.52	11.43	11.65	21.67	20.05	21.53	30.12
Sb (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Dissolved)	5.76	6.05	10.59	12.01	12.15	6.19	7.02	6.42	5.66	5.63
Sn (Dissolved)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Dissolved)	0.01	0.04	0.10	0.11	0.13	0.06	0.09	0.09	0.16	0.18
Ti (Dissolved)	0.02	0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.00
V (Dissolved)	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Zn (Dissolved)	0.06	0.10	0.07	0.03	0.01	0.07	0.05	0.06	0.06	0.04
Total Cations										
Ag (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al (Total)	16.05	3.07	0.98	2.05	0.96	1.07	0.76	8.44	1.57	1.93
As (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B (Total)	0.03	0.01	0.01	0.03	0.00	0.03	0.01	0.15	0.00	0.02
Ba (Total)	0.18	0.05	0.02	0.04	0.02	0.03	0.03	0.11	0.03	0.07
Be (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca (Total)	22.82	14.62	20.40	19.81	15.85	21.94	28.70	26.72	27.07	33.42
Cd (Total)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Co (Total)	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr (Total)	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Cu (Total)	0.24	0.03	0.01	0.00	0.00	0.00	0.00	0.81	0.00	0.02
Fe (Total)	16.84	3.56	1.34	3.07	2.21	1.34	0.93	4.54	0.95	0.98
K (Total)	2.79	1.15	0.38	0.63	0.51	0.68	0.92	1.19	0.73	0.84
Li (Total)	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Mg (Total)	5.75	3.24	4.02	4.72	4.00	3.59	5.02	4.76	5.18	7.01
Mn (Total)	0.09	0.05	0.54	0.04	0.04	0.17	0.22	0.39	0.03	0.14
Mo (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na (Total)	2.11	2.17	4.24	3.43	3.11	3.91	4.68	3.42	3.75	4.91
Ni (Total)	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05
Pb (Total)	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00
S (Total)	4.91	5.82	15.95	13.09	11.33	11.86	22.19	12.57	20.37	30.10
Sb (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Se (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si (Total)	19.80	7.73	10.21	13.62	12.69	6.87	7.39	8.52	6.22	6.56
Sn (Total)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sr (Total)	0.46	0.15	0.10	0.15	0.11	0.10	0.12	0.22	0.16	0.14
Ti (Total)	0.33	0.00	0.02	0.01	0.01	0.01	0.01	0.06	0.01	0.00
V (Total)	0.04	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.01	0.01
Zn (Total)	6.14	0.07	0.06	0.04	0.01	0.09	0.03	0.71	0.05	0.10

Appendix A.5a Raw Water Data for Kawuneeche Valley Wetland

NM= Not Measured
NC=Not Calculated

Sample ID	W24		W29		W41	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.02	nd	0.06	nd	0.00
Al	9668.96	44.49	23637.85	212.86	16354.12	155.80
As	nd	0.29	nd	1.34	nd	0.20
B	16.14	0.32	22.49	0.50	9.10	0.07
Ba	58.58	0.19	213.87	234.71	97.34	0.92
Be	0.88	0.02	0.99	0.03	0.63	0.00
Ca	2649.74	15.82	2556.06	51.09	8218.59	78.33
Cd	nd	0.03	nd	0.04	nd	0.01
Co	6.45	0.01	7.59	0.14	2.62	0.02
Cr	15.56	0.05	22.10	0.27	9.71	0.08
Cu	4.25	0.03	11.84	0.39	23.58	0.13
Fe	16721.53	80.38	13681.39	136.61	8283.73	70.58
K	3419.03	12.33	4188.56	84.40	1866.91	18.18
Li	8.37	0.10	16.75	0.29	8.23	0.03
Mg	2931.55	42.31	3507.08	62.48	2207.57	21.37
Mn	203.38	1.20	133.32	2.59	88.24	0.55
Mo	nd	0.06	nd	0.17	nd	0.06
Na	388.78	2.10	166.86	7.03	227.11	2.27
Ni	13.38	0.13	10.94	0.11	8.86	0.05
Pb	8.82	0.21	nd	5.18	11.35	0.11
S	296.96	13.13	NM	NM	1548.31	7.49
Sb	nd	0.42	nd	0.75	nd	0.09
Se	nd	0.20	nd	0.54	nd	0.15
Si	7.29	0.39	53.42	38.08	42.22	0.21
Sn	0.03	0.04	nd	16.11	nd	0.09
Sr	569.23	6.81	307.93	3.28	343.72	3.65
Ti	164.07	2.04	2160.00	21.05	22.54	0.15
V	4.88	0.04	38.25	0.49	2.37	0.02
Zn	71.36	1.16	82.79	1.66	47.98	0.34

nd= non-detect
NM= Not Measured

Appendix A.5b Raw Data For Soils Collected at Kawuneeche Valley Wetland on 9-28-97.

Sample ID	W43		W59		WAA	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.01	nd	0.01	nd	0.01
Al	14460.18	25.17	16991.13	116.24	8230.01	8.18
As	nd	0.70	nd	0.38	nd	0.07
B	16.19	0.19	6.36	0.05	7.29	0.04
Ba	84.88	0.12	99.39	0.69	37.77	0.05
Be	1.59	0.02	4.16	0.02	0.40	0.00
Ca	4191.79	7.31	3849.83	26.37	6767.94	8.66
Cd	nd	0.02	nd	0.02	nd	0.01
Co	3.63	0.03	2.55	0.01	1.61	0.02
Cr	13.71	0.11	17.50	0.08	8.24	0.08
Cu	12.52	0.15	23.52	0.08	9.71	0.02
Fe	9811.94	13.98	6418.27	42.21	6530.13	7.62
K	1990.77	2.56	1781.06	4.25	919.37	0.32
Li	5.60	0.07	7.31	0.02	3.27	0.02
Mg	1970.88	12.40	2071.79	12.19	1428.10	18.18
Mn	59.93	0.67	32.17	0.07	52.46	0.14
Mo	nd	0.01	nd	0.02	nd	0.04
Na	407.08	3.79	389.64	1.87	158.75	0.85
Ni	8.44	0.06	7.50	0.04	6.47	0.07
Pb	6.51	0.15	8.70	0.12	9.45	0.09
S	970.72	10.05	695.37	5.18	1055.19	13.23
Sb	nd	0.21	nd	0.12	nd	0.17
Se	nd	0.18	nd	0.10	nd	0.15
Si	42.61	0.35	6.31	0.04	13.67	0.22
Sn	nd	0.05	0.72	0.06	nd	0.06
Sr	338.64	1.84	248.14	2.89	267.27	2.35
Ti	212.94	0.37	24.86	0.04	58.69	0.25
V	24.27	0.32	21.71	0.05	9.44	0.09
Zn	67.19	0.61	50.90	0.14	34.72	0.09

nd= non-detect
NM= Not Measured

Appendix A.5b Raw Data For Soils Collected at Kawuneeche Valley Wetland on 9-28-97.

Sample ID	WBB		WCC		WDD	
Analyte	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)	Conc. (mg/kg)	Std. Dev. (mg/kg)
Ag	nd	0.01	nd	0.01	nd	0.01
Al	7533.33	183.06	8591.41	99.97	7516.43	35.47
As	nd	0.45	nd	0.22	nd	0.37
B	4.44	0.13	3.66	0.08	4.49	0.06
Ba	47.97	1.27	44.44	0.52	41.87	0.18
Be	0.46	0.01	0.97	0.01	1.41	0.02
Ca	5673.41	146.58	5747.82	68.85	4450.69	20.53
Cd	nd	0.03	nd	0.03	nd	0.01
Co	2.37	0.06	1.72	0.05	1.61	0.00
Cr	10.58	0.27	8.51	0.14	6.84	0.06
Cu	5.72	0.15	6.35	0.04	7.99	0.11
Fe	4181.41	86.53	3554.75	32.93	4103.52	18.80
K	1328.01	35.16	992.16	11.47	836.62	4.11
Li	3.97	0.10	3.08	0.03	2.44	0.02
Mg	1674.75	55.22	1290.97	23.63	940.59	11.87
Mn	111.39	2.71	32.49	0.41	18.35	0.24
Mo	nd	0.03	nd	0.02	nd	0.03
Na	261.46	1.47	240.85	1.45	323.05	2.44
Ni	6.25	0.16	4.73	0.06	4.08	0.05
Pb	4.20	0.07	3.25	0.04	3.20	0.12
S	1125.50	42.51	1172.58	27.78	1517.07	20.75
Sb	nd	0.31	nd	0.06	nd	0.19
Se	nd	0.17	nd	0.05	nd	0.09
Si	68.97	1.66	29.57	0.57	14.29	0.14
Sn	nd	0.04	nd	0.08	nd	0.11
Sr	163.57	2.04	146.32	0.40	181.80	1.16
Ti	35.58	0.68	32.98	0.37	41.38	0.49
V	2.45	0.06	3.23	0.04	9.53	0.11
Zn	43.41	1.00	46.85	0.55	26.12	0.34

nd= non-detect
NM= Not Measured

Appendix A.5b Raw Data For Soils Collected at Kawuneeche Valley Wetland on 9-28-97.

Sample ID	W24		W29		W41	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.50	0.07	0.36	0.20	0.20	0.23
Al	14.10	0.76	7.02	1.42	8.97	0.76
As	nd	nd	nd	nd	nd	nd
B	nd	nd	4.32	2.01	7.14	1.94
Ba	53.94	0.18	38.47	0.18	52.56	0.96
Be	0.10	0.03	0.07	0.01	0.04	0.00
Ca	5397.32	9.03	3267.09	11.31	3775.33	74.22
Cd	nd	nd	nd	nd	nd	nd
Co	0.16	0.14	nd	nd	nd	nd
Cr	nd	nd	0.15	0.28	nd	nd
Cu	4.64	0.03	3.74	0.15	7.78	0.09
Fe	92.96	1.16	73.09	1.64	117.35	1.97
K	11312.63	64.63	11490.51	121.80	8628.79	165.45
Li	0.30	0.17	0.30	0.33	0.34	0.27
Mg	1086.40	2.08	780.40	3.18	1676.98	14.87
Mn	597.29	0.54	449.13	2.93	193.58	3.05
Mo	0.87	0.47	0.82	0.53	0.58	0.67
Na	31.34	0.91	43.49	3.44	50.11	3.40
Ni	1.31	0.02	0.76	0.58	0.41	0.52
Pb	nd	nd	nd	nd	0.16	1.81
S	nd	nd	nd	nd	nd	nd
Sb	0.06	2.46	nd	nd	nd	nd
Se	3.57	3.14	1.57	5.53	1.53	3.73
Si	124.10	0.52	89.56	1.45	29.95	1.88
Sn	2.59	1.26	2.15	0.60	2.16	1.82
Sr	37.41	8.94	18.58	4.76	17.80	15.17
Ti	nd	nd	0.15	0.07	nd	nd
V	0.39	0.13	0.32	0.17	0.29	0.22
Zn	31.34	0.28	28.88	0.57	32.91	0.46

nd= non-detect

Appendix A.5c Raw Data for Vegetation Collected at Kawuneeche Valley Wetland on 9-28-97. Reported as Average of Two Samples.

Sample ID	W43		W44		W59	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.40	0.15	0.19	0.15	0.36	0.17
Al	6.62	2.26	30.22	1.83	11.10	3.81
As	0.13	1.25	nd	nd	nd	nd
B	nd	nd	6.61	3.45	8.95	3.98
Ba	42.03	0.67	41.41	0.16	46.84	0.39
Be	0.08	0.01	0.05	0.02	0.06	0.01
Ca	4712.49	80.27	4072.10	18.82	4890.03	30.57
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	0.18	0.37	0.20	0.46
Cr	nd	nd	0.08	0.20	0.02	0.31
Cu	4.50	0.13	3.89	0.57	4.45	0.28
Fe	55.49	1.77	103.07	1.53	49.62	1.31
K	5763.30	98.05	8071.44	36.52	7609.19	71.37
Li	0.31	0.19	0.64	0.34	0.27	0.41
Mg	1943.51	9.14	1056.78	4.16	1047.71	5.90
Mn	160.46	3.27	258.24	0.96	399.05	1.33
Mo	0.78	0.22	1.27	0.85	1.24	0.52
Na	50.06	3.60	54.85	2.04	29.06	4.22
Ni	0.65	0.26	0.90	0.33	0.55	0.20
Pb	0.48		nd	nd	nd	nd
S	nd	nd	nd	nd	nd	nd
Sb	1.32	1.03	nd	nd	0.08	0.54
Se	3.67	3.36	1.43	2.41	3.35	4.31
Si	178.93	3.08	75.56	0.81	123.83	1.86
Sn	2.97	1.65	1.51	1.67	1.38	2.27
Sr	33.56	26.51	11.83	12.47	25.08	20.45
Ti	0.10	0.09	3.82	0.05	nd	nd
V	0.08	0.20	0.31	0.25	0.14	0.12
Zn	54.58	1.24	39.71	0.43	37.80	0.76

nd= non-detect

Appendix A.5c Raw Data for Vegetation Collected at Kawuneeche Valley Wetland on 9-28-97. Reported as Average of Two Samples.

Sample ID	WAA		WBB		WCC	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.31	0.29	0.25	0.24	1.18	0.27
Al	13.74	2.63	12.35	1.46	10.57	2.49
As	nd	nd	nd	nd	nd	nd
B	12.10	3.71	nd	nd	18.48	3.21
Ba	19.64	0.19	40.46	0.34	40.67	0.38
Be	0.02	0.01	0.02	0.02	0.04	0.01
Ca	3983.00	43.41	4067.34	26.63	4286.61	34.59
Cd	nd	nd	nd	nd	nd	nd
Co	nd	nd	0.19	0.60	0.13	0.25
Cr	nd	nd	nd	nd	nd	nd
Cu	3.64	0.13	9.33	0.09	3.44	0.23
Fe	73.29	1.19	99.49	1.54	72.37	1.33
K	7492.30	88.04	9423.55	71.85	6668.68	81.58
Li	1.43	0.51	0.43	0.32	0.99	0.43
Mg	1280.55	8.12	1069.96	5.67	1598.28	7.12
Mn	157.26	1.52	436.96	3.22	283.00	2.74
Mo	1.51	0.37	1.36	0.66	0.94	0.28
Na	90.19	2.49	104.27	2.71	87.16	2.77
Ni	0.12	0.70	0.50	0.48	0.86	0.17
Pb	0.37	1.38	0.86	2.92	nd	nd
S	nd	nd	nd	nd	nd	nd
Sb	nd	nd	nd	nd	0.78	2.55
Se	1.25	5.09	0.76	4.08	2.20	2.67
Si	92.25	1.64	37.20	1.38	47.07	0.96
Sn	2.40	0.56	1.09	1.86	1.84	1.53
Sr	15.09	9.41	13.13	30.11	27.37	14.79
Ti	nd	nd	0.38	0.04	2.06	0.11
V	0.35	0.17	0.35	0.19	0.09	0.56
Zn	42.35	0.61	44.15	0.59	77.32	1.16

nd= non-detect

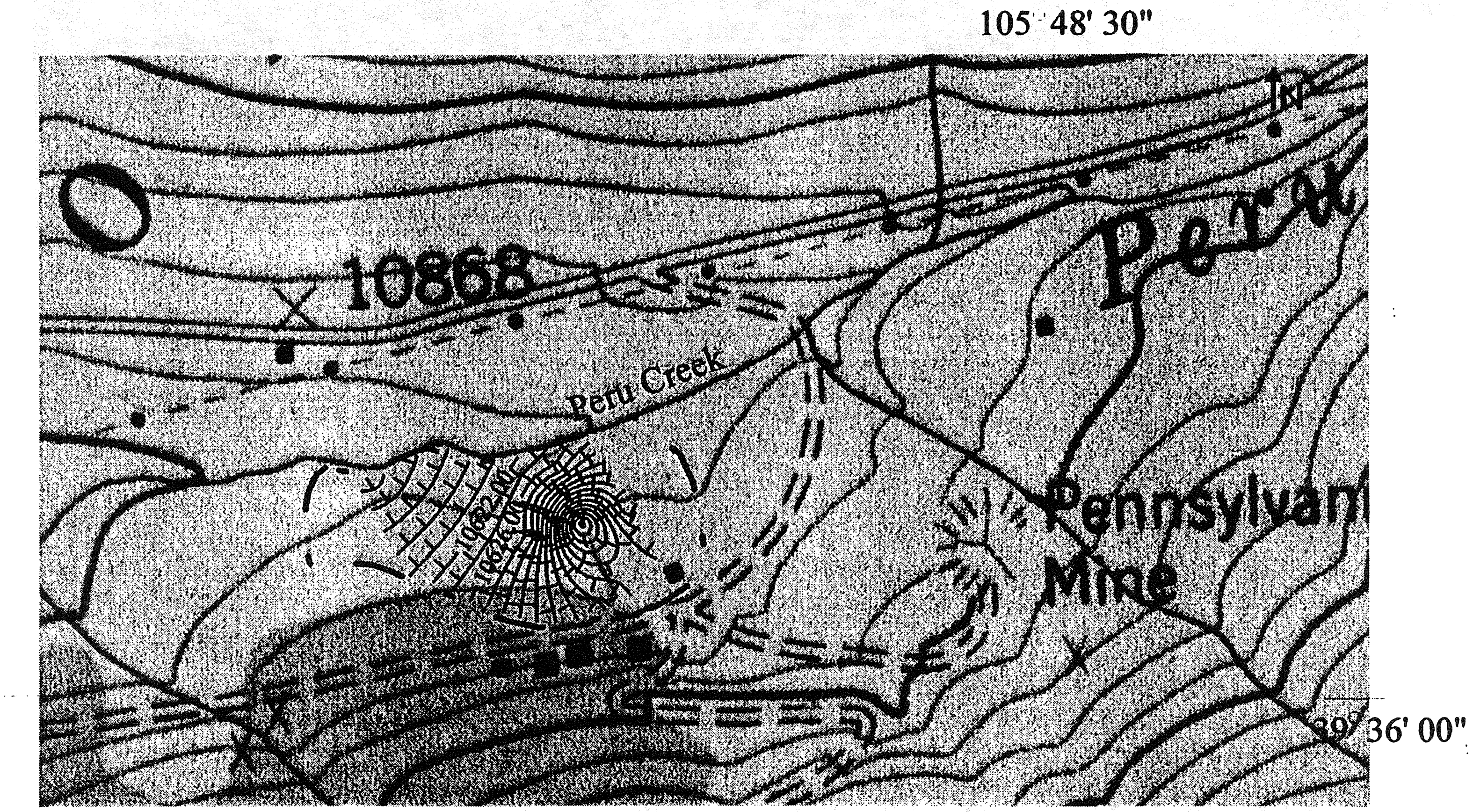
Appendix A.5c Raw Data for Vegetation Collected at Kawuneeche Valley Wetland on 9-28-97. Reported as Average of Two Samples.

Sample ID	WDD		WEE	
Analyte	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)	Avg. Conc. (mg/kg)	Avg. Std. Dev. (mg/kg)
Ag	0.26	0.10	1.13	1.63
Al	21.67	1.59	19.96	2.82
As	nd	nd	nd	nd
B	nd	nd	24.79	15.34
Ba	56.51	0.64	56.40	0.22
Be	0.06	0.01	0.05	0.01
Ca	5400.71	60.66	5685.07	26.09
Cd	nd	nd	nd	nd
Co	0.21	0.19	nd	nd
Cr	nd	nd	0.09	0.54
Cu	3.98	0.16	4.51	0.10
Fe	120.26	2.03	58.73	0.36
K	9733.60	92.76	7325.79	39.45
Li	0.38	0.57	1.25	0.57
Mg	1842.21	19.15	1602.60	3.76
Mn	414.03	4.24	423.09	1.51
Mo	0.65	0.92	1.71	0.75
Na	38.87	2.45	27.25	1.68
Ni	0.56	0.83	0.52	0.29
Pb	nd	nd	2.06	1.67
S	nd	nd	nd	nd
Sb	nd	nd	nd	nd
Se	2.51	4.22	3.52	6.30
Si	94.12	1.69	81.53	1.36
Sn	2.19	0.86	0.93	2.11
Sr	38.08	21.68	20.62	15.03
Ti	6.80	0.10	0.58	0.07
V	0.49	0.19	0.35	0.11
Zn	56.65	1.27	97.46	3.03

nd= non-detect

Appendix A.5c Raw Data for Vegetation Collected at Kawuneeche Valley Wetland on 9-28-97. Reported as Average of Two Sam

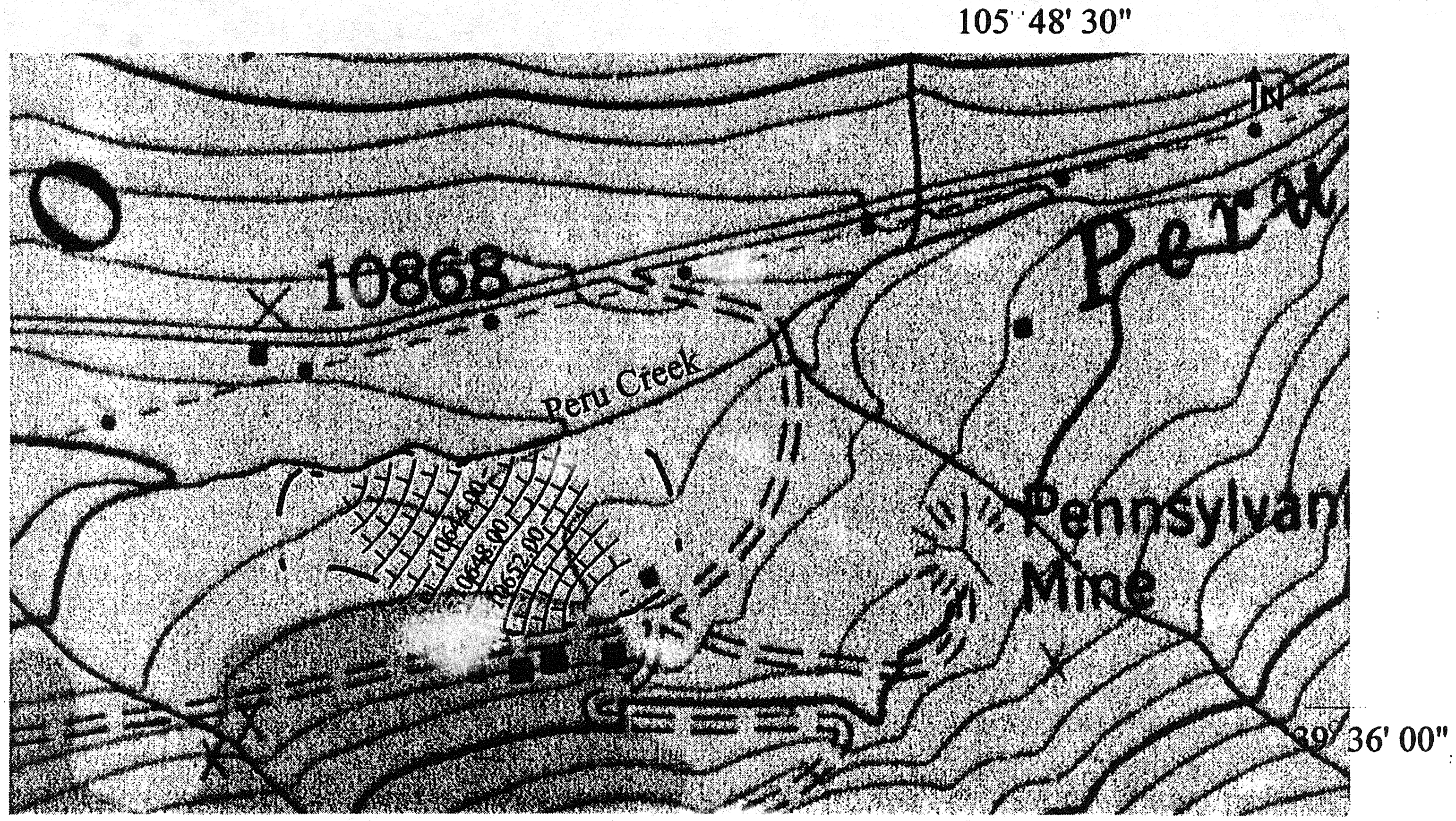
Appendix B.1a Potentiometric Surface in Unconsolidated Layer at Pennsylvania Mine Wetland on 6-12-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

—— - Pennsylvania Mine Wetland Boundary

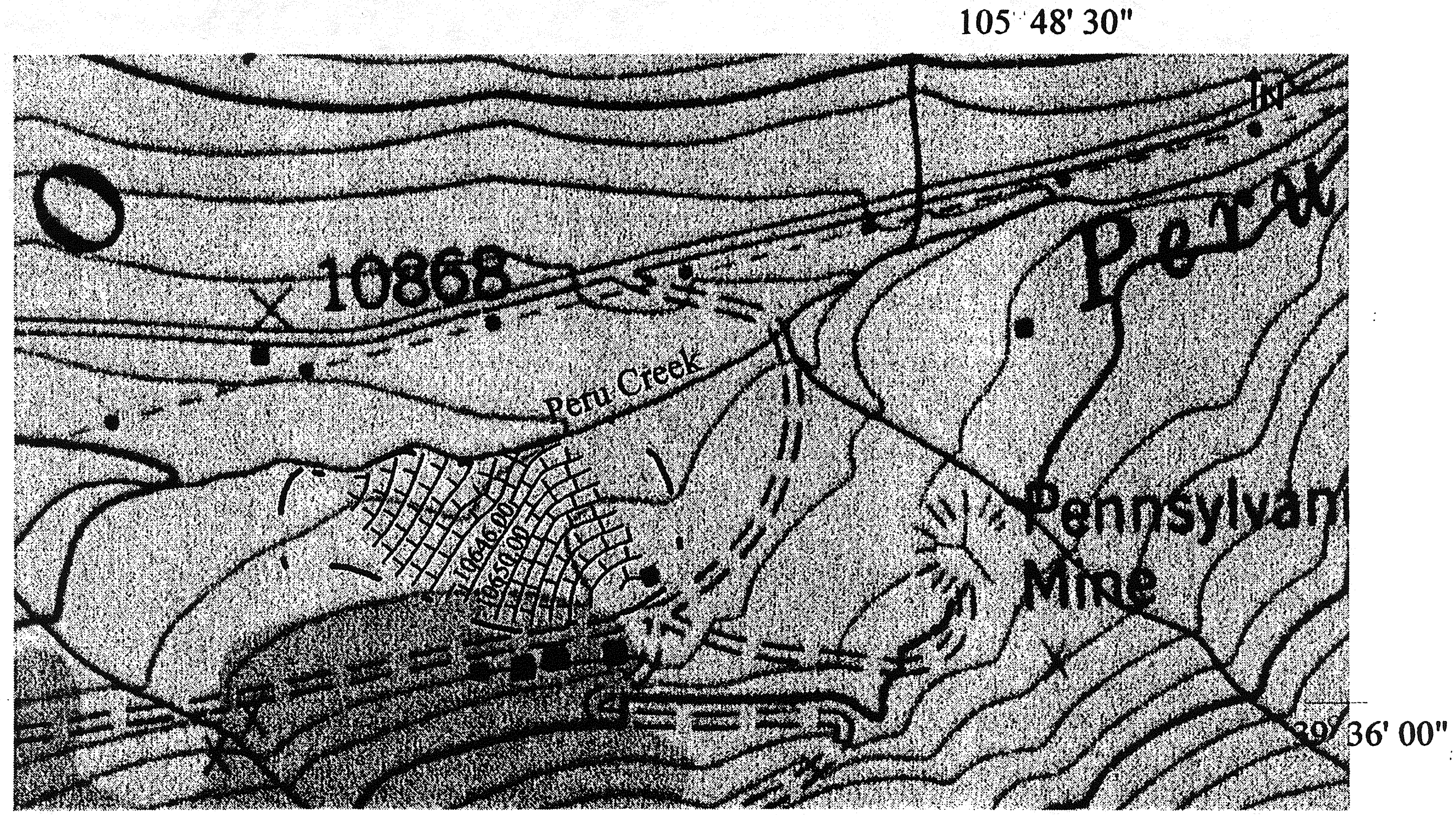
Appendix B.1b Potentiometric Surface in Unconsolidated Layer at Pennsylvania Mine Wetland on 6-19-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

— - Pennsylvania Mine Wetland Boundary

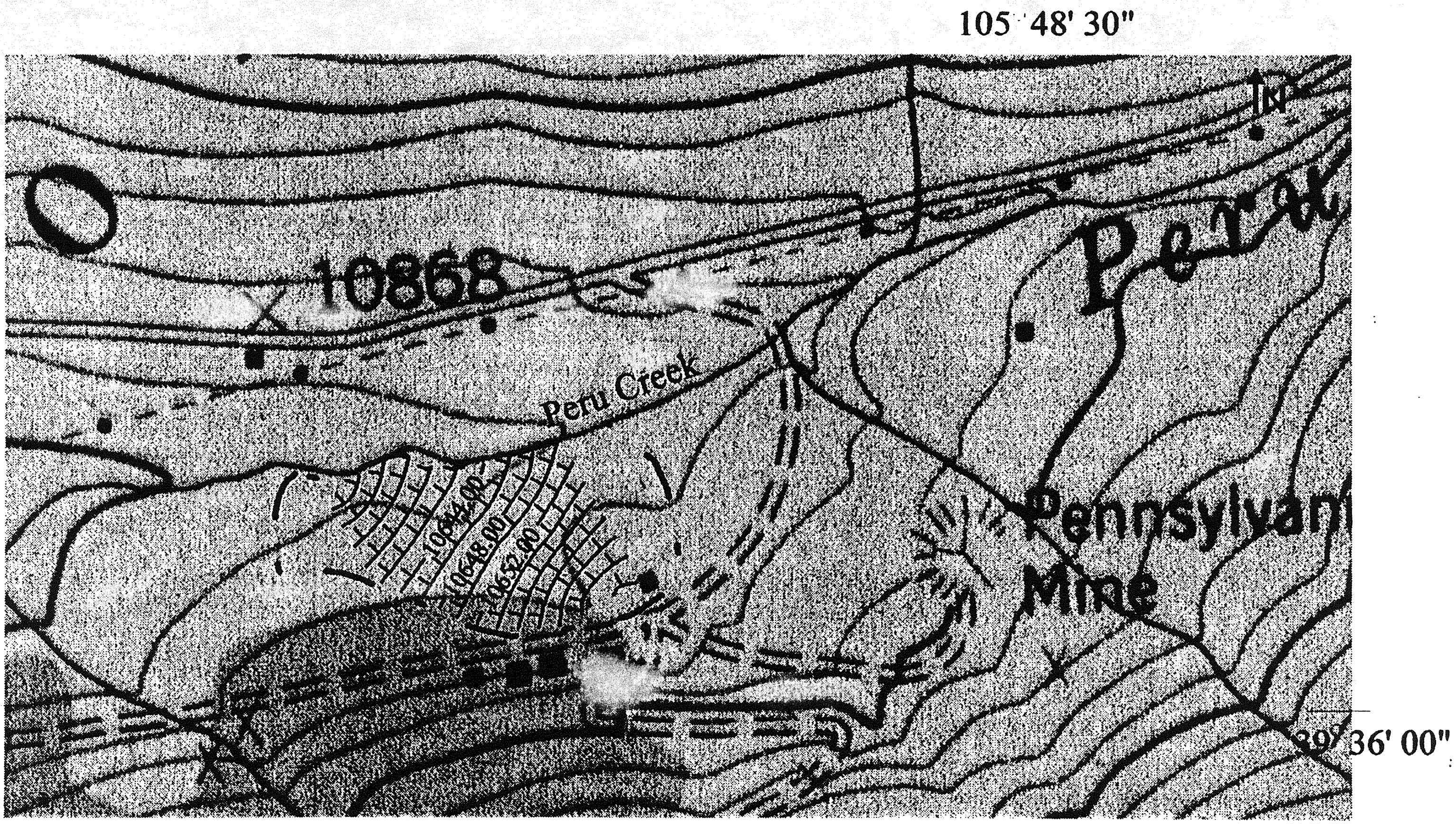
Appendix B.1c Potentiometric Surface in Peat at Pennsylvania Mine Wetland on 6-19-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

— - Pennsylvania Mine Wetland Boundary

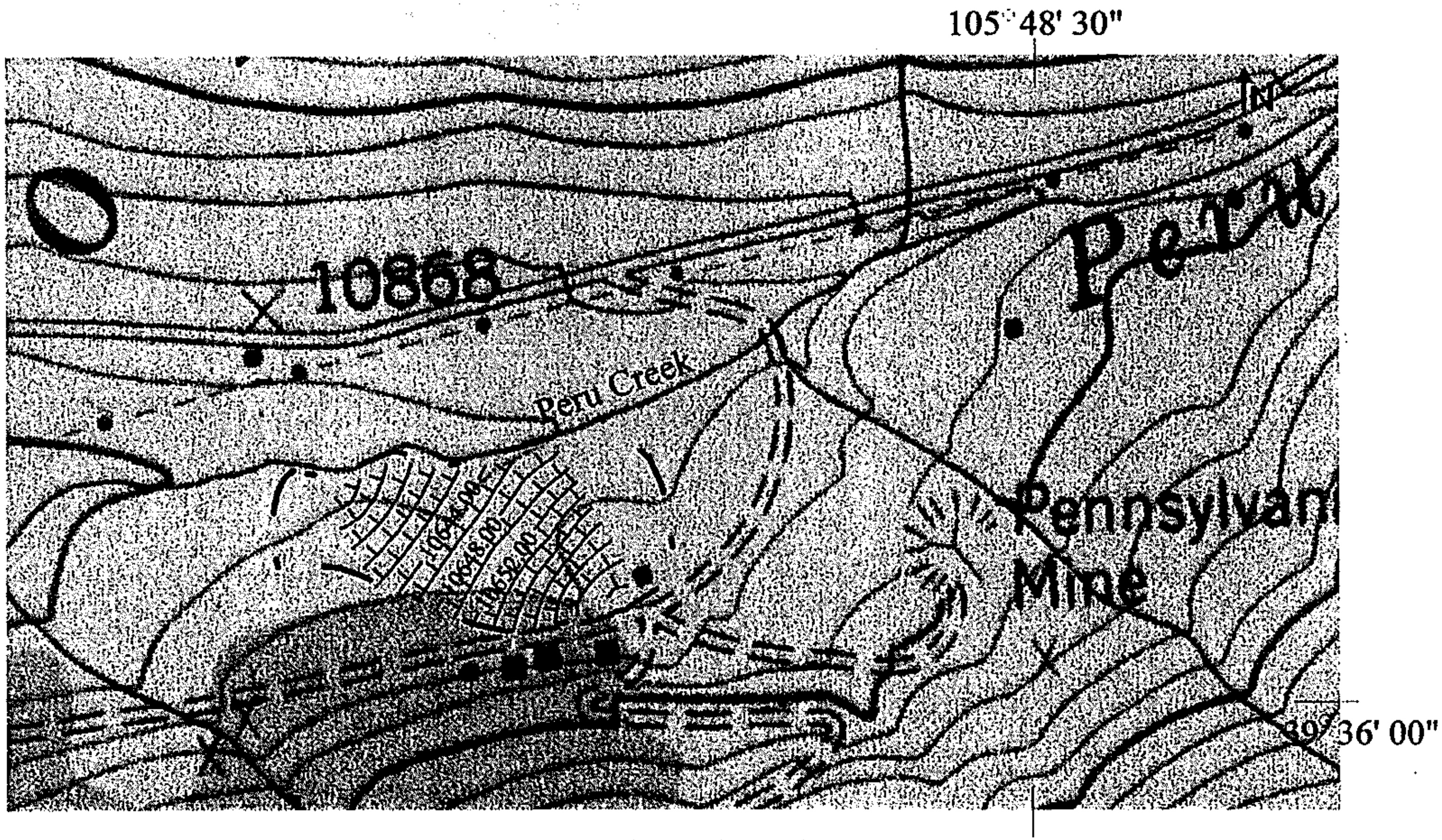
Appendix B.1d Potentiometric Surface in Unconsolidated Layer at Pennsylvania Mine Wetland on 8-04-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

— - Pennsylvania Mine Wetland Boundary

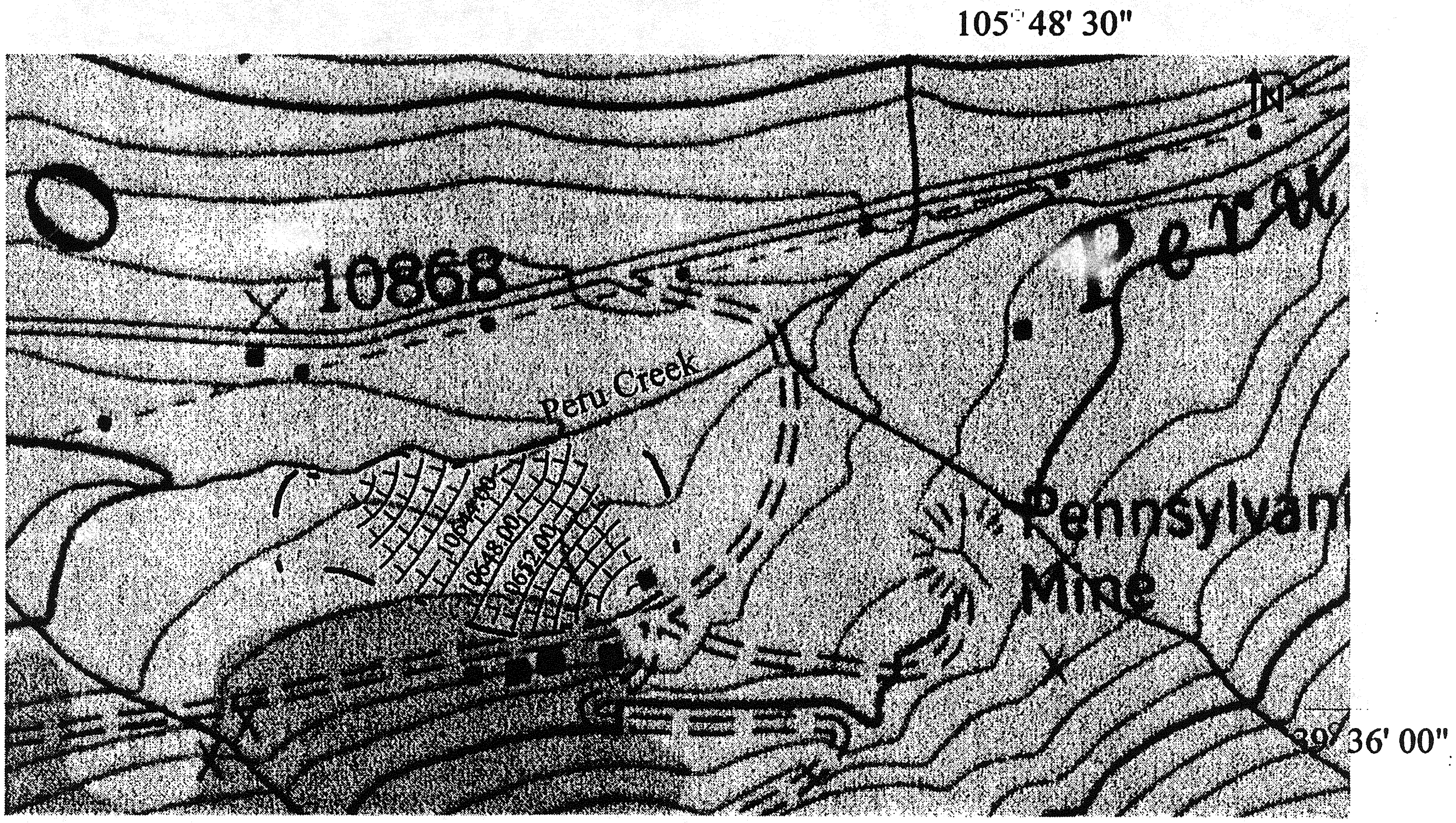
Appendix B.1e Potentiometric Surface in Peat at Pennsylvania Mine Wetland on 8-04-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

—— - Pennsylvania Mine Wetland Boundary

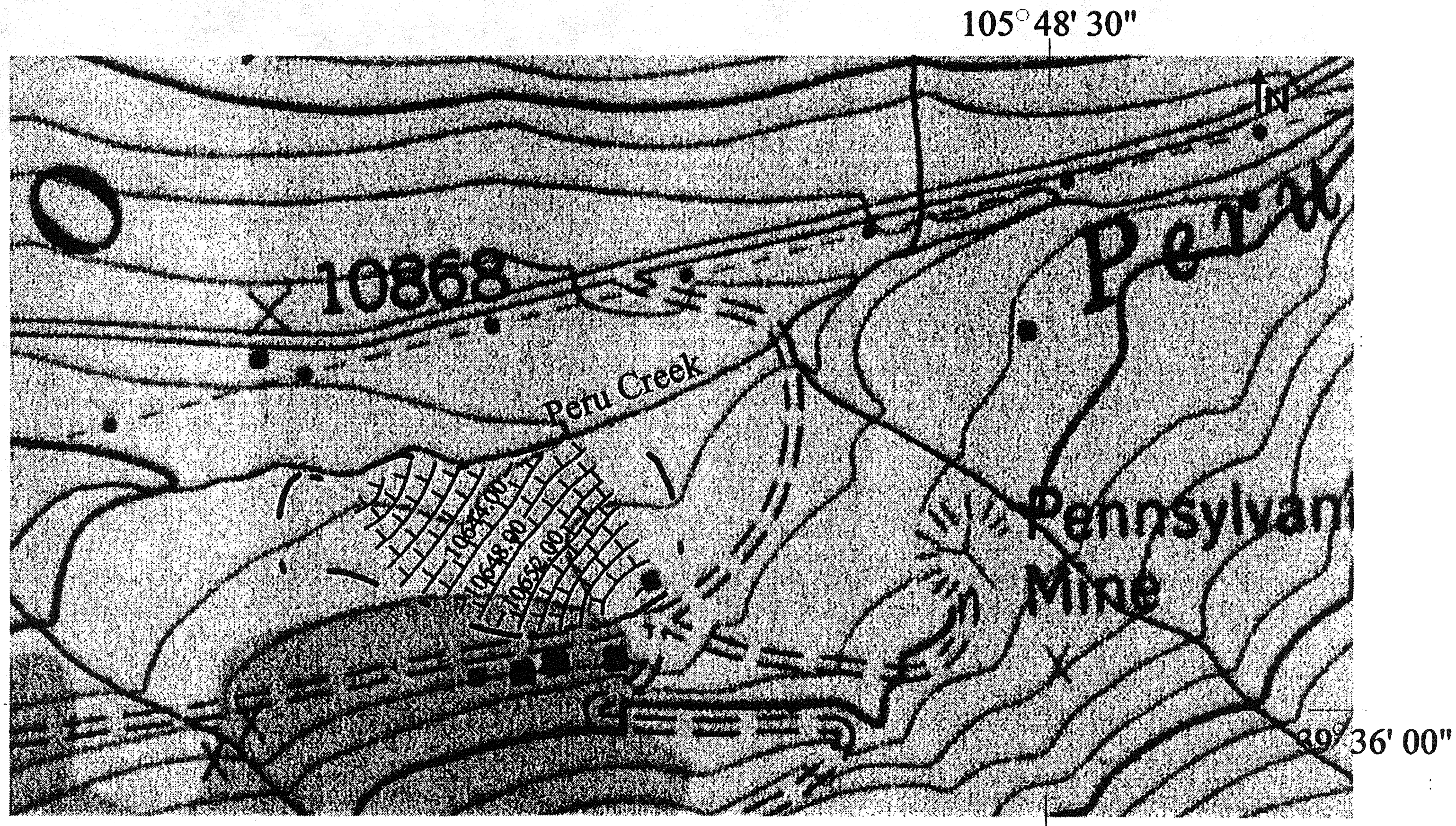
Appendix B.1f Potentiometric Surface in Unconsolidated Layer at Pennsylvania Mine Wetland on 9-13-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

— - Pennsylvania Mine Wetland Boundary

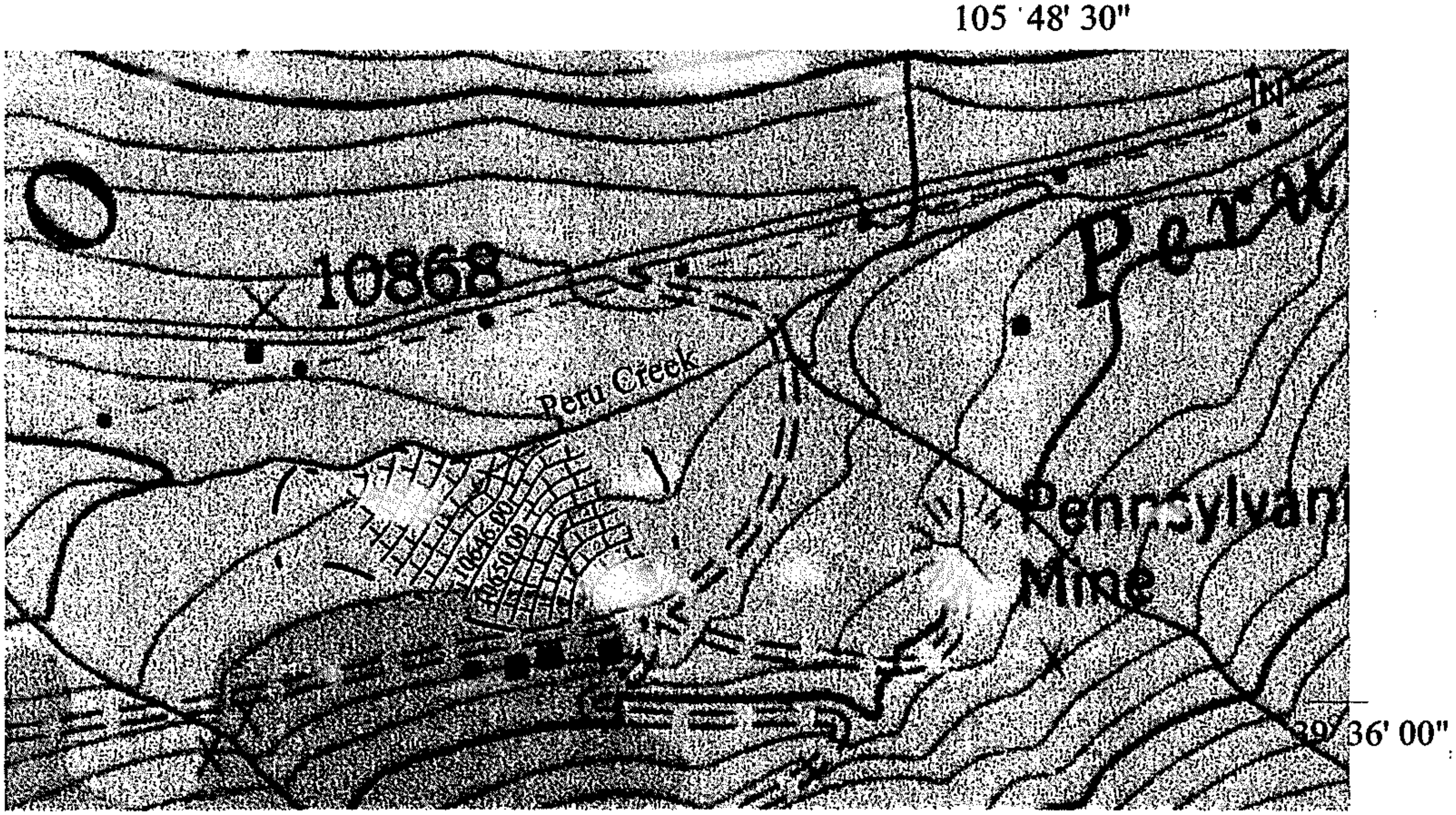
Appendix B.1g Potentiometric Surface in Peat at Pennsylvania Mine Wetland on 9-13-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

— - Pennsylvania Mine Wetland Boundary

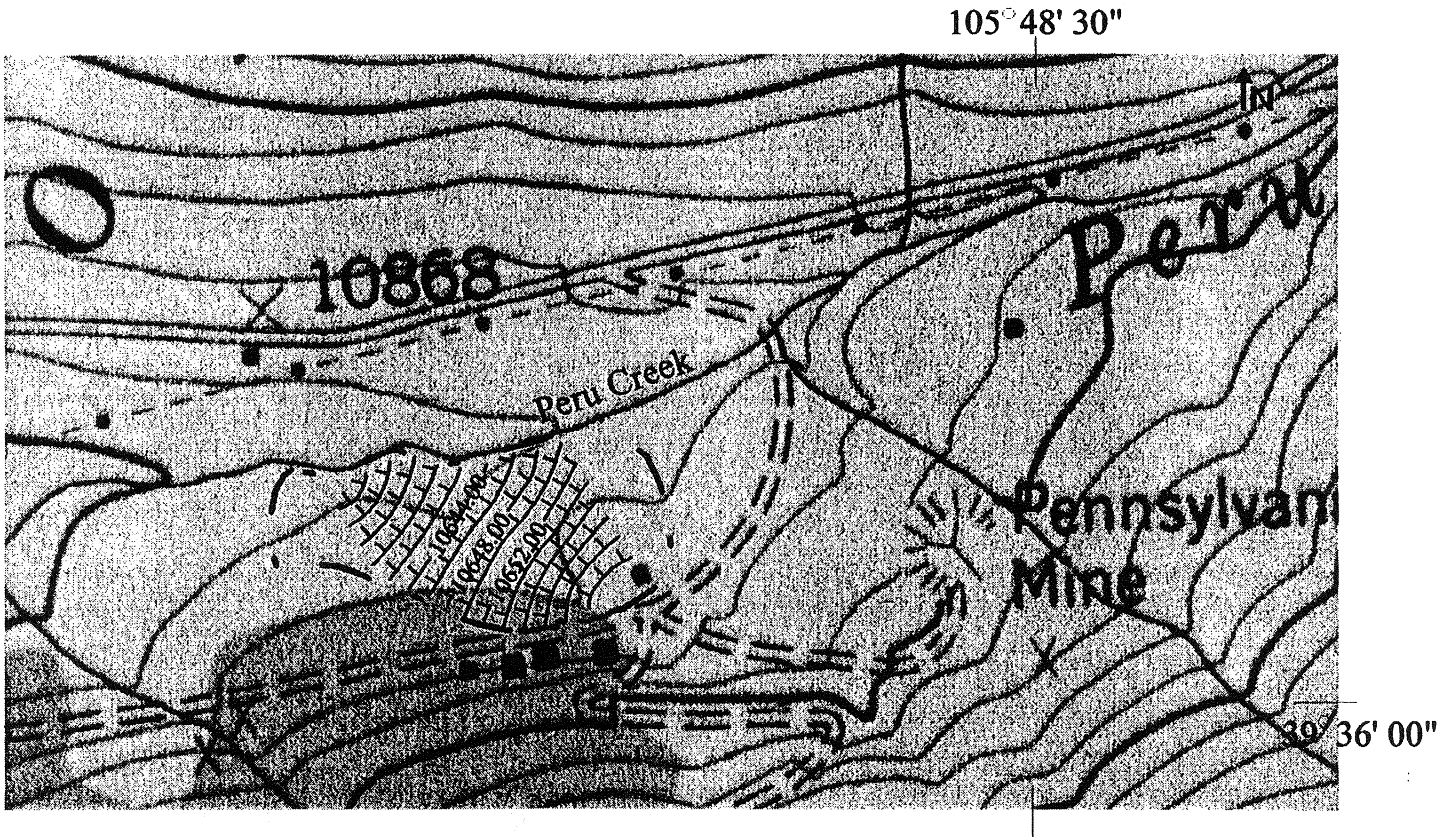
Appendix B.1h Potentiometric Surface in Unconsolidated Layer at Pennsylvania Mine Wetland on 10-18-97.



Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

—— - Pennsylvania Mine Wetland Boundary

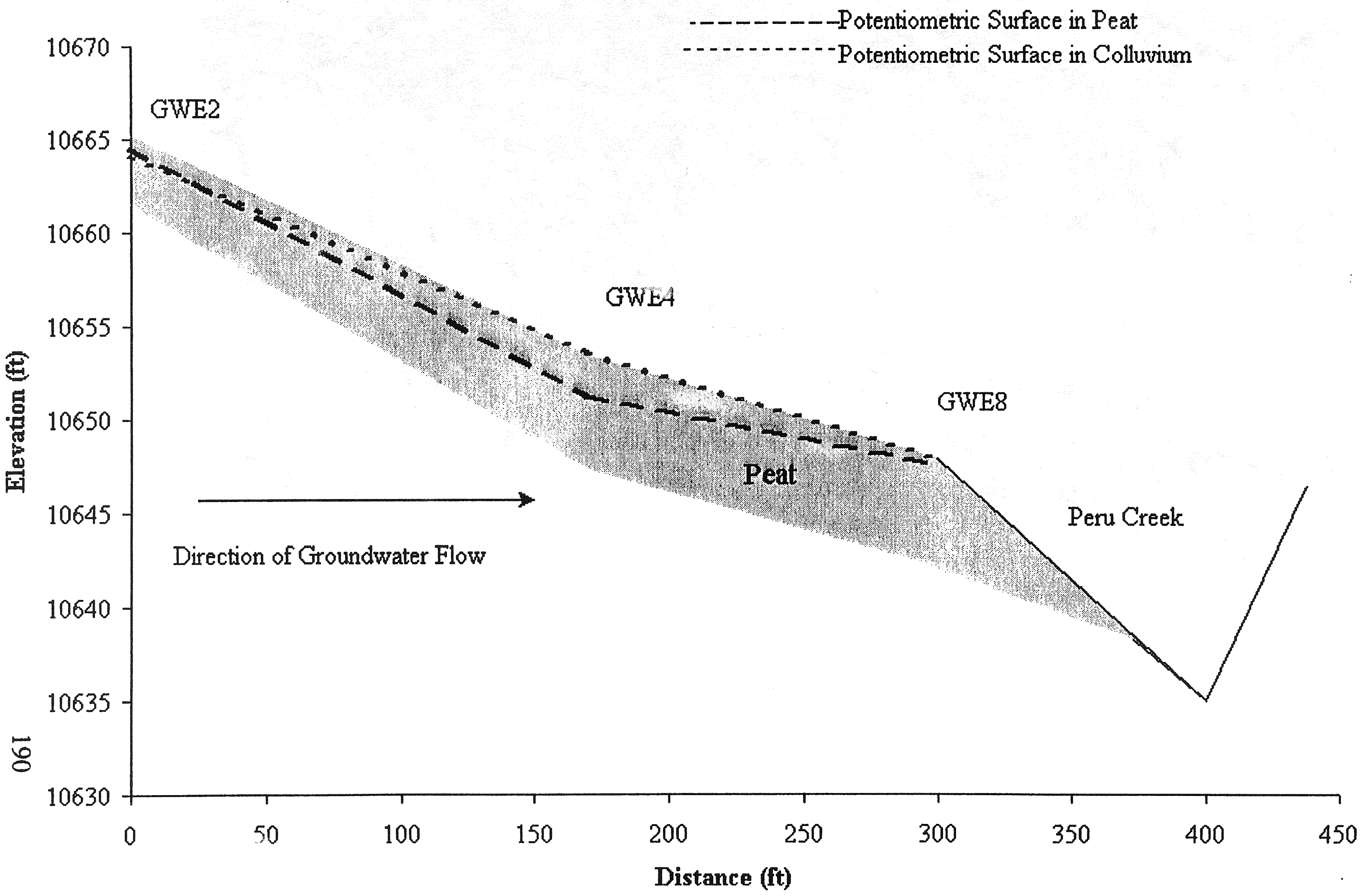
Appendix B.1i Potentiometric Surface in Peat at Pennsylvania Mine Wetland on 10-18-97.



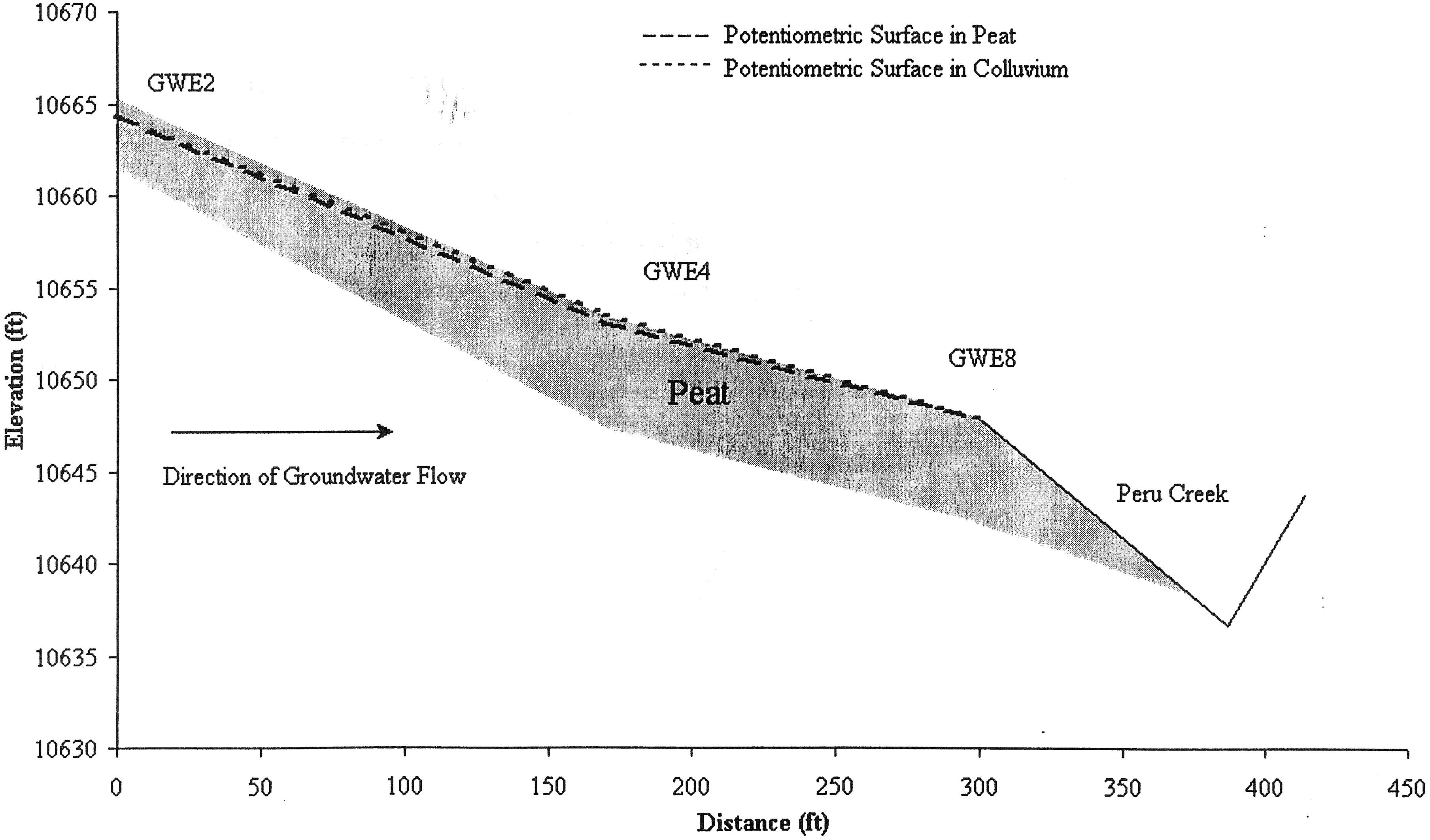
Contours Indicate Two Foot Change. Hach Marks Indicate Downhill Direction.

— - Pennsylvania Mine Wetland Boundary

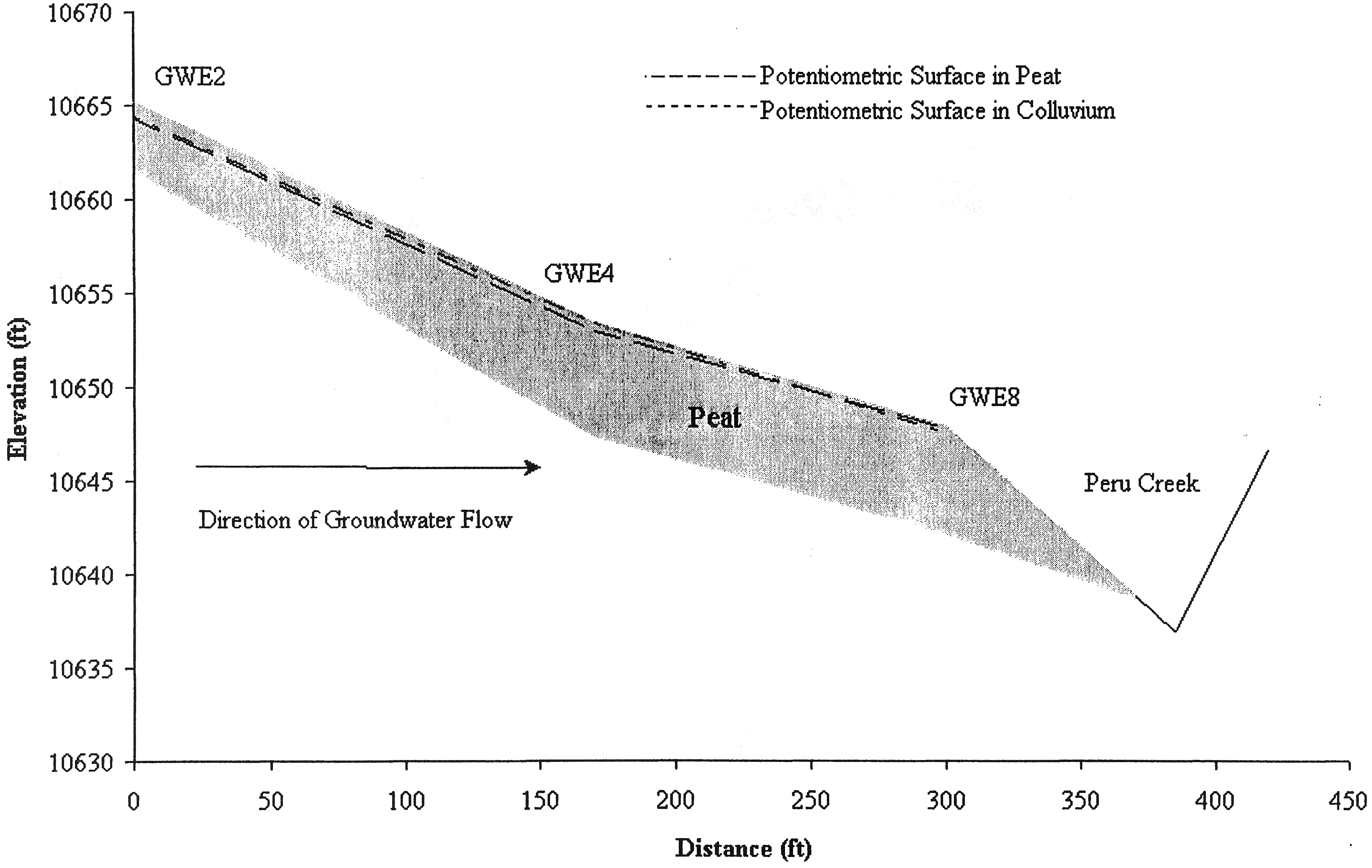
Appendix B.1j Transect I Cross Section of Pennsylvania Mine Wetland on 6-19-97.



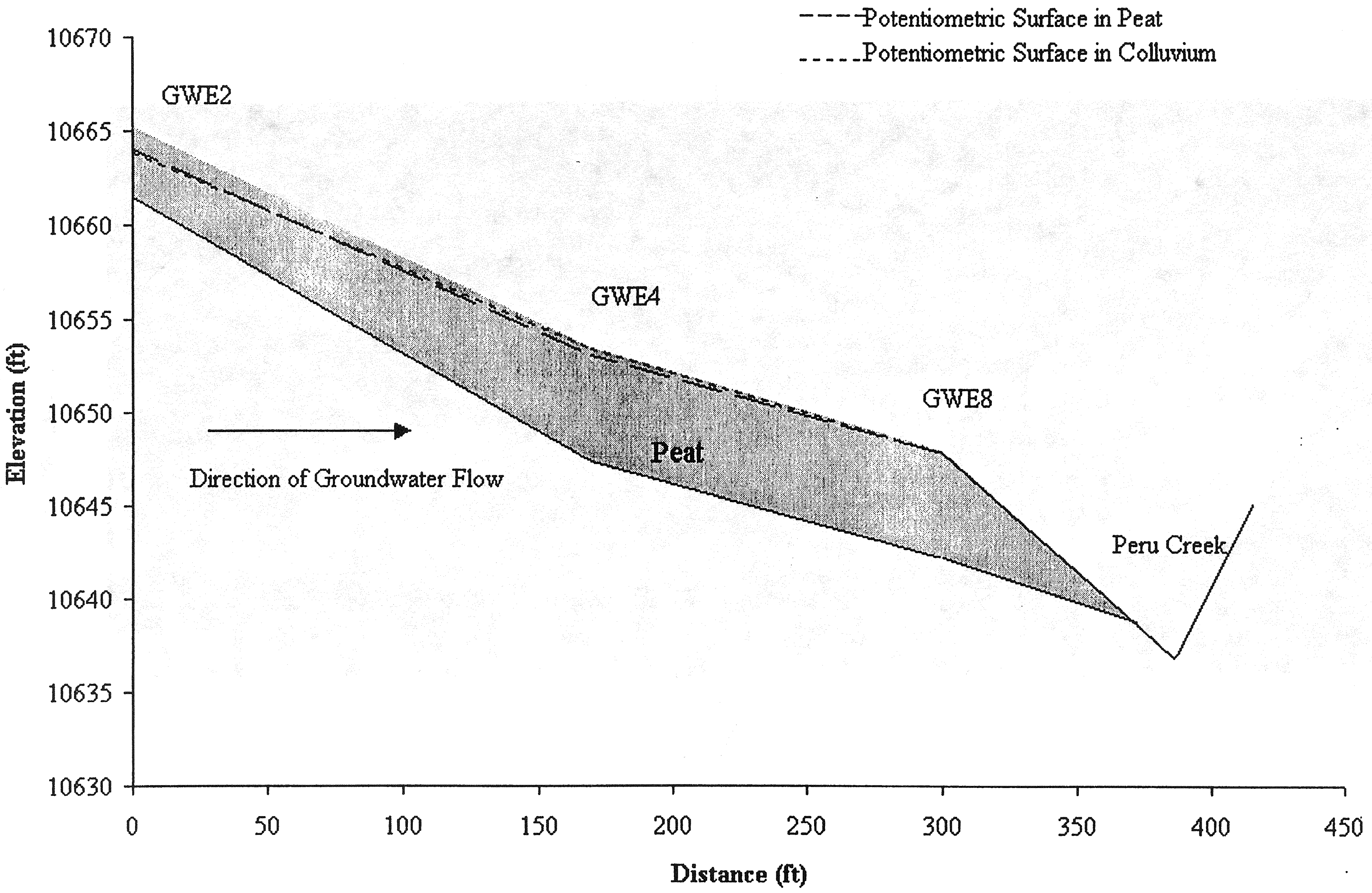
Appendix B. 1k Transect I Cross Section of Pennsylvania Mine Wetland on 8-04-97.



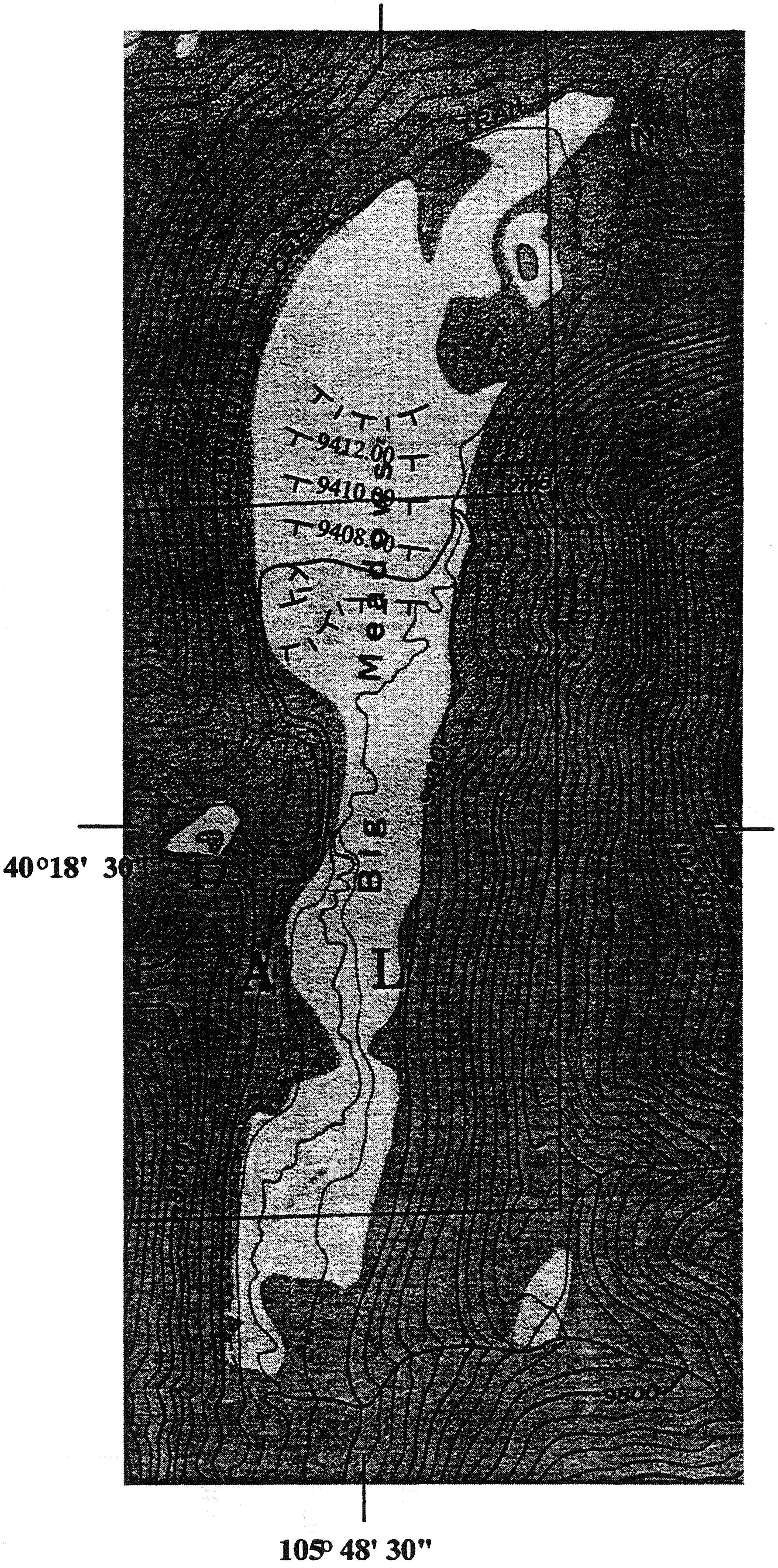
Appendix B. 11 Transect I Cross Section of Pennsylvania Mine Wetland on 9-13-97.



Appendix B. 1m Transect I Cross Section of Pennsylvania Mine Wetland on 10-18-97.



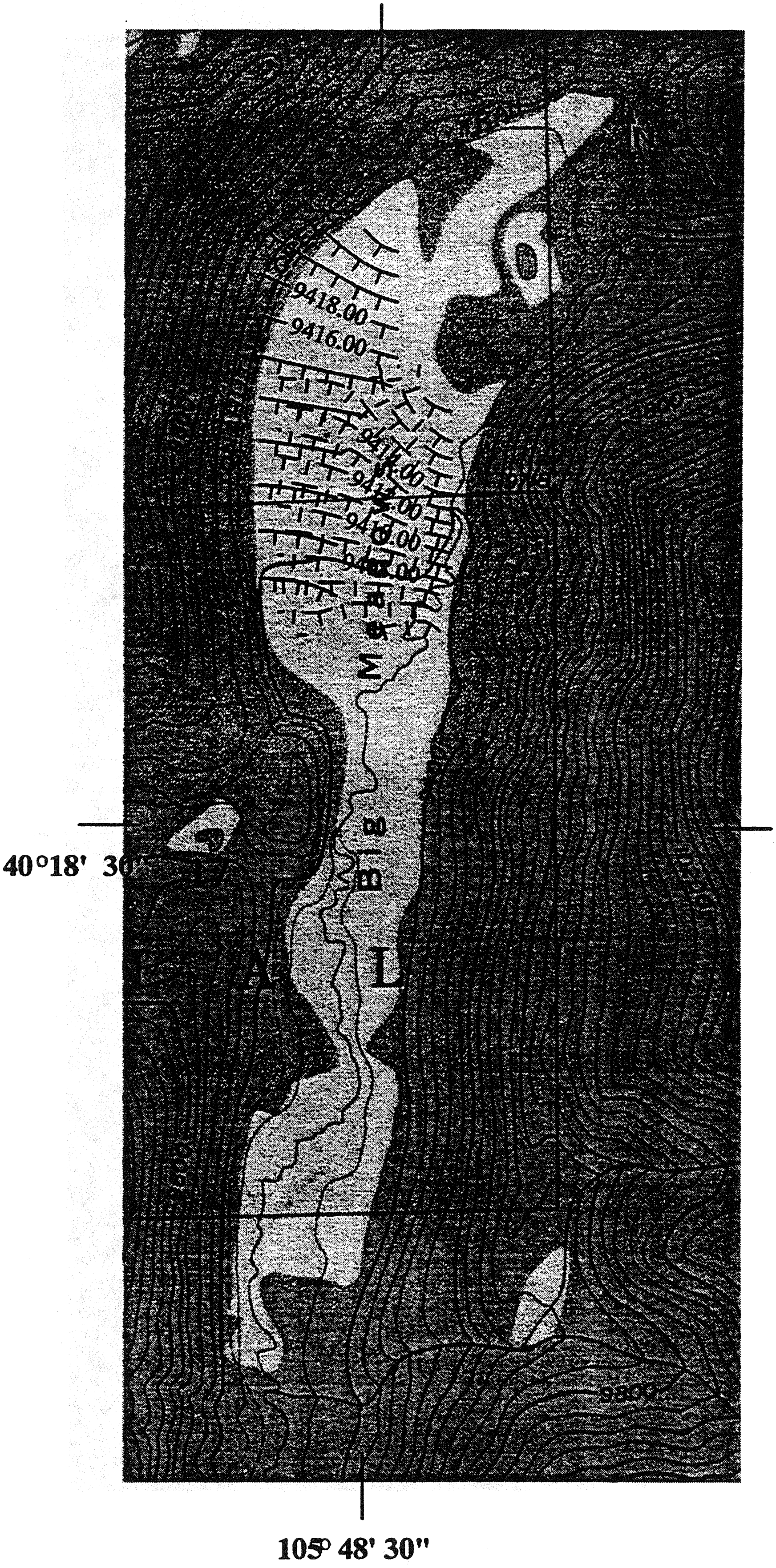
Appendix B2.a Potentiometric Surface in Unconsolidated Layer at Big Meadows Wetland on 6-10-97.



Contours Indicate Two Foot Change.
Hach Marks Indicate Downhill Direction.

— — — Potentiometric Surface in Unconsolidated Layer

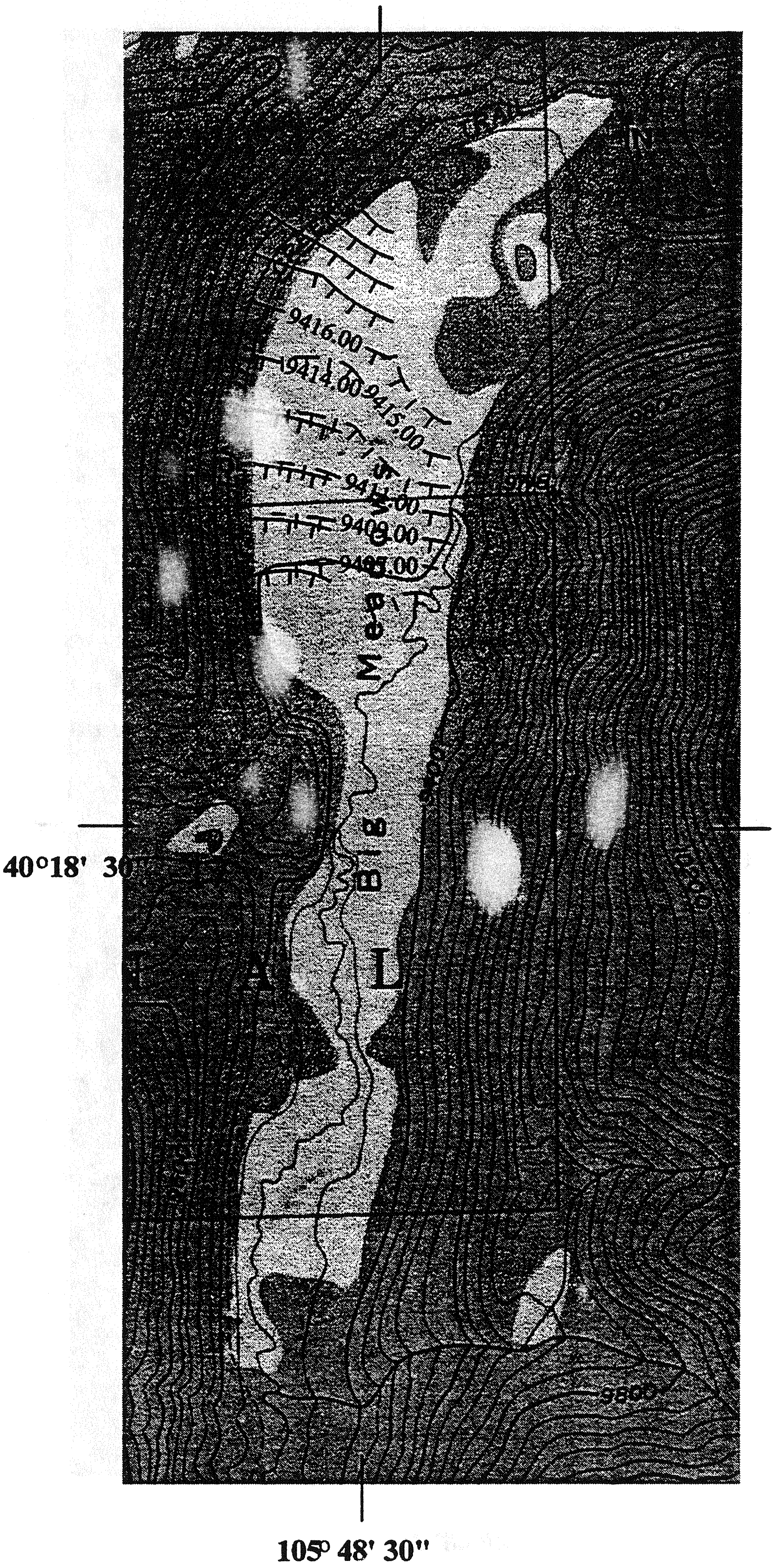
Appendix B2.b Potentiometric Surface in Unconsolidated Layer at Big Meadows Wetland on 6-25-97.



Contours Indicate Two Foot Change.
Hach Marks Indicate Downhill Direction.

– – – Potentiometric Surface in Unconsolidated Layer
——— Potentiometric Surface in Peat Layer

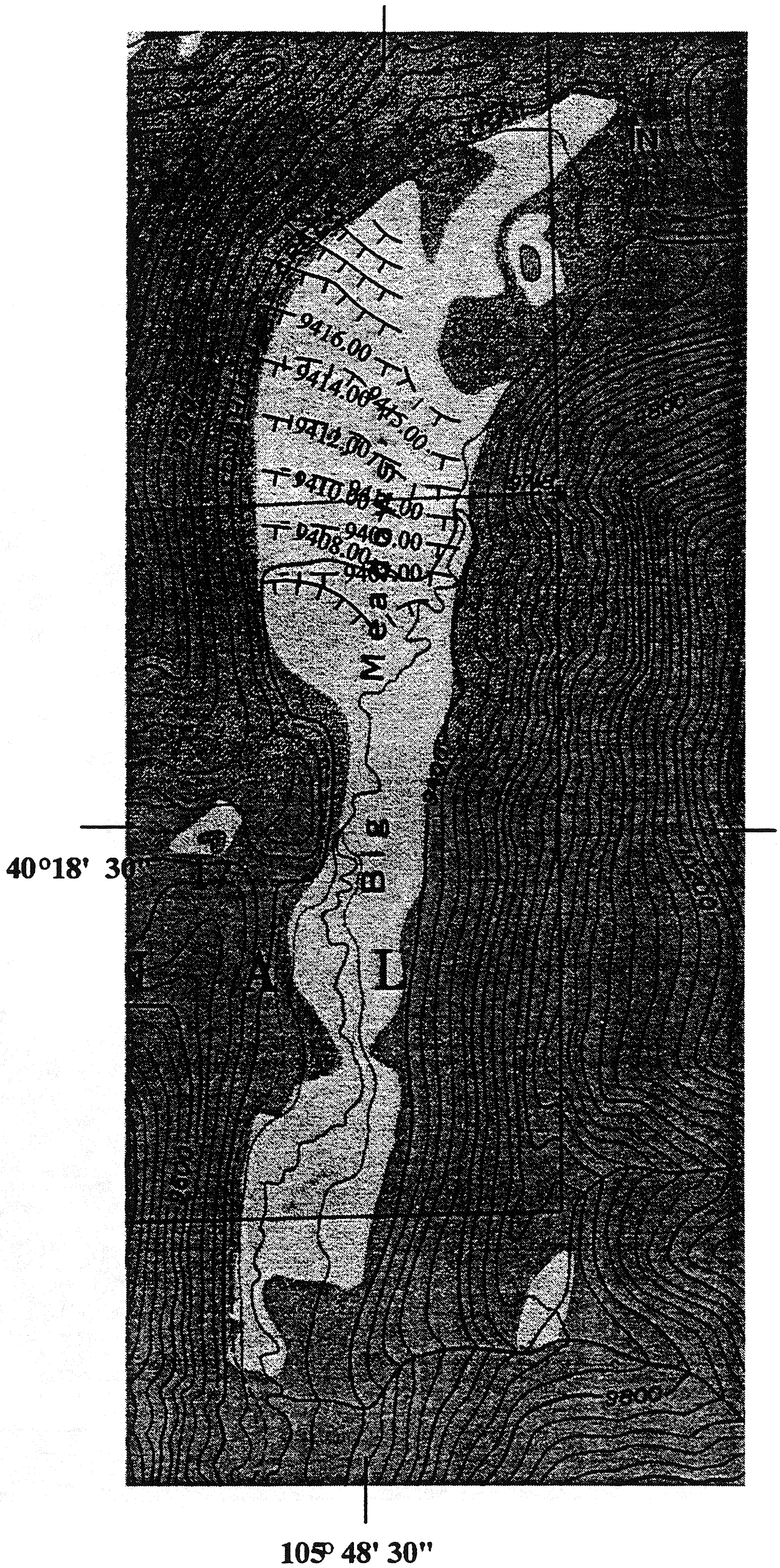
Appendix B2.c Potentiometric Surface in Unconsolidated Layer at Big Meadows Wetland on 8-12-97.



Contours Indicate Two Foot Change.
Hach Marks Indicate Downhill Direction.

— — — Potentiometric Surface in Unconsolidated Layer
——— Potentiometric Surface in Peat Layer

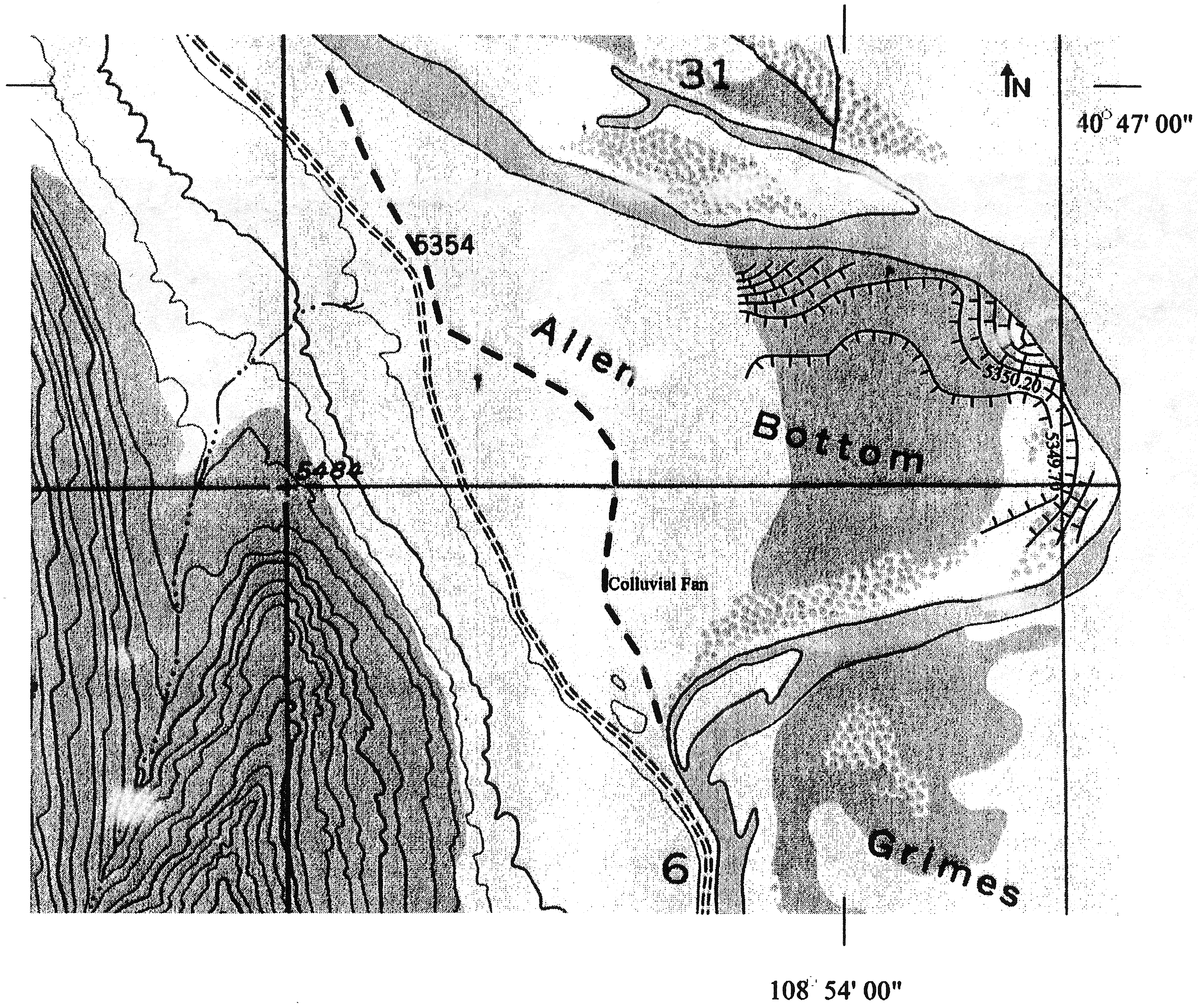
Appendix B.2d Potentiometric Surface in Unconsolidated Layer at Big Meadows Wetland on 9-27-97.



Contours Indicate Two Foot Change.
Hach Marks Indicate Downhill Direction.

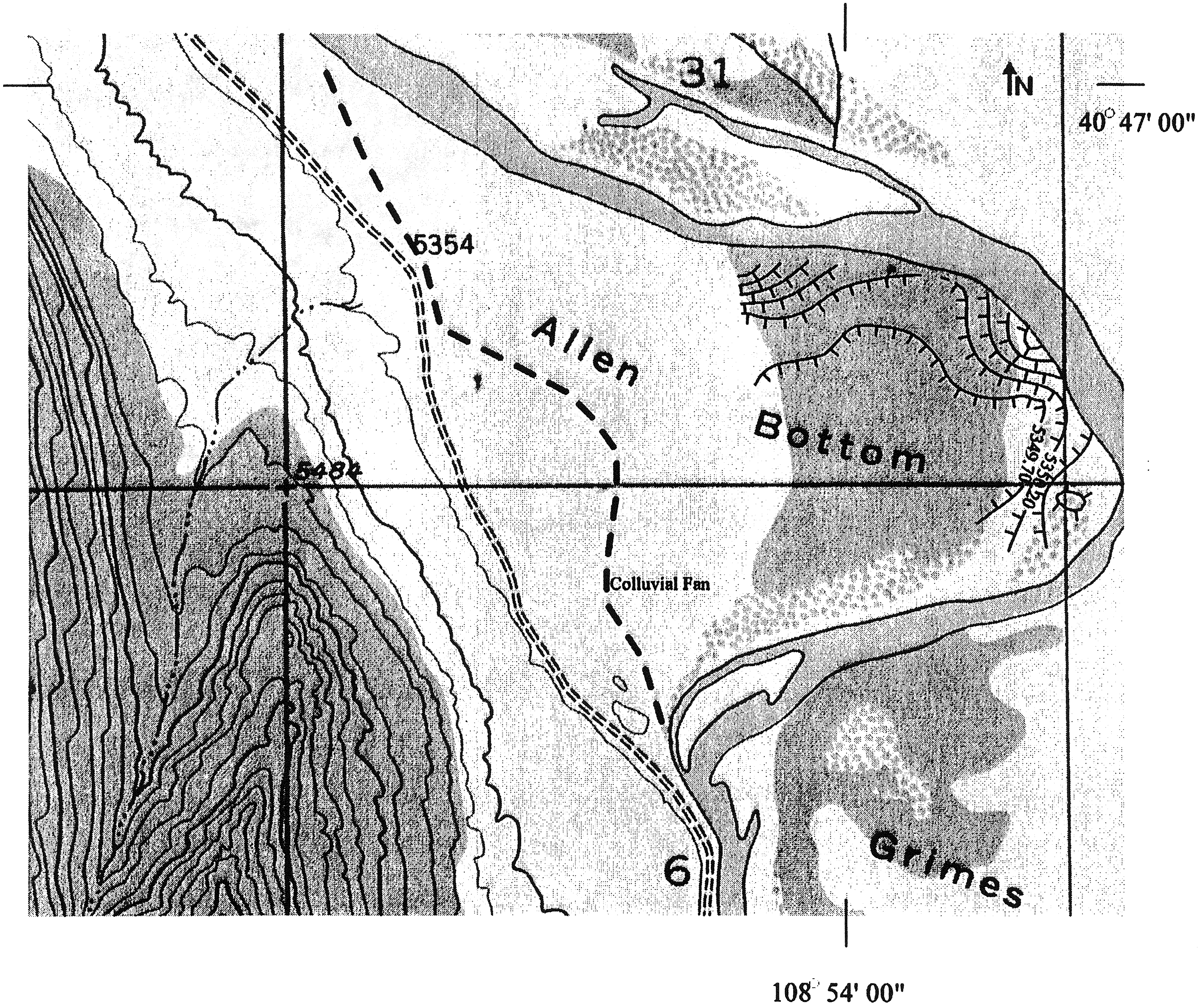
— — — Potentiometric Surface in Unconsolidated Layer
———— Potentiometric Surface in Peat Layer

Appendix B.3a Potentiometric Surface at Allen Bottom Wetland on 5-03-97.



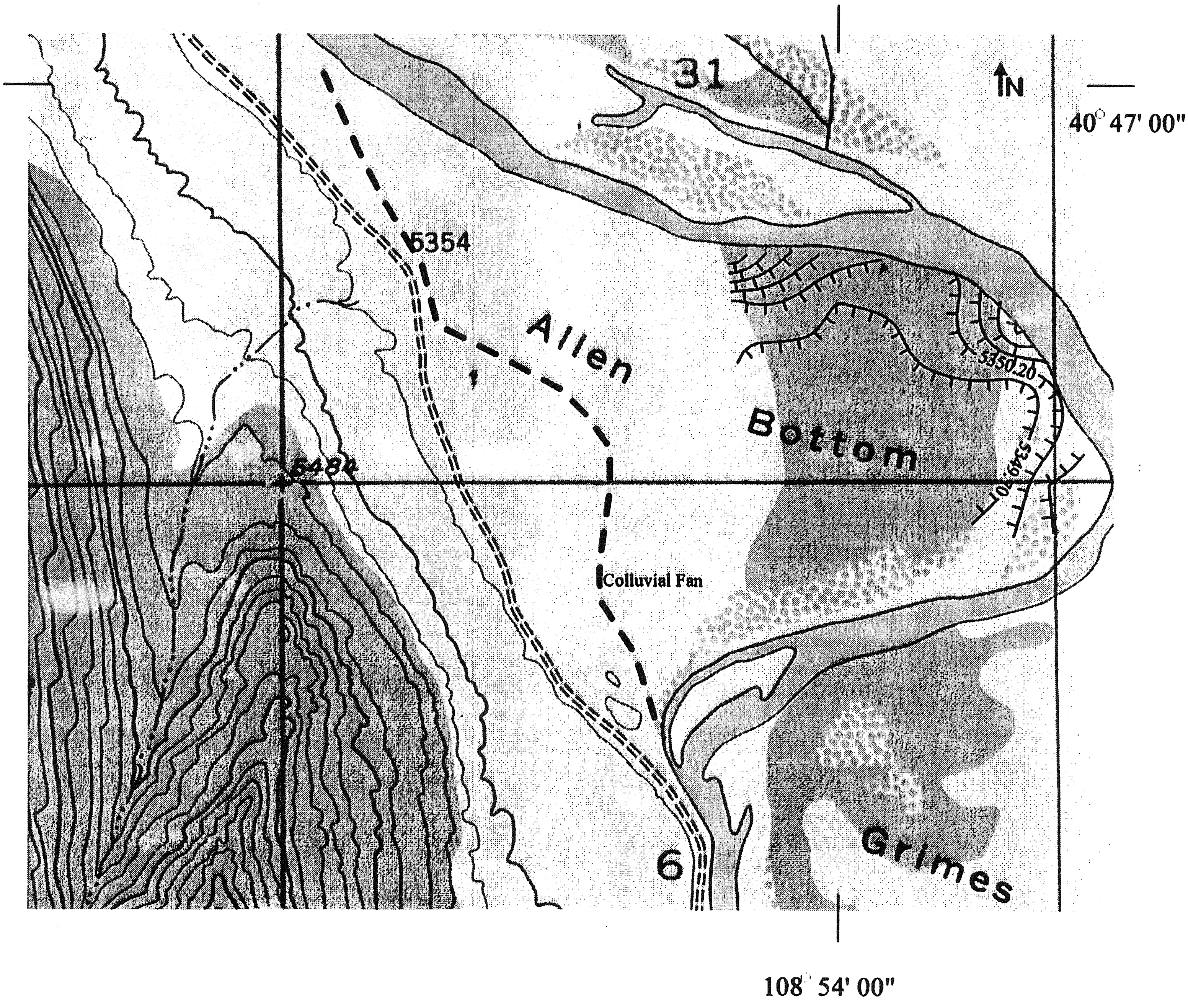
Contours Indicate 0.5 Foot Change. Hack Mark dicate Downhill Direction.

Appendix B.3b Potentiometric Surface at Allen Bottom Wetland on 5-21-97



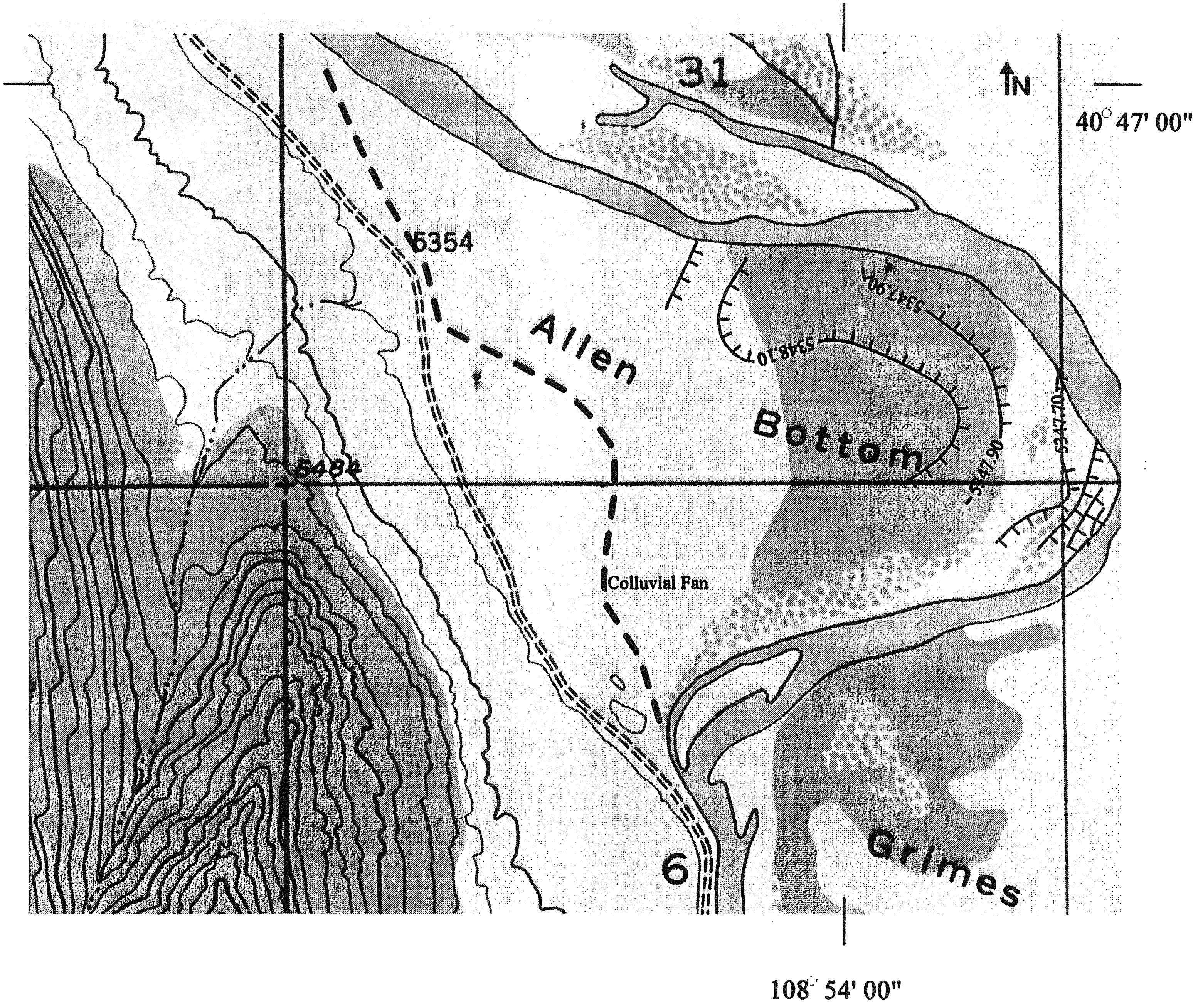
Contours Indicate 0.5 Foot Change. Hack Marks Indicate Downhill Direction.

Appendix B.3c Potentiometric Surface at Allen Bottom Wetland on 6-05-97.



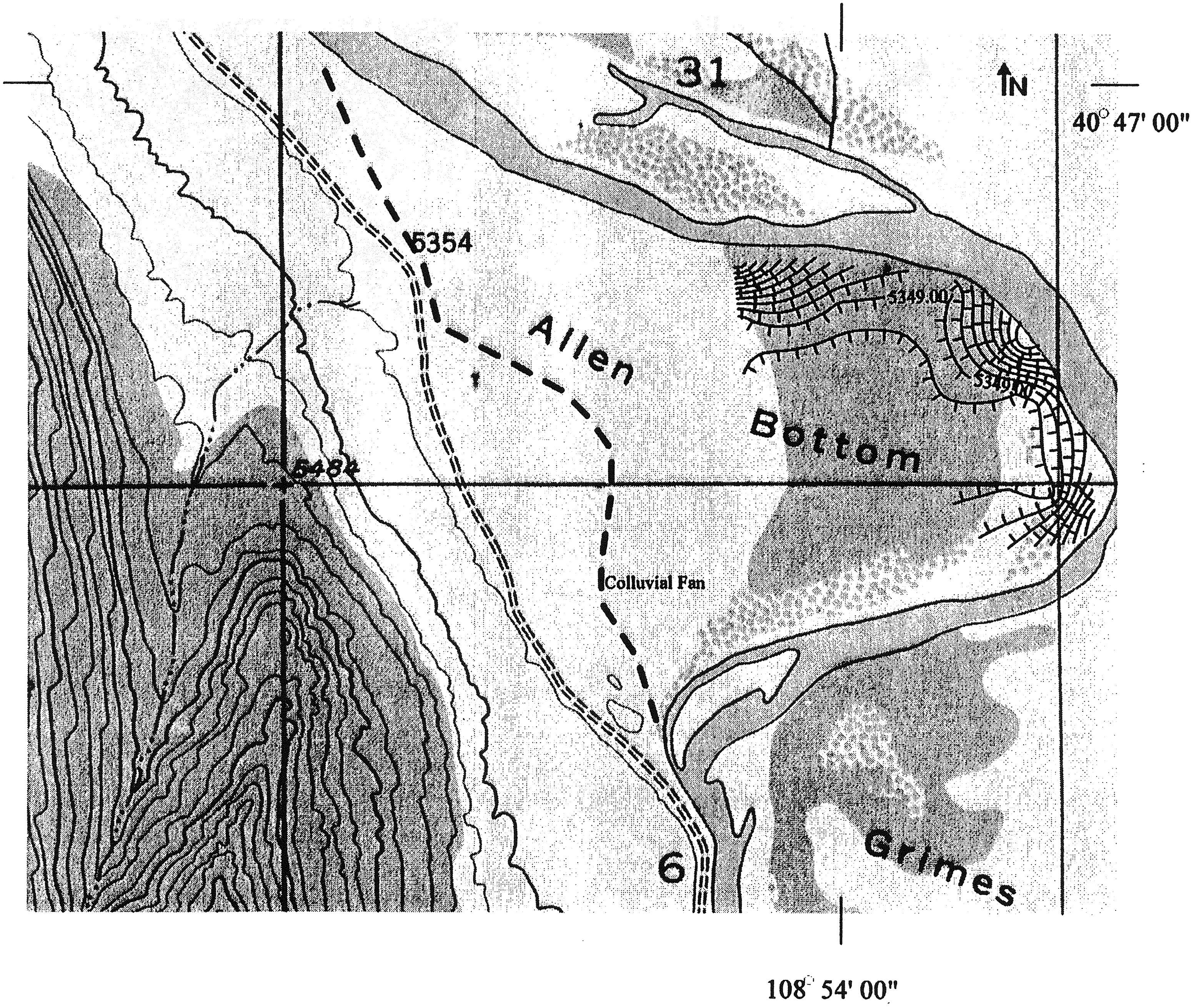
Contours Indicate 0.5 Foot Change. Hack Mark dicate Downhill Direction.

Appendix B.3d Potentiometric Surface at Allen Bottom Wetland on 7-22-97



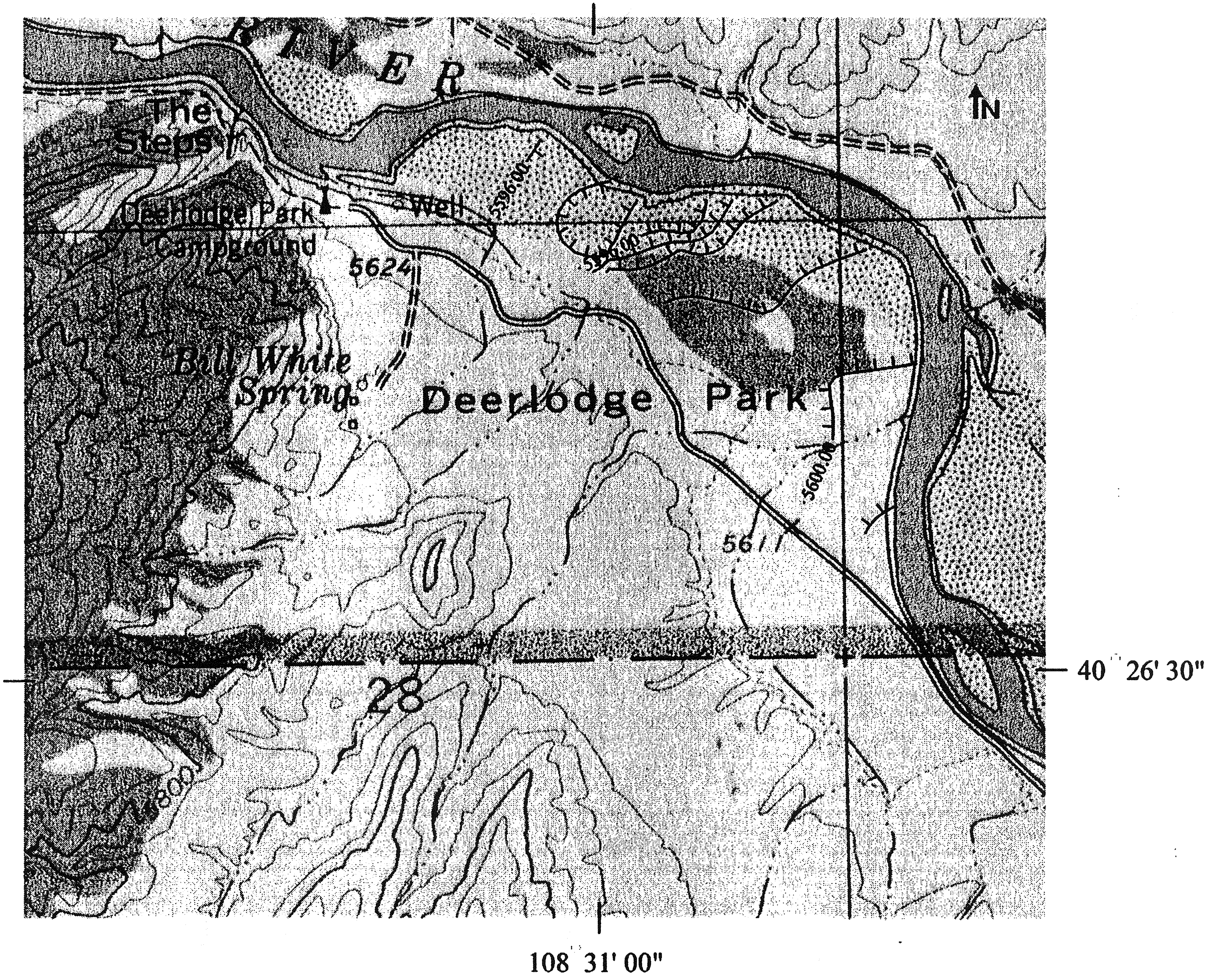
Contours Indicate 0.2 Foot Change. Hack Marks Indicate Downhill Direction.

Appendix B.3e Potentiometric Surface at Allen Bottom Wetland on 10-31-97



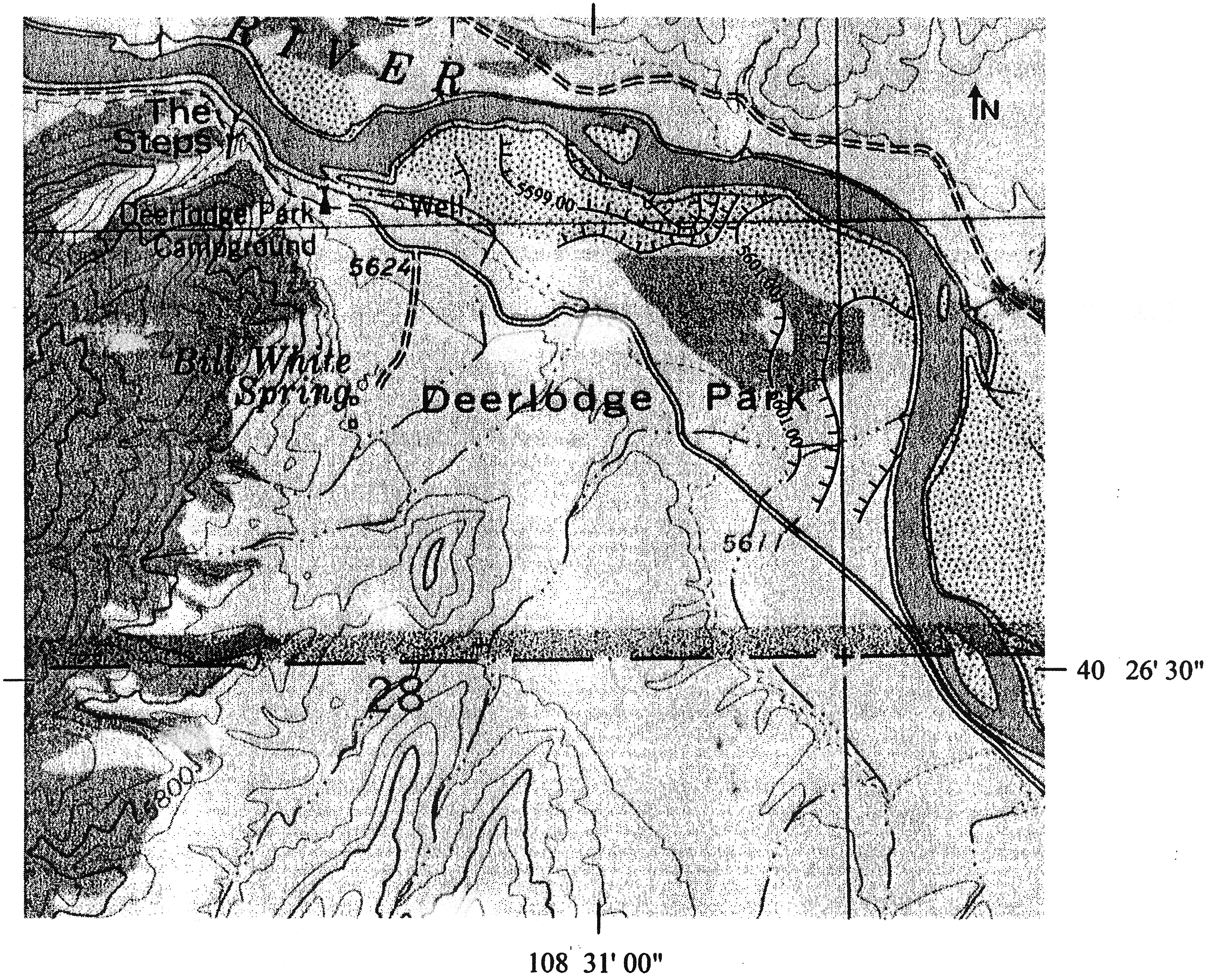
Contours Indicate 0.5 Foot Change. Hack Marks licate Downhill Direction.

Appendix B.4a Potentiometric Surface at Deerlodge Wetland on 4-18-97.



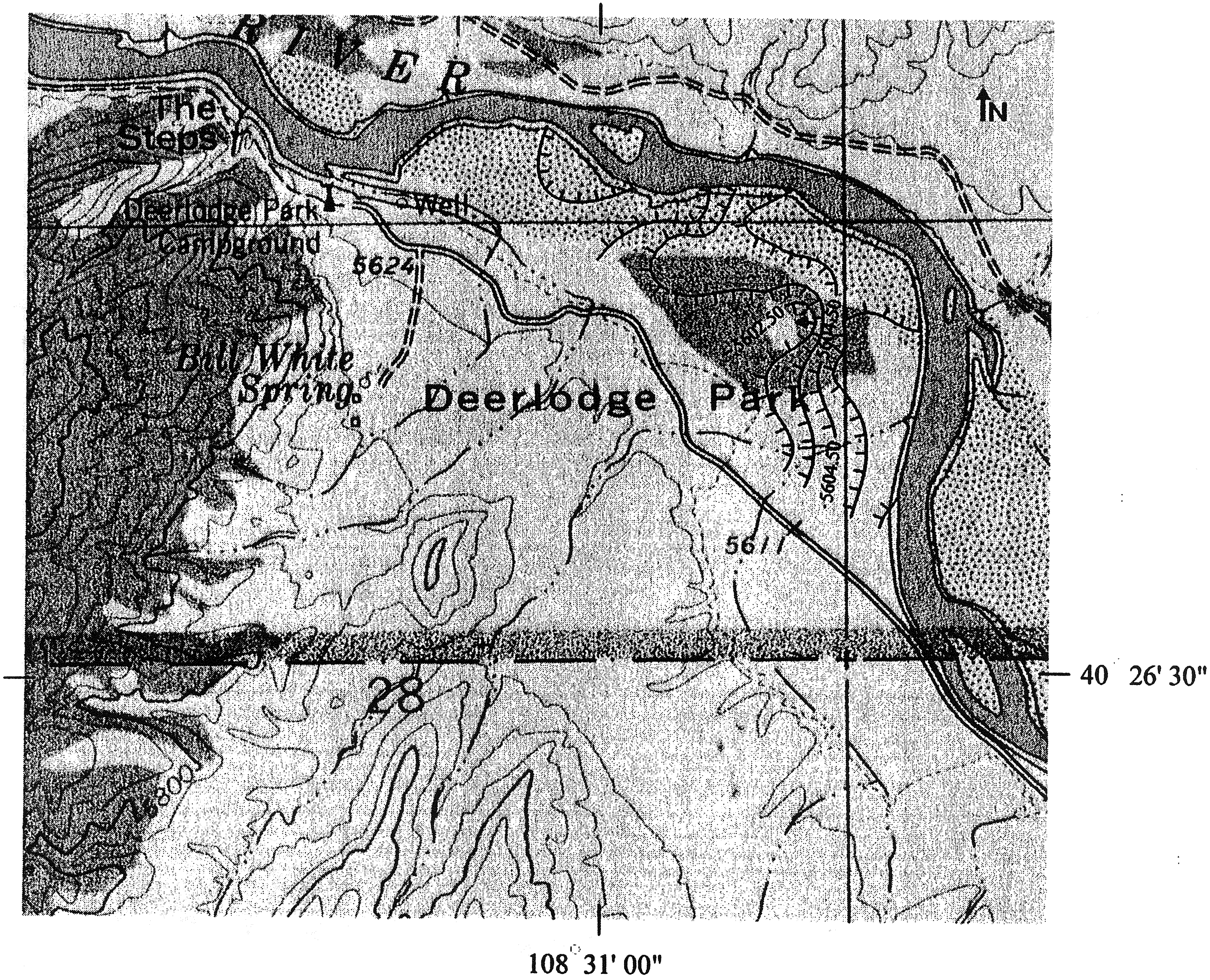
Contours Indicate One Foot Change. Hach Marks Indicate Downhill Direction.

Appendix B.4b Potentiometric Surface at Deerlodge Wetland on 5-03-97.



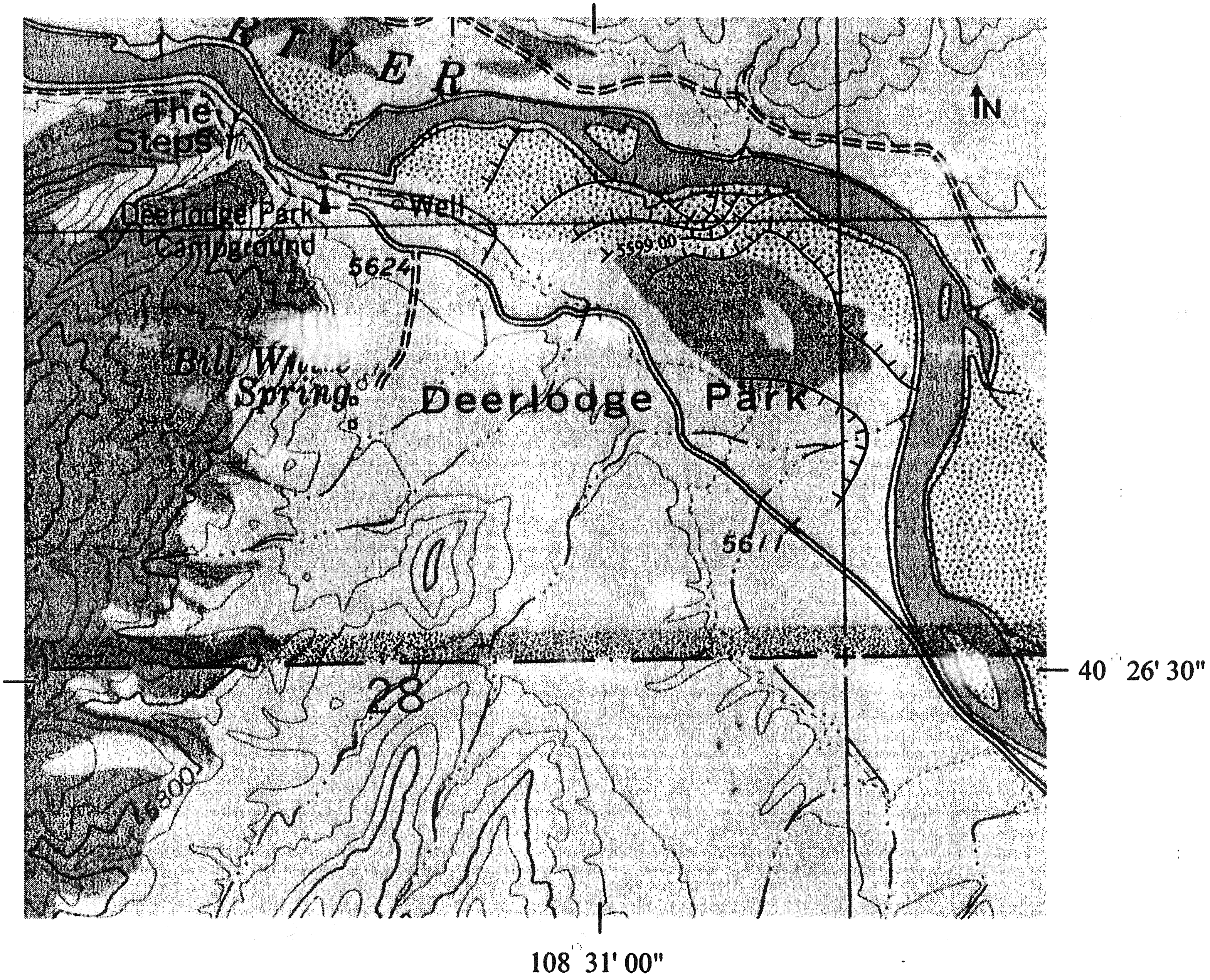
Contours Indicate One Foot Change. Hach Marks Indicate Downhill Direction.

Appendix B.4c Potentiometric Surface at Deerlodge Wetland on 5-20-97.



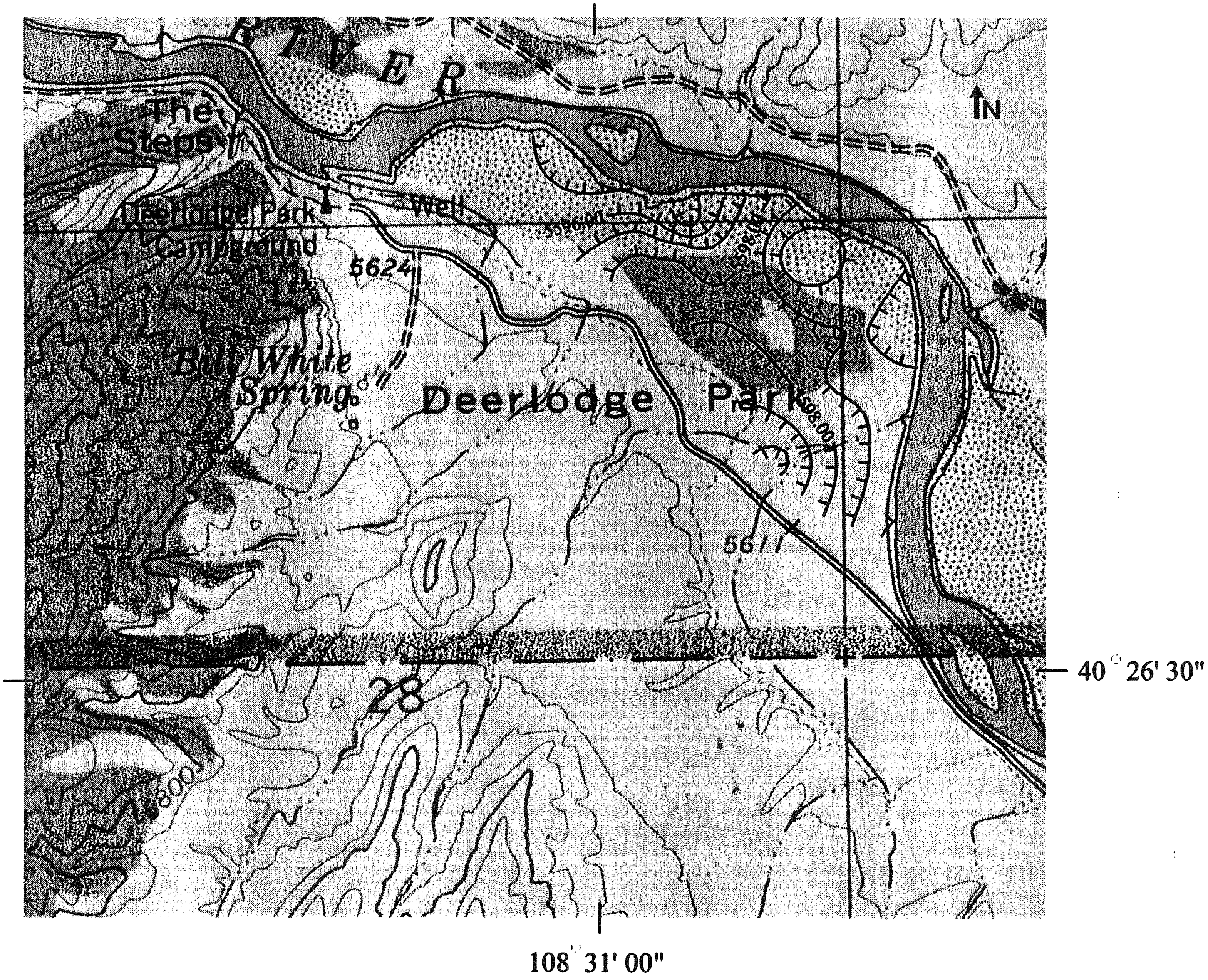
Contours Indicate One Foot Change. Hach Marks Indicate Downhill Direction.

Appendix B.4d Potentiometric Surface at Deerlodge Wetland on 7-09-97.



Contours Indicate One Foot Change. Hach Marks Indicate Downhill Direction.

Appendix B.4e Potentiometric Surface at Deerlodge Wetland on 11-01-97.



Contours Indicate One Foot Change. Hach Marks Indicate Downhill Direction.

DILLON 1 E, COLORADO

Station Metadata

From NCDC Station Historical Listing for NWS Cooperative Network
ObsTyp: t-Temperature-1, p-Daily precip-2, w-(blank), s-(blank), e-Evap-5
h-Hourly precip - 6 0.01" Universal, or - 7 0.10" Fisher-Porter
U - Observed, but beginning date is uncertain

Count	Number (Coop)	Station Name (From NCDC listing)	Lat ddmm	Long dddmm	Elev ftx10	Start yy mm	ObsTyp tpwseh	End yy mm
338	052281-2	DILLON 1 S	3936	10603	890	48 08	UU	61 06
339	052281-2	DILLON	3937	10604	879	61 06	UU	64 01
340	052281-2	DILLON 1 E	3938	10602	908	64 01	UU	75 01
341	052281-2	DILLON 1 E	3938	10602	908	75 01	12	82 01
342	052281-2	DILLON 1 E	3938	10602	906	82 01	12	90 01
343	052281-2	DILLON 1 E	3938	10602	906	90 01	12	99 99

Statistics by element

(From WRCC data archives)
Last Compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers are total Number of observations

STATION	START	END	PRECP	SNWFL	SNWDP	TMAX	TMIN	TOBS	EVAP	WNDMV
52281	19090502	19961230	31531	31257	18254	31218	31176	17196	0	0

STATION - NCDC COOP Station number
START - First Date in record
END - Last Date in record (when last compiled)
PRECP - Precipitation
SNWFL - Snowfall
SNWDP - Snow depth
TMAX - Daily Max. Temperature
TMIN - Daily Min. Temperature
TOBS - Temperature at Observation time
EVAP - Evaporation
WNDMV - Wind Movement

Statistics by observation

(From WRCC data archives)
Last compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers represent one day and one day is considered present if any element is reported.

STATION	NAME	START	END	POSBL	PRSNT	LNGPR	MISSG	LNGMS
52281	DILLON 1 E	19090502	19961230	32021	31589	10439	432	212

STATION - NCDC COOP Station number
NAME - Most recent name in NCDC history file
START - First Date in record
END - Last Date in record (when last compiled)
POSBL - Possible number of observations between START and END date
PRSNT - Number of days present in record
LNGPR - Largest number of consecutive observations
MISSG - Total number of missing days (no observation)
LNGMS - Largest number of consecutive missing observations

Appendix C.1a Dillon 1E Station Metadata. Reprinted From Western Regional Climate Center.

DILLON 1 E, COLORADO (052281)

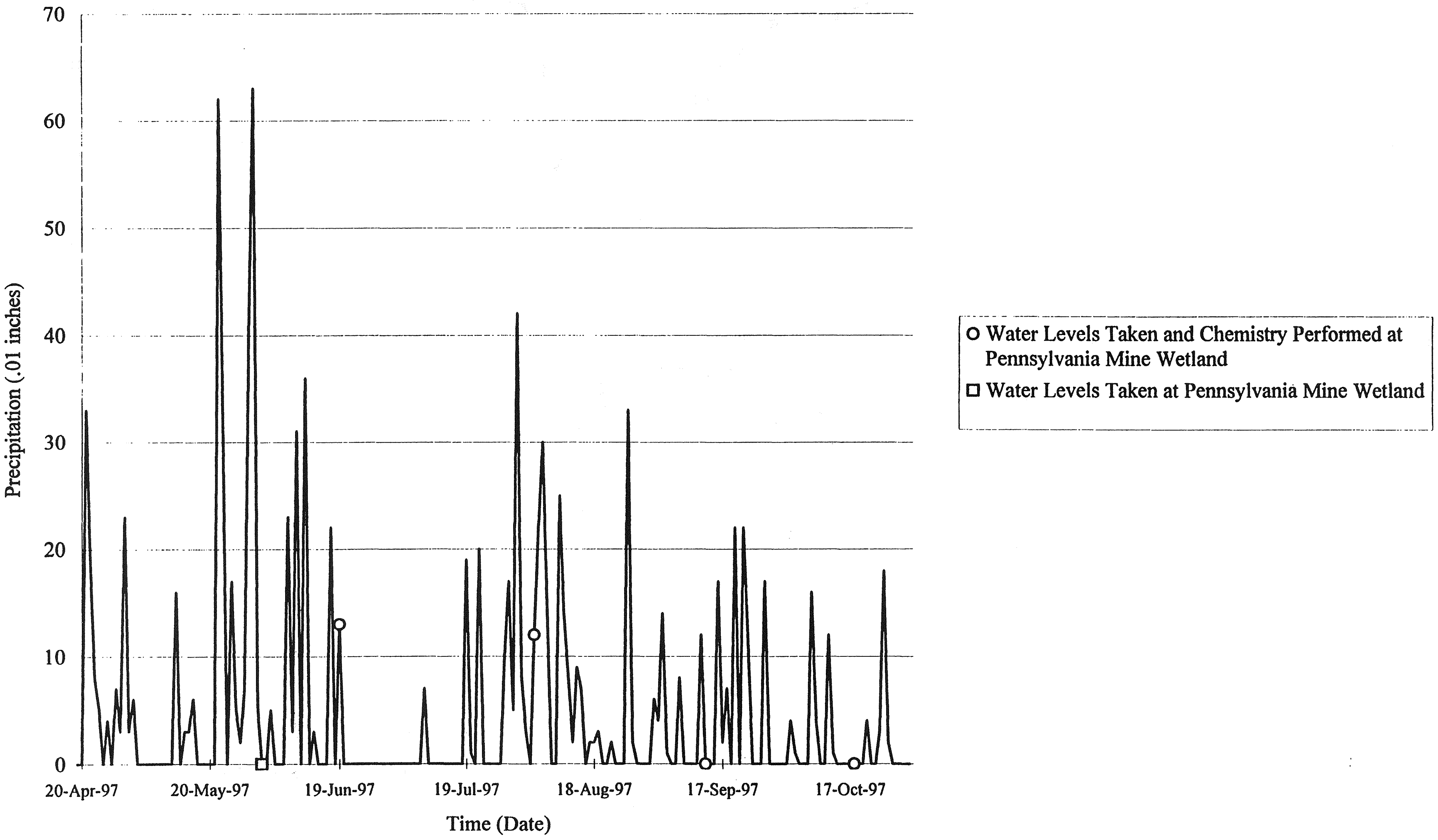
Period of Record Monthly Climate Summary

Period of Record : 5/ 2/1909 to 1/31/1998

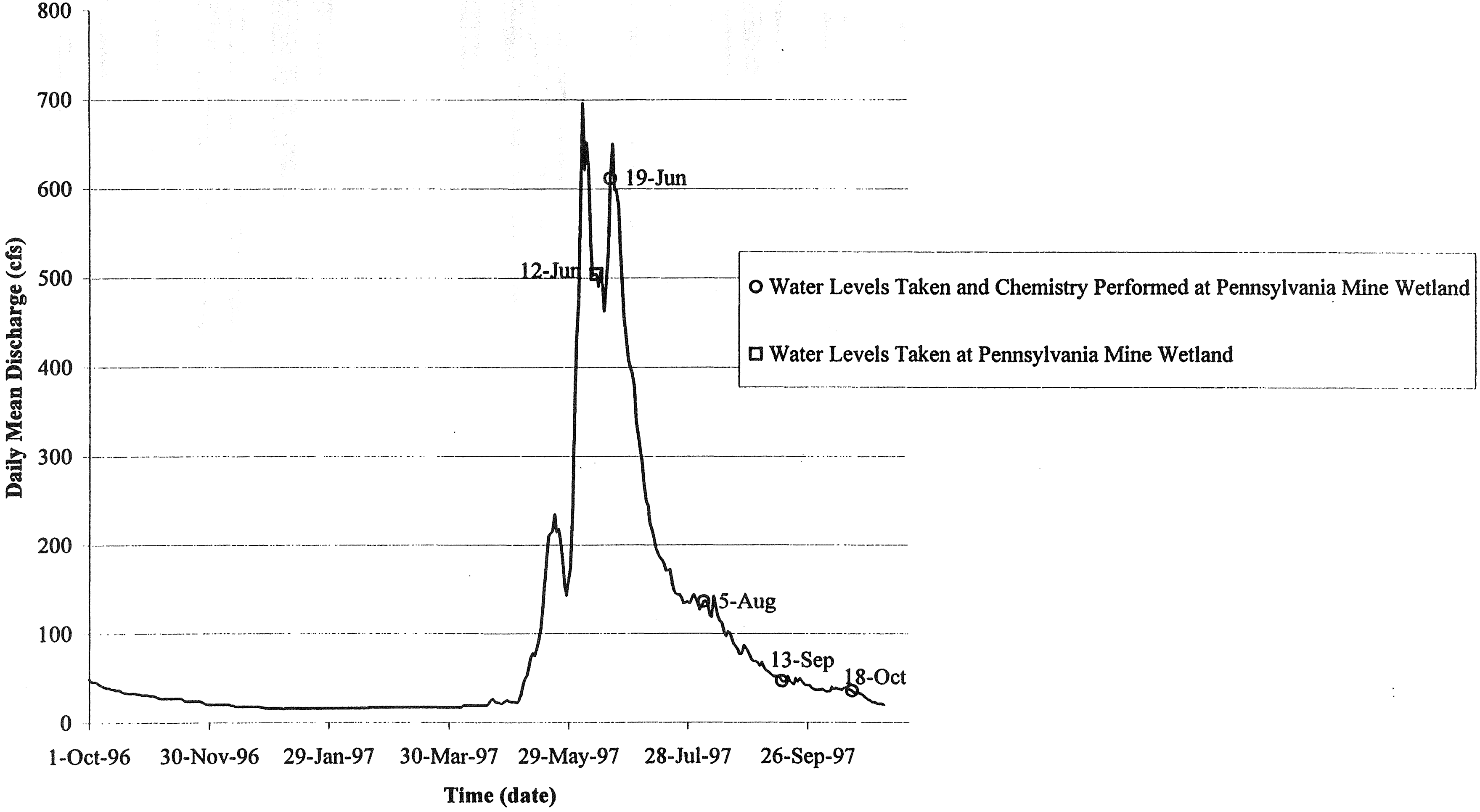
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	31.4	34.2	38.7	47.6	58.4	68.9	73.9	72.5	66.3	55.5	40.8	32.8	51.8
Average Min. Temperature (F)	-1.7	1.1	7	17.2	25.5	31.1	37	35.6	28.5	19.9	9.6	1	17.7
Average Total Precipitation (in.)	1.1	1.2	1.52	1.65	1.46	1.12	1.84	1.7	1.33	1.06	1	1.13	16.11
Average Total SnowFall (in.)	18.6	19.4	23	18.7	7.7	0.8	0	0	1.7	7.8	15.3	18.1	131.2
Average Snow Depth (in.)	9	11	9	3	0	0	0	0	0	0	2	6	3

Appendix C.1b Dillon 1E Monthly Climate Summary. Reprinted From Western Regional Climate Center.

Appendix C.1c Precipitation at Dillon 1E Station, #52281, April 1997 - October 1997.



Appendix C.1d Snake River Daily Mean Discharge (cfs). Oct. 1996 - Nov. 1997.
Snake River near Montezuma, CO Station # 09047500.



GRAND LAKE 1 NW, COLORADO

Station Metadata

From NCDC Station Historical Listing for NWS Cooperative Network
ObsTyp: t-Temperature-1, p-Daily precip-2, w-(blank), s-(blank), e-Evap-5
h-Hourly precip - 6 0.01" Universal, or - 7 0.10" Fisher-Porter
U - Observed, but beginning date is uncertain

Count	Number (Coop)	Station Name (From NCDC listing)	Lat ddmm	Long dddmm	Elev ftx10	Start yy mm	ObsTyp tpwseh	End yy mm
546	053496-2	GRAND LAKE 1 NW	4016	10550	839	48 08	UU	49 08
547	053496-2	GRAND LAKE 1 NW	4016	10550	859	49 08	UU	65 08
548	053496-2	GRAND LAKE 1 NW	4016	10550	868	65 09	UU	79 05
549	053496-2	GRAND LAKE 1 NW	4016	10550	872	79 05	UU	99 99

Statistics by element

(From WRCC data archives)
Last Compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers are total Number of observations

STATION	START	END	PRECP	SNWFL	SNWDP	TMAX	TMIN	TOBS	EVAP	WNDMV
53496	19480801	19961230	17651	17487	17199	17482	17478	17342	0	0

STATION - NCDC COOP Station number
START - First Date in record
END - Last Date in record (when last compiled)
PRECP - Precipitation
SNWFL - Snowfall
SNWDP - Snow depth
TMAX - Daily Max. Temperature
TMIN - Daily Min. Temperature
TOBS - Temperature at Observation time
EVAP - Evaporation
WNDMV - Wind Movement

Statistics by observation

(From WRCC data archives)
Last compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers represent one day and one day is considered present if any element is reported.

STATION	NAME		START	END	POSBL	PRSNT	LNGPR	MISSG	LNGMS
53496	GRAND LAKE 1 NW		19480801	19961230	17685	17685	17684	0	0

STATION - NCDC COOP Station number
NAME - Most recent name in NCDC history file
START - First Date in record
END - Last Date in record (when last compiled)
POSBL - Possible number of observations between START and END date
PRSNT - Number of days present in record
LNGPR - Largest number of consecutive observations
MISSG - Total number of missing days (no observation)
LNGMS - Largest number of consecutive missing observations

Appendix C.2a Grand Lake 1NW Station Metadata. Reprinted From Western Regional Climate Center.

GRAND LAKE 1 NW, COLORADO (053496)

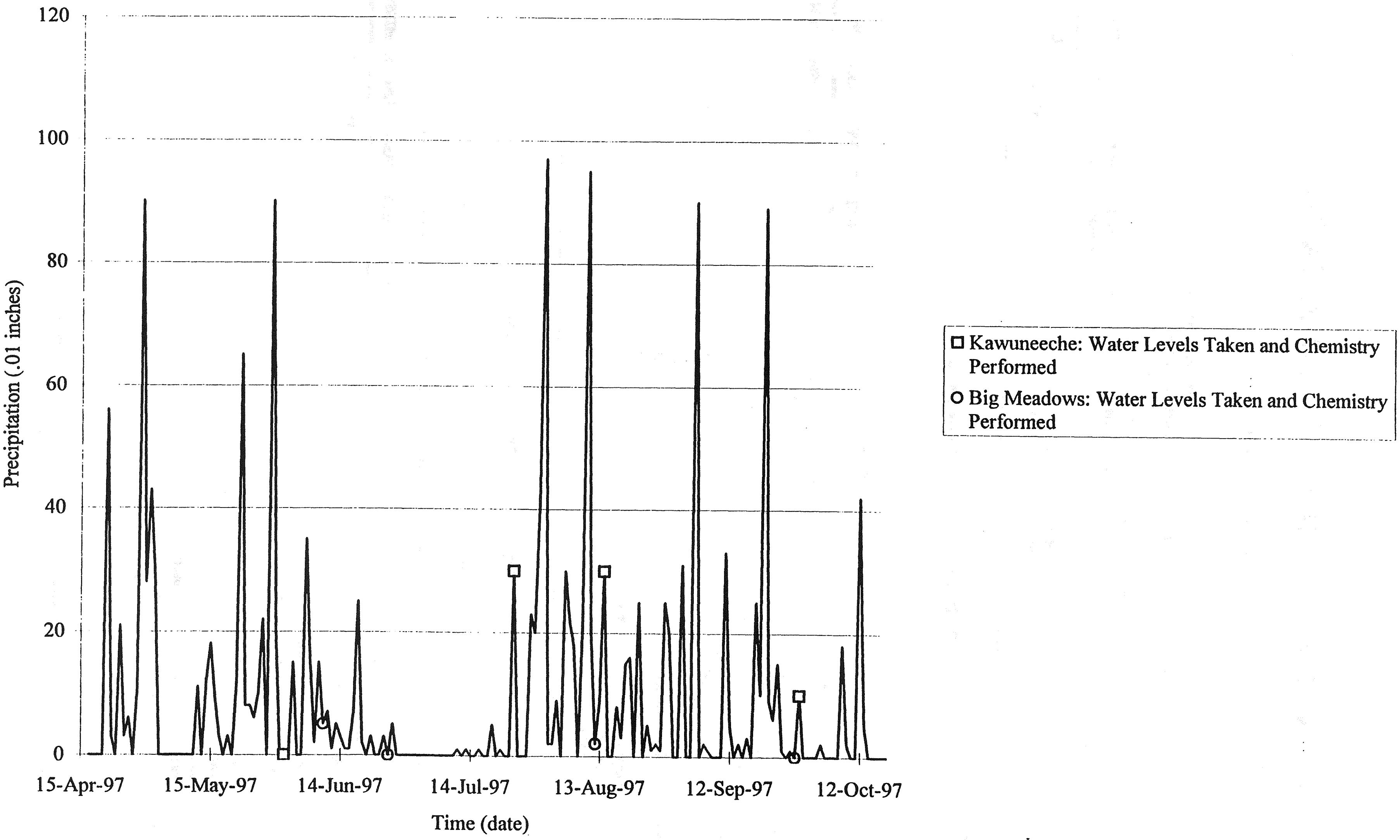
Period of Record Monthly Climate Summary

Period of Record : 8/ 1/1948 to 2/28/1998

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	30.8	34.8	40.3	48.7	59.2	70	75.3	73.7	67.4	56.6	40.2	31.9	52.5
Average Min. Temperature (F)	1.8	3.7	10.1	18.7	26.9	32.6	37.3	36.2	29.5	21.7	11.7	3.5	19.5
Average Total Precipitation (in.)	1.68	1.43	1.54	1.88	1.94	1.6	2.07	2.12	1.68	1.28	1.33	1.64	20.18
Average Total SnowFall (in.)	29.7	22.4	19.5	16.8	4.7	0.4	0	0	1.1	5.9	19	27.2	146.7
Average Snow Depth (in.)	19	25	25	12	1	0	0	0	0	0	3	11	8

Appendix C.2b Grand Lake 1NW Monthly Climate Summary. Reprinted From Western Regional Climate Center.

Appendix C.2c Precipitation at Grand Lake 1NW Station, # 53496, April 1997 - October 1997.



BROWNS PARK REFUGE, COLORADO

Station Metadata

From NCDC Station Historical Listing for NWS Cooperative Network
ObsTyp: t-Temperature-1, p-Daily precip-2, w-(blank), s-(blank), e-Evap-5
h-Hourly precip - 6 0.01" Universal, or - 7 0.10" Fisher-Porter
U - Observed, but beginning date is uncertain

Count	Number (Coop)	Station Name (From NCDC listing)	Lat ddmm	Long dddmm	Elev ftx10	Start yy mm	ObsTyp tpwseh	End yy mm
143	051017-2	BROWNS PARK REFUGE	4048	10855	535	66 04	UU	85 12
144	051017-2	BROWNS PARK REFUGE	4048	10855	535	85 12	12	99 99

Statistics by element

(From WRCC data archives)
Last Compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers are total Number of observations

STATION	START	END	PRECP	SNWFL	SNWDP	TMAX	TMIN	TOBS	EVAP	WNDMV
51017	19660407	19961230	11127	9684	9267	10969	10947	10931	0	0

STATION - NCDC COOP Station number
START - First Date in record
END - Last Date in record (when last compiled)
PRECP - Precipitation
SNWFL - Snowfall
SNWDP - Snow depth
TMAX - Daily Max. Temperature
TMIN - Daily Min. Temperature
TOBS - Temperature at Observation time
EVAP - Evaporation
WNDMV - Wind Movement

Statistics by observation

(From WRCC data archives)
Last compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers represent one day and one day is considered present if any element is reported.

STATION	NAME	START	END	POSBL	PRSNT	LNGPR	MISSG	LNGMS
51017	BROWNS PARK REFUGE	19660407	19961230	11227	11151	8157	76	31

STATION - NCDC COOP Station number
NAME - Most recent name in NCDC history file
START - First Date in record
END - Last Date in record (when last compiled)
POSBL - Possible number of observations between START and END date
PRSNT - Number of days present in record
LNGPR - Largest number of consecutive observations
MISSG - Total number of missing days (no observation)
LNGMS - Largest number of consecutive missing observations

Appendix C.3a Browns Park Refuge Station Metadata. Reprinted From Western Regional Climate Center.

BROWNS PARK REFUGE, COLORADO (051017)

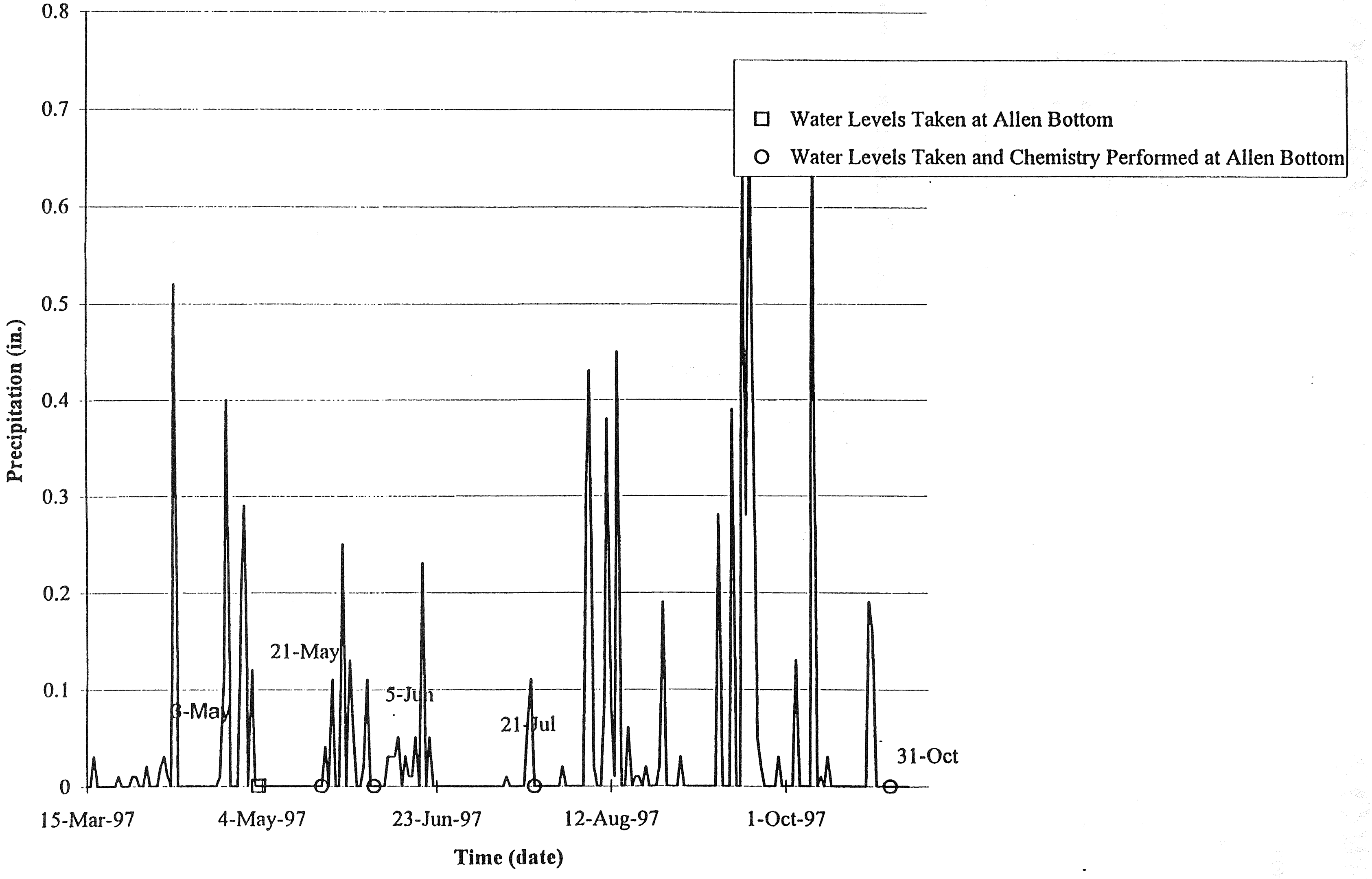
Period of Record Monthly Climate Summary

Period of Record : 4/ 7/1966 to 7/31/1997

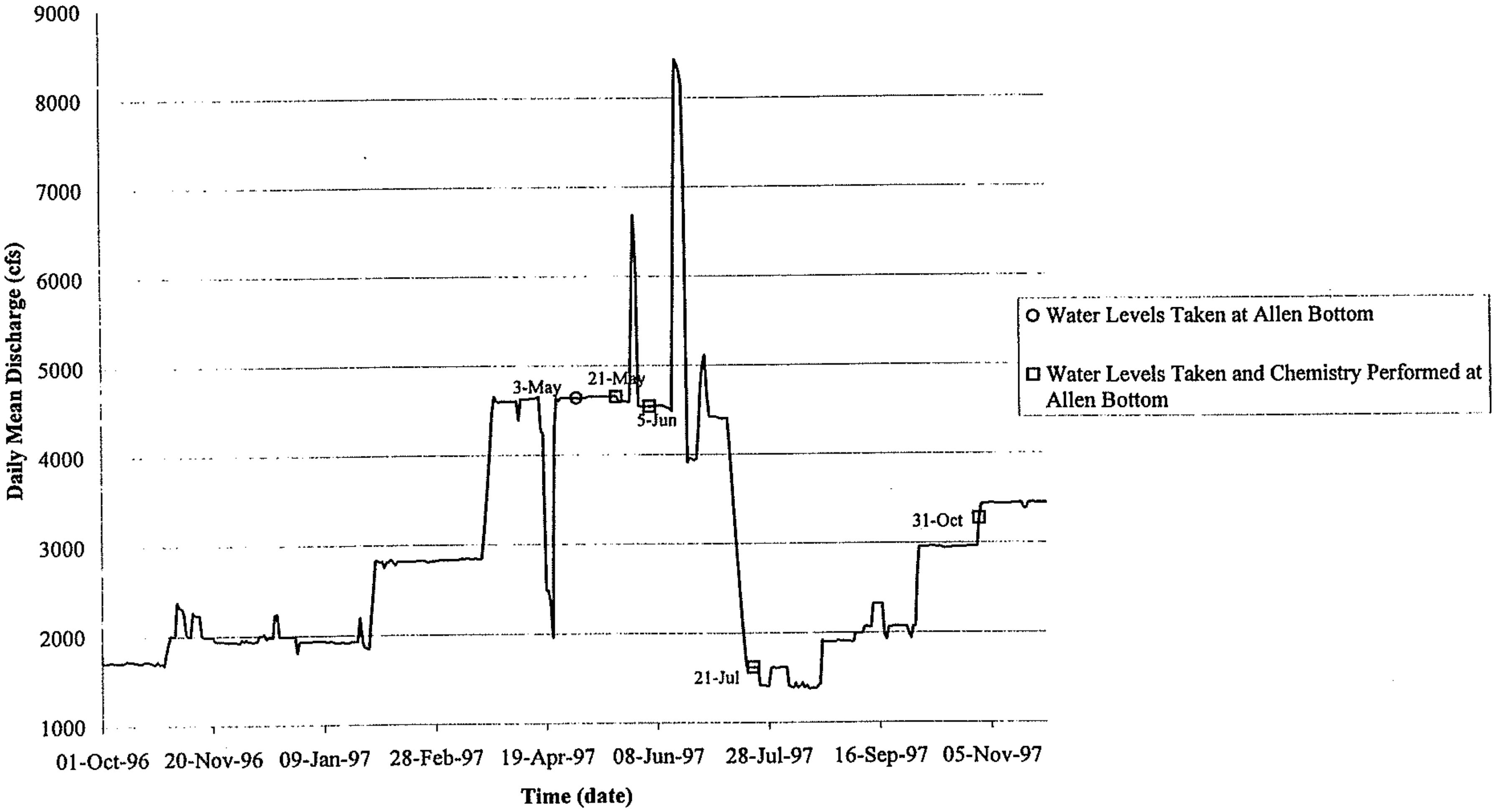
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	38.4	44.2	52.2	61.7	71.9	82.6	89.1	87.6	78.4	65.5	49.1	39.6	63.4
Average Min. Temperature (F)	7.6	13	21.2	27.8	35.6	41.8	46.7	44.7	36.1	26.3	17.8	9.1	27.3
Average Total Precipitation (in.)	0.36	0.43	0.69	0.82	1.06	0.73	0.68	0.58	0.89	1.17	0.58	0.41	8.4
Average Total SnowFall (in.)	2.8	3.9	1.4	1.1	0.3	0	0	0	0	0.9	1.9	5.7	18
Average Snow Depth (in.)	0	0	0	0	0	0	0	0	0	0	0	1	0

Appendix C.3b Browns Park Refuge Monthly Climate Center. Reprinted From Western Regional Climate Center.

Appendix C.3c Precipitation at Browns Park National Wildlife Refuge Station, #51017, March 1997 - November 1997.



Appendix C.3d Green River Daily Mean Discharge for Water Year. Oct. 1996 - Sept. 1997.
Green River near Greendale, UT Station # 0924500.



DINOSAUR NATL MONUMENT, COLORADO

Station Metadata

From NCDC Station Historical Listing for NWS Cooperative Network
ObsTyp: t-Temperature-1, p-Daily precip-2, w-(blank), s-(blank), e-Evap-5
h-Hourly precip - 6 0.01" Universal, or - 7 0.10" Fisher-Porter
U - Observed, but beginning date is uncertain

Count	Number (Coop)	Station Name (From NCDC listing)	Lat ddmm	Long dddmm	Elev ftx10	Start yy mm	ObsTyp tpwseh	End yy mm
344	052286-2	DINOSAUR NATL MONUMENT	4014	10858	592	65 06	12 6	88 09
345	052286-2	DINOSAUR NATL MONUMENT	4014	10858	592	88 09	12 7	99 99

Statistics by element

(From WRCC data archives)
Last Compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers are total Number of observations

STATION	START	END	PRECP	SNWFL	SNWDP	TMAX	TMIN	TOBS	EVAP	WNDMV
52286	19650601	19961230	11431	11393	11062	11435	11428	10870	0	0

STATION - NCDC COOP Station number
START - First Date in record
END - Last Date in record (when last compiled)
PRECP - Precipitation
SNWFL - Snowfall
SNWDP - Snow depth
TMAX - Daily Max. Temperature
TMIN - Daily Min. Temperature
TOBS - Temperature at Observation time
EVAP - Evaporation
WNDMV - Wind Movement

Statistics by observation

(From WRCC data archives)
Last compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers represent one day and one day is considered present if any element is reported.

STATION	NAME	START	END	POSBL	PRSNT	LNGPR	MISSG	LNGMS
52286	DINOSAUR NATL MONUMENT	19650601	19961230	11537	11445	6665	92	31

STATION - NCDC COOP Station number
NAME - Most recent name in NCDC history file
START - First Date in record
END - Last Date in record (when last compiled)
POSBL - Possible number of observations between START and END date
PRSNT - Number of days present in record
LNGPR - Largest number of consecutive observations
MISSG - Total number of missing days (no observation)
LNGMS - Largest number of consecutive missing observations

Appendix C.4a Dinosaur National Monument Station Metadata. Reprinted From Western Regional Climate Center.

MAYBELL, COLORADO

Station Metadata

From NCDC Station Historical Listing for NWS Cooperative Network
ObsTyp: t-Temperature-1, p-Daily precip-2, w-(blank), s-(blank), e-Evap-5
h-Hourly precip - 6 0.01" Universal, or - 7 0.10" Fisher-Porter
U - Observed, but beginning date is uncertain

Count	Number (Coop)	Station Name (From NCDC listing)	Lat ddmm	Long dddmm	Elev ftx10	Start yy mm	ObsTyp tpwseh	End yy mm
835	055446-2	MAYBELL	4031	10805	593	58 06	UU	67 09
836	055446-2	MAYBELL	4031	10805	594	67 09	UU	74 10
837	055446-2	MAYBELL	4031	10805	593	77 09	UU	80 09
838	055446-2	MAYBELL	4031	10805	591	83 02		12 99 99

Statistics by element

(From WRCC data archives)
Last Compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers are total Number of observations

STATION	START	END	PRECP	SNWFL	SNWDP	TMAX	TMIN	TOBS	EVAP	WNDMV
55446	19580601	19961230	11656	11361	10757	11479	11472	11316	0	0

STATION - NCDC COOP Station number
START - First Date in record
END - Last Date in record (when last compiled)
PRECP - Precipitation
SNWFL - Snowfall
SNWDP - Snow depth
TMAX - Daily Max. Temperature
TMIN - Daily Min. Temperature
TOBS - Temperature at Observation time
EVAP - Evaporation
WNDMV - Wind Movement

Statistics by observation

(From WRCC data archives)
Last compiled on May 3, 1997
Dates are format of YYYYMMDD. Numbers represent one day and one day is considered present if any element is reported.

STATION	NAME	START	END	POSBL	PRSNT	LNGPR	MISSG	LNGMS
55446	MAYBELL	19580601	19961230	14094	11823	3744	2271	1096

STATION - NCDC COOP Station number
NAME - Most recent name in NCDC history file
START - First Date in record
END - Last Date in record (when last compiled)
POSBL - Possible number of observations between START and END date
PRSNT - Number of days present in record
LNGPR - Largest number of consecutive observations
MISSG - Total number of missing days (no observation)
LNGMS - Largest number of consecutive missing observations

Appendix C.4b Maybell Station Metadata. Reprinted From Western Regional Climate Center.

DINOSAUR NATL MONUMENT, COLORADO (052286)

Period of Record Monthly Climate Summary

Period of Record : 6/ 1/1965 to 2/28/1998

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	32.1	38.8	50	60.7	71.6	83.2	90.2	87.9	77.7	63.2	45.7	33.8	61.3
Average Min. Temperature (F)	9.3	14.6	24.3	31.2	40	48.6	55.8	54	45.1	34.3	22.9	12.1	32.7
Average Total Precipitation (in.)	0.67	0.58	0.96	1.09	1.37	1.09	1.01	0.88	1.19	1.43	0.8	0.67	11.72
Average Total SnowFall (in.)	10.7	7.1	7	4.2	0.8	0.3	0	0	0.3	2	5.3	9.1	46.8
Average Snow Depth (in.)	6	6	2	0	0	0	0	0	0	0	1	3	1

Appendix C.4c Dinosaur National Monument Climate Summary. Reprinted From Western Regional Climate Center.

MAYBELL, COLORADO (055446)

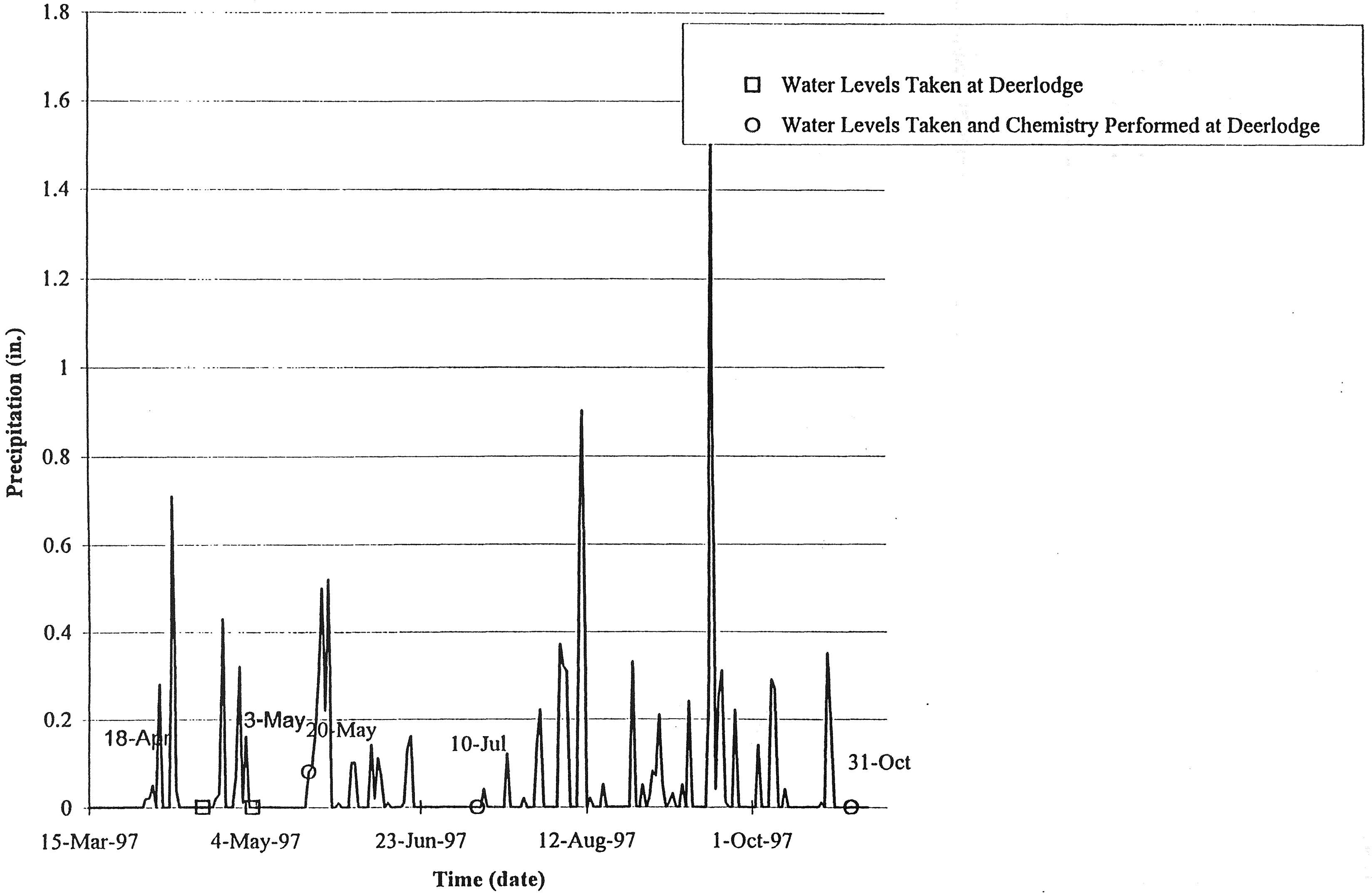
Period of Record Monthly Climate Summary

Period of Record : 6/ 1/1958 to 2/28/1998

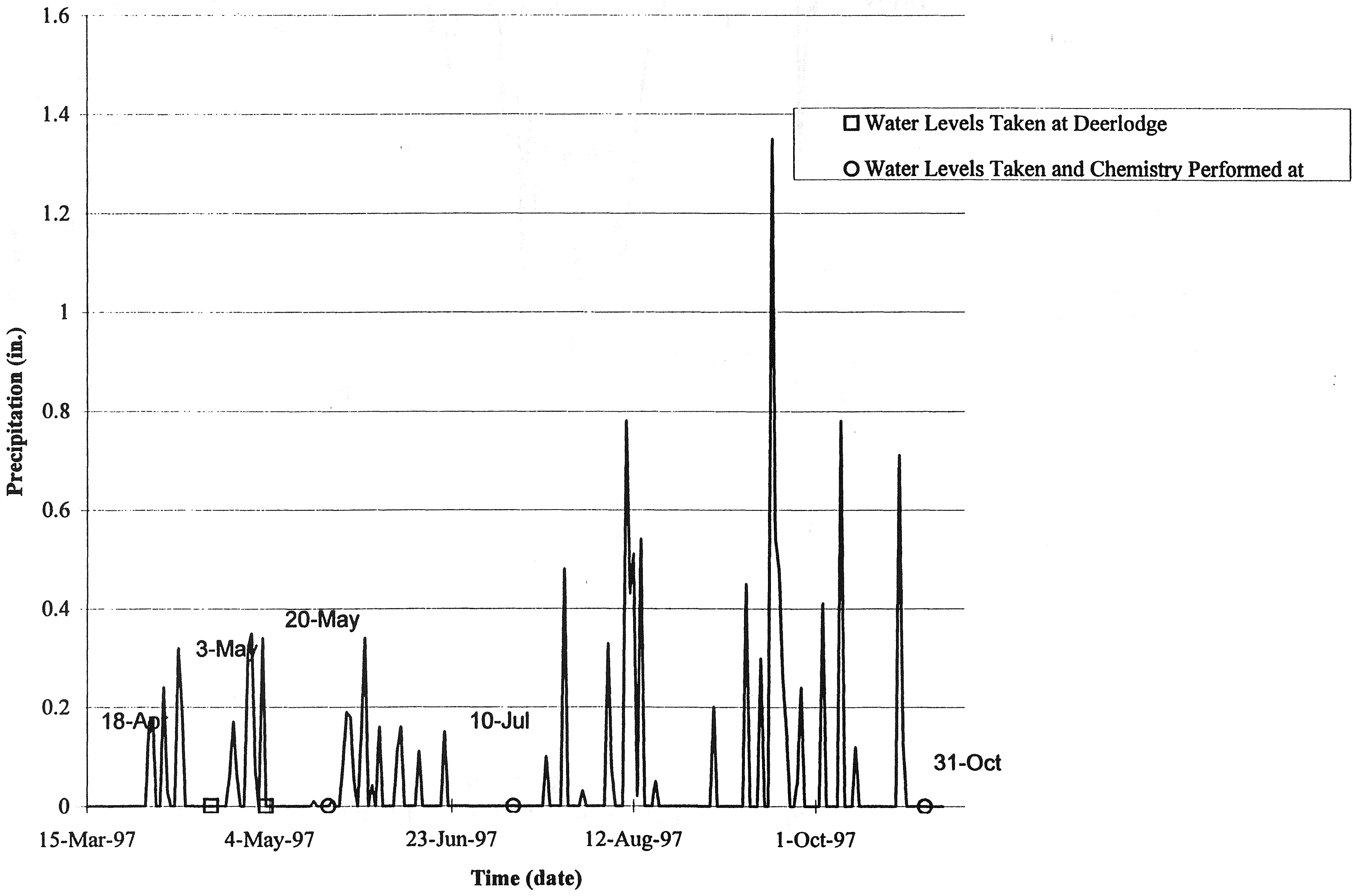
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	32.1	37.6	47.7	59	70.1	79.9	86.8	84.7	74.7	62.7	45.7	34.3	59.7
Average Min. Temperature (F)	1.6	6.7	18	26.2	33.5	40.7	46.5	45.1	36.2	25.2	15.8	4.4	25
Average Total Precipitation (in.)	0.81	0.87	1.01	1.34	1.16	0.99	0.84	0.9	1.25	1.29	1.18	0.94	12.57
Average Total SnowFall (in.)	13	10.9	8.4	4.8	0.9	0.1	0	0	0.6	1.9	10.7	13.2	64.4
Average Snow Depth (in.)	6	5	2	0	0	0	0	0	0	0	1	3	1

Appendix C.4d Maybell Monthly Climate Center. Reprinted From Western Regional Climate Center.

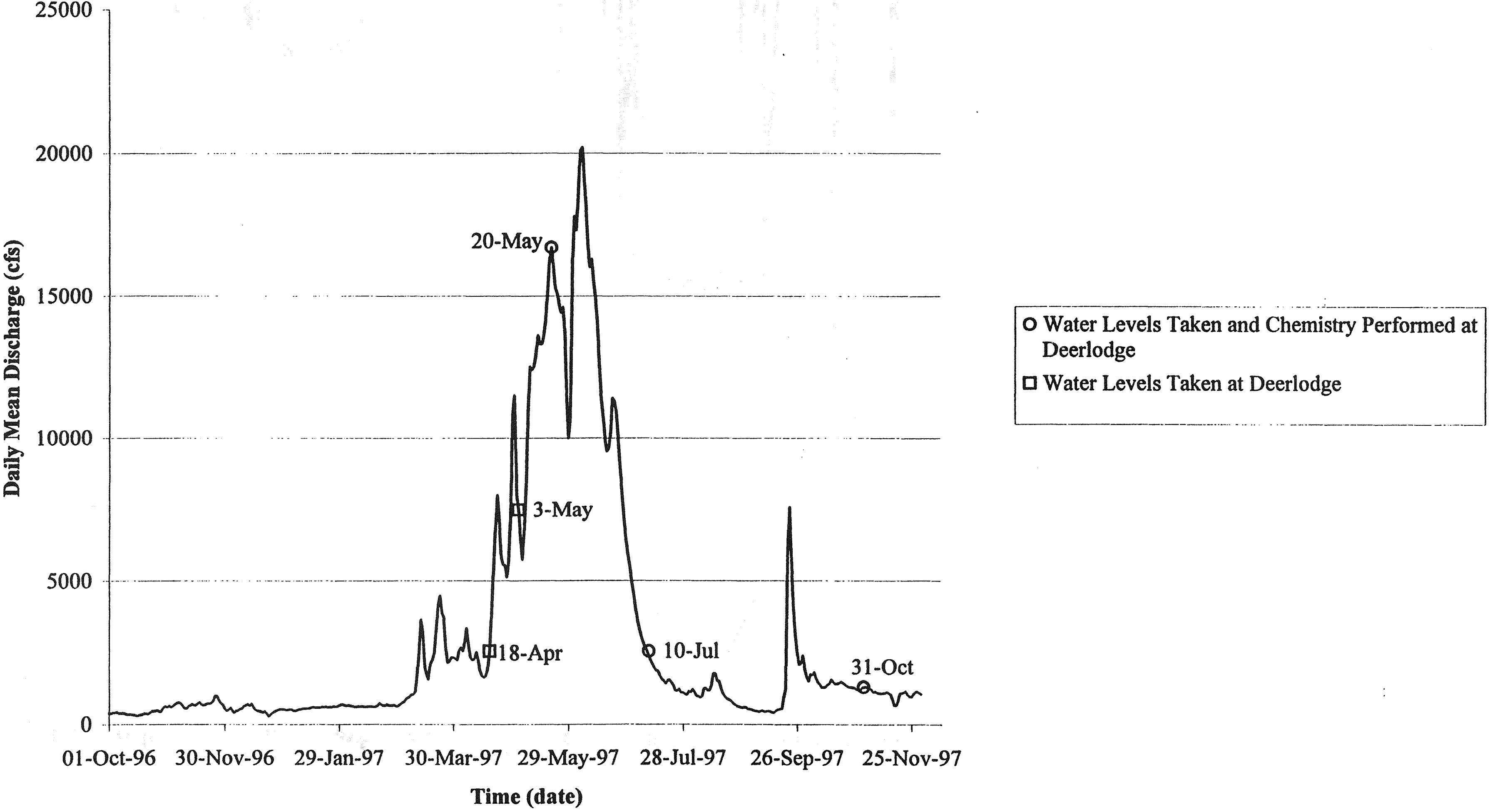
Appendix C.4e Precipitation at Dinosaur National Monument Station, #52286, March 1997 - November 1997.



Appendix C.4f Precipitation at Maybell Station, #55446, March 1997 - November 1997.



Appendix C.4g Yampa River Daily Mean Discharge (cfs) . Oct. 1996 - Nov. 1997.
Yampa River at Deer Lodge, CO Station # 09260050.



	Pennsylvania Mine Unconsolidated				Pennsylvania Mine Peat				Big Meadows Unconsolidated		
	SM	PSM	M	PM	SM	PSM	M	PM	PSM	M	PM
pH	0.0038 (A)	0.00063 (A)	0.0063 (A)	0.0052 (A)	0.0148 (B)	0.0153 (B)	0.0137 (B)	0.0124 (A)	-0.0016 (A)	-0.0022 (A)	-0.0054 (B)
Eh	-0.2841 (A)	-0.4269 (A)	0.4193 (A)	-0.3475 (A)	-0.9754 (B)	-1.0564 (B)	-1.2331 (B)	-0.769 (A)	0.1137 (A)	0.1889 (A)	0.4000 (B)
Dissolved Oxygen	-0.028 (A)	-0.0488 (B)	-0.0373 (B)	-0.0267 (B)	-0.0196 (B)	-0.0496 (C)	-0.0295 (B)	-0.0184 (B)	-0.0263 (A)	-0.0203 (C)	NM
Nitrate	-0.0801 (C)	-0.0098 (A)	0.0093 (A)	0.001 (A)	-0.0495 (A)	0.0158 (A)	-0.0432 (B)	0.0523 (A)	0.0303 (A)	0.0367 (A)	-0.0525 (A)
Chloride	-0.0146 (A)	-0.0312 (A)	0.0025 (A)	0.0068 (A)	-0.0143 (A)	0.0097 (B)	0.0083 (A)	-0.0038 (A)	-0.0243 (B)	-0.0325 (A)	0.0133 (A)
Sulfate	0.3127 (A)	1.1778 (A)	0.1179 (A)	-0.9223 (A)	-1.5896 (A)	-.4072 (A)	-1.3345 (A)	-1.5718 (A)	0.0061 (A)	-0.0881 (A)	0.064 (B)
Dissolved Iron	0.134 (A)	0.2078 (A)	0.2019 (A)	0.1784 (A)	0.1631 (A)	0.2089 (A)	0.2349 (A)	0.1271 (A)	-0.0584 (A)	-0.2219 (B)	-0.1426 (B)
Dissolved Zinc	-0.0798 (A)	-0.043 (A)	-0.051 (A)	-0.1029 (A)	-0.1544 (D)	-0.1252 (D)	-0.1241 (D)	-0.1576 (C)	0.0002 (A)	-0.0001 (A)	0.0007 (B)

Linear regression of measured parameters versus distance along hydrologic flow paths. Slope of line is indicated as a number, R^2 follows in parentheses.

where (A)= $R^2 < .25$
(B)= $0.25< R^2 >0.50$
(C)= $0.50< R^2 >0.75$
(D)= $0.75< R^2 >1.0$

NM= Not Measured
NA= Zinc Concentrations Below Detection Limit
SM= Snow Melt
PSM= Post Snow Melt
M= Monsoon
PM= Post Monsoon

Appendix D.1a Linear Regression of Measured Parameters Versus Distance Along Hydrologic Flow Paths in Slope Wetlands.

	Pennsylvania Mine Unconsolidated				Pennsylvania Mine Peat					Big Meadows Unconsolidated	
	SM	PSM	M	PM	SM	PSM	M	PM		M	PM
Dissolved Oxygen - Chloride	0	+	0	-	0	+	0	+		0	NM
Dissolved Oxygen - Nitrate	0	0	0	-	0	+	+	+		-	NM
Dissolved Oxygen - Sulfate	-	-	0	+	0	+	+	0		NM	NM
Dissolved Oxygen - Dissolved Iron	-	0	0	0	-	-	-	0		+	NM
Dissolved Oxygen - Dissolved Zinc	+	0	0	0	+	+	+	0		+	NM
Chloride - Nitrate	0	+	0	+	+	+	0	+		0	0
Chloride - Sulfate	0	-	0	0	0	+	0	0		NM	+
Chloride - Dissolved Iron	0	-	0	+	0	-	0	0		0	-
Chloride - Dissolved Zinc	0	+	0	-	0	+	0	0		0	+
Chloride - pH	0	-	0	+	0	-	0	0		0	0
Chloride - Eh	0	+	0	-	0	+	0	0		0	0
Sulfate - Nitrate	0	-	+	0	+	+	+	0		NM	0
Sulfate - Dissolved Iron	+	+	+	0	0	-	0	0		NM	-
Sulfate - Dissolved Zinc	-	0	-	0	+	+	+	+		NM	+
Sulfate - pH	+	+	0	0	0	-	-	-		NM	0
Sulfate - Eh	-	-	0	+	+	+	+	+		NM	0
Nitrate - Dissolved Iron	0	-	+	+	0	-	-	0		-	0
Nitrate - Dissolved Zinc	0	+	-	-	0	+	+	0		-	0
Nitrate - pH	-	-	0	+	0	-	-	0		0	+
Nitrate - Eh	0	+	0	-	0	+	+	0		+	-
Dissolved Iron - Dissolved Zinc	-	-	-	-	-	-	-	-		+	-
Dissolved Iron - pH	+	+	+	+	+	+	+	0		0	0
Dissolved Iron - Eh	-	-	0	-	-	-	-	0		0	0
Dissolved Zinc - pH	-	-	-	-	-	-	-	-		0	0
Dissolved Zinc - Eh	+	+	0	+	+	+	+	+		-	0
pH - Eh	0	-	-	-	-	-	-	-		0	0
Herbaceous biomass - Nitrate	NC	NC	NC	NC	0	+	+	0		0	0
Herbaceous biomass - Chloride	NC	NC	NC	NC	0	+	0	0		-	+
Herbaceous biomass - Sulfate	NC	NC	NC	NC	+	0	+	+		NM	+
Herbaceous biomass - Dissolved Iron	NC	NC	NC	NC	-	-	-	0		0	-
Herbaceous biomass - Dissolved Zinc	NC	NC	NC	NC	+	+	+	0		0	+

Correlation in means of up, mid, and down gradient samples. + indicates a positive correlation of > 0.85, - indicates a negative correlation of < -0.85, and 0 indicates no correlation (>-0.85 and <0.85)

%TPS= Percent Total Pore Space	SM= Snow Melt
%OM= Percent Organic Matter	PSM= Post Snow Melt
NM= Not Measured	M= Monsoon
NA= Zinc Concentrations Below Detection Limit	PM= Post Monsoon
NC= Correlation Not Determined	

Appendix D.1b Correlations Between Means of Measured Parameters in Slope Wetlands.

	Pennsylvania Mine Unconsolidated				Pennsylvania Mine Peat					Big Meadows Unconsolidated	
	SM	PSM	M	PM	SM	PSM	M	PM		M	PM
%OM - Nitrate	NC	NC	NC	NC	0	-	-	0		0	-
%OM - Chloride	NC	NC	NC	NC	0	-	0	0		0	0
%OM - Sulfate	NC	NC	NC	NC	-	-	-	-		NM	0
%OM - Dissolved Iron	NC	NC	NC	NC	+	+	+	0		0	0
%OM - Dissolved Zinc	NC	NC	NC	NC	-	-	-	-		0	0
%TPS - Nitrate	NC	NC	NC	NC	0	-	-	0		0	0
%TPS - Chloride	NC	NC	NC	NC	0	-	0	0		0	-
%TPS - Sulfate	NC	NC	NC	NC	0	-	0	-		NM	-
%TPS - Dissolved Iron	NC	NC	NC	NC	+	+	+	+		+	+
%TPS - Dissolved Zinc	NC	NC	NC	NC	-	-	-	-		0	0
Temperature - Nitrate	-	-	0	+	0	-	-	+		+	0
Temperature - Chloride	0	-	+	+	0	-	0	+		0	-
Temperature - Sulfate	0	+	0	-	-	0	-	0		0	-
Temperature - Dissolved Iron	0	+	0	0	+	+	0	0		0	0
Temperature - Dissolved Zinc	0	-	0	0	-	-	-	0		-	-
Specific Conductivity - Nitrate	0	-	0	-	0	0	+	-		-	0
Specific Conductivity - Chloride	0	-	+	-	0	0	0	0		0	-
Specific Conductivity - Sulfate	+	+	0	0	0	0	+	0		0	-
Specific Conductivity - Dissolved Iron	+	+	0	-	-	0	0	0		+	+
Specific Conductivity - Dissolved Zinc	-	-	0	+	+	0	+	0		+	-

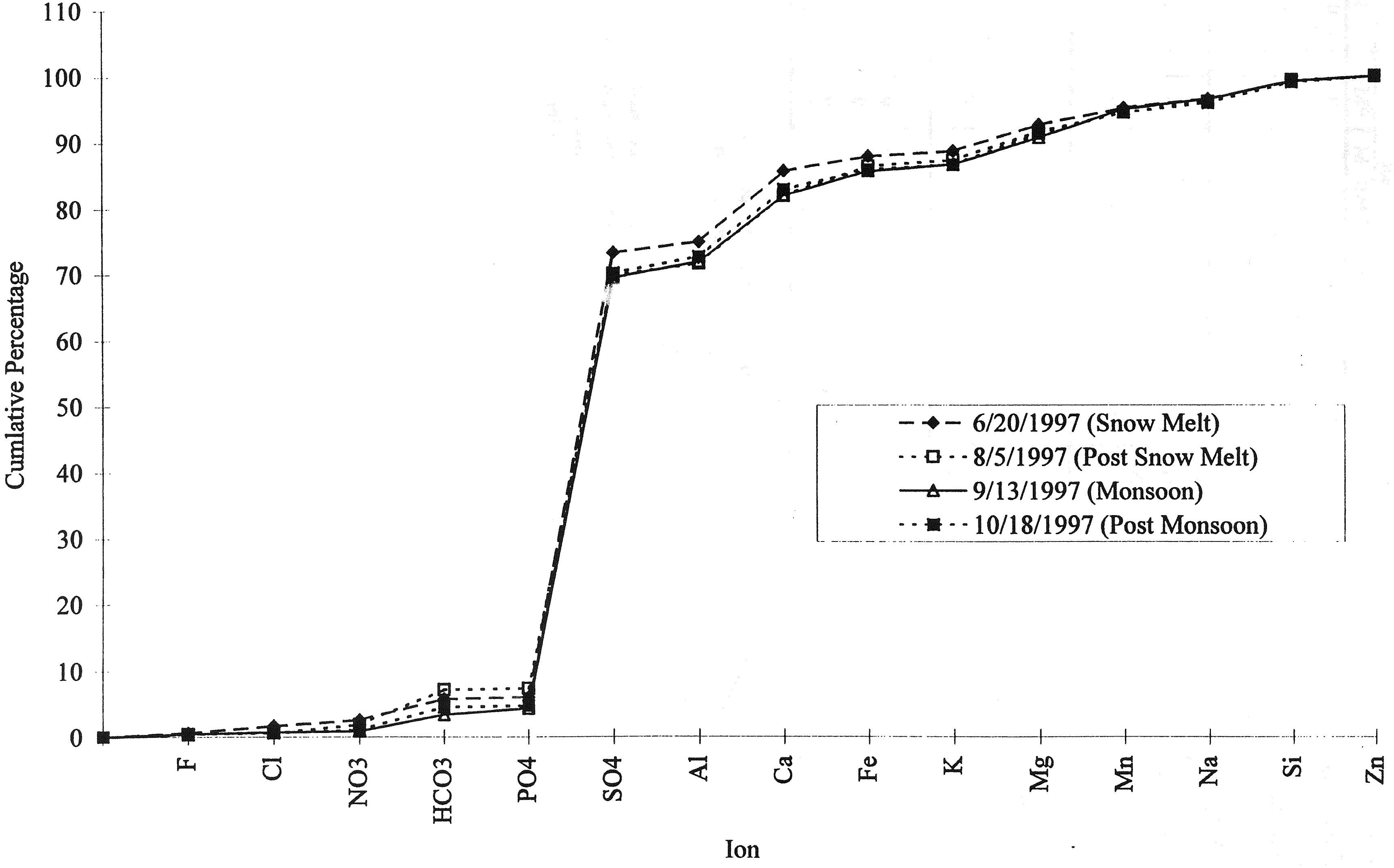
Correlation in averages of up, mid, and down gradient samples. + indicates a positive correlation of > 0.85, - indicates a negative correlation of < -0.85, and 0 indicates no correlation (>-0.85 and <0.85)

%TPS= Percent Total Pore Space
%OM= Percent Organic Matter
NM= Not Measured
NA= Zinc Concentrations Below Detection Limit
NC= Correlation Not Determined

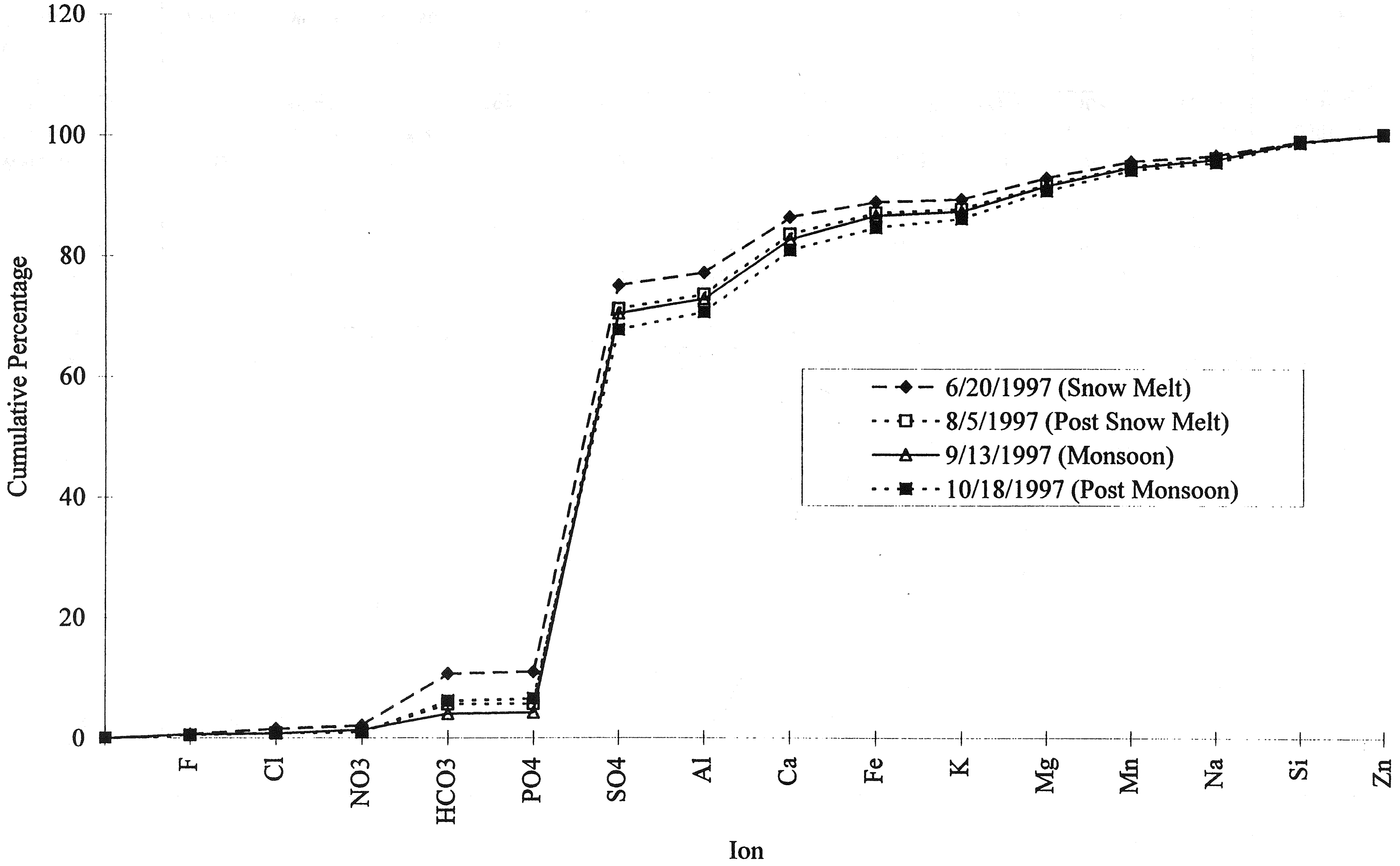
SM= Snow Melt
PSM= Post Snow Melt
M= Monsoon
PM= Post Monsoon

Appendix D.1b Correlations Between Means of Measured Parameters in Slope Wetlands.

Appendix D.1c Peru Creek (Peat Wells) Mean Cumulative Percent Composition based on mg/l.



Appendix D.1d Peru Creek (Unconsolidated) Mean Cumulative Percent Composition based on mg/l.

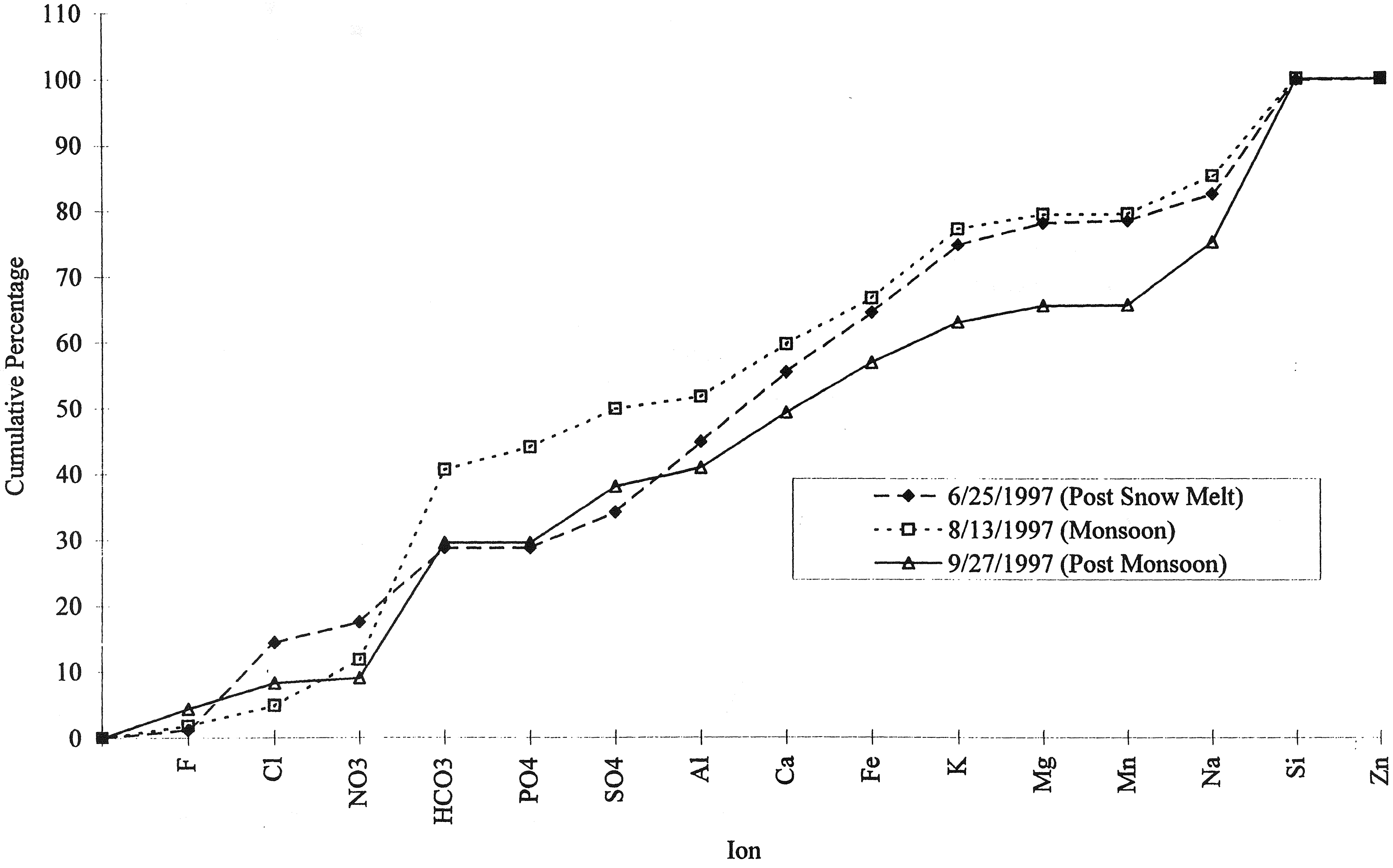


Analyte	GWC1P	GWC2P	GWE10P	GWE2P	GWE3P	GWE4P	GWE5P	GWE6P	GWE7P	GWE8P	GWE9P	Mean Concentration
Aluminum												
Water (mg/kg)[1]	21.37	2.01	1.25	25.94	23.10	1.74	1.86	4.57	0.55	14.01	5.45	9.26
Soil (mg/kg)	7261.94	4346.56	9454.37	15599.72	17859.49	8013.01	5016.56	5437.26	4559.39	6557.32	7472.83	8325.31
Plant (mg/kg)	516.90	129.22	185.26	313.57	982.50	236.69	373.95	438.44	468.33	603.64	515.41	433.08
Calcium												
Water (mg/kg)[1]	59.23	54.55	26.31	23.27	27.48	21.67	30.79	45.75	24.84	37.40	21.15	33.86
Soil (mg/kg)	315.48	230.26	1560.91	327.40	585.84	1068.85	279.01	509.52	827.21	357.85	420.39	589.34
Plant (mg/kg)	3610.16	2701.57	2629.18	3311.69	2775.63	3085.65	2810.60	3315.73	3477.59	2458.97	3880.14	3096.08
Iron												
Water (mg/kg)[1]	1.39	11.30	19.94	9.97	1.83	4.01	37.11	1.14	0.43	9.34	8.64	9.55
Soil (mg/kg)	7648.57	4839.17	35932.92	186038.11	42703.16	15690.97	123733.15	30599.81	5853.69	134061.23	37261.09	56760.17
Plant (mg/kg)	654.58	180.91	190.97	277.00	139.22	641.17	139.81	306.20	92.76	266.56	444.09	303.02
Potassium												
Water (mg/kg)[1]	2.46	2.22	5.35	5.54	1.20	1.84	2.46	0.61	1.87	3.03	0.72	2.48
Soil (mg/kg)	5952.34	2674.47	5578.32	3333.77	4341.37	2478.63	1326.16	3092.88	902.18	1730.03	3158.64	3142.62
Plant (mg/kg)	10336.54	15531.35	14419.53	4111.91	3654.40	11656.74	12268.36	12277.37	16631.23	11396.49	12904.89	11380.80
Magnesium												
Water (mg/kg)[1]	20.48	15.11	12.31	21.89	18.30	9.42	14.88	17.75	9.71	20.71	9.80	15.49
Soil (mg/kg)	491.67	331.64	1544.21	1470.22	3272.50	1493.55	460.45	910.09	820.52	689.11	669.82	1104.89
Plant (mg/kg)	843.62	669.32	1573.98	886.08	1175.86	1736.49	1471.10	1426.64	2196.12	1841.51	2269.82	1462.78
Zinc												
Water (mg/kg)[1]	9.52	0.14	0.15	9.83	11.81	0.16	0.35	0.23	0.14	0.44	3.68	3.31
Soil (mg/kg)	7455.75	11746.72	6428.23	405.84	397.10	14316.75	264.36	5686.20	10997.27	10636.11	4286.22	6601.87
Plant (mg/kg)	507.78	44.28	210.21	368.48	793.61	239.75	341.85	712.48	681.45	308.96	524.68	430.32
Sodium												
Water (mg/kg)[1]	8.82	8.33	6.49	3.37	2.87	3.25	3.88	5.69	3.81	3.40	3.05	4.82
Soil (mg/kg)	409.35	290.28	401.50	258.17	377.93	255.57	94.11	294.78	166.48	152.82	234.38	266.85
Plant (mg/kg)	185.49	112.33	179.99	107.45	2419.79	160.02	84.49	255.63	185.61	238.93	195.05	374.98

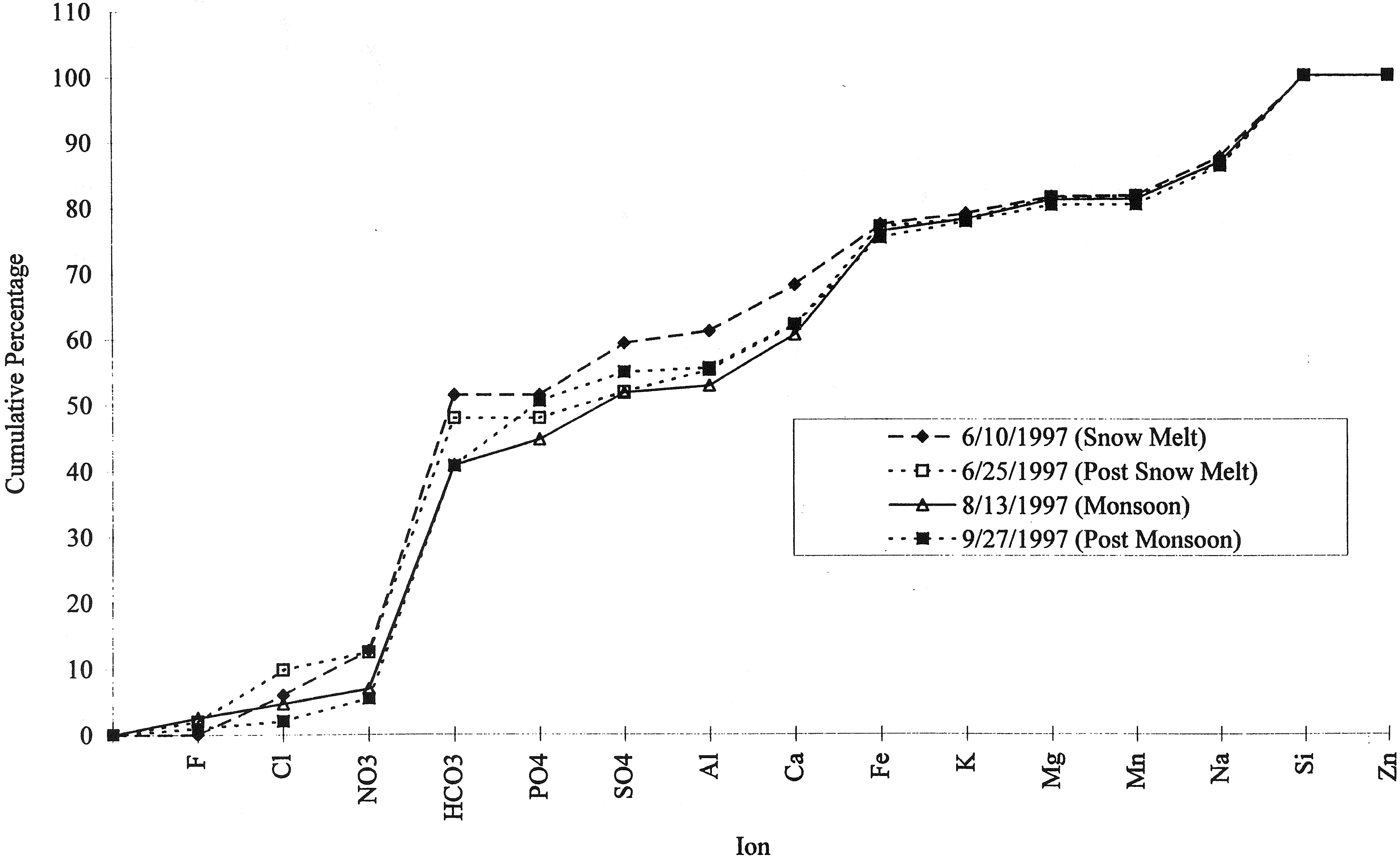
[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

Appendix D.1e Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Pennsylvania Mine Peat Samples Collected on 10/18/97.

Appendix D.2a Big Meadows (Peat Wells) Mean Cumulative Percent Composition based on mg/l.



Appendix D.2b Big Meadows (Unconsolidated Wells) Mean Cumulative Percent Composition based on mg/l.



Analyte	BMA	BMB	BMC	BMD	BME	Mean Concentration
Aluminum						
Water (mg/kg)[1]	78.08	71.31	6.57	0.34	1.35	31.53
Soil (mg/kg)	26267.23	27811.47	5757.67	7772.51	5378.47	14597.47
Plant (mg/kg)	9.51	90.19	10.00	12.75	17.83	28.06
Calcium						
Water (mg/kg)[1]	23.63	38.61	7.43	7.67	3.46	16.16
Soil (mg/kg)	1863.93	2915.47	1345.04	3157.63	2556.19	2367.65
Plant (mg/kg)	3193.31	4028.34	3851.07	3399.54	3128.29	3520.11
Iron						
Water (mg/kg)[1]	38.11	36.41	33.22	7.33	5.57	24.13
Soil (mg/kg)	9723.82	15172.52	5266.21	4496.60	6020.20	8135.87
Plant (mg/kg)	52.38	178.34	115.50	174.84	153.58	134.93
Potassium						
Water (mg/kg)[1]	4.92	2.88	1.72	2.71	0.27	2.50
Soil (mg/kg)	2475.63	2715.06	723.46	920.73	841.00	1535.17
Plant (mg/kg)	7824.99	5944.10	8557.39	10262.83	9023.54	8322.57
Magnesium						
Water (mg/kg)[1]	13.94	14.24	2.39	1.19	1.37	6.63
Soil (mg/kg)	3375.91	3850.00	737.54	1130.50	948.78	2008.55
Plant (mg/kg)	1255.90	1412.67	2513.83	1653.41	1317.45	1630.65
Zinc						
Water (mg/kg)[1]	0.17	0.12	0.04	0.05	0.00	0.07
Soil (mg/kg)	53.01	53.45	15.89	15.96	13.63	30.39
Plant (mg/kg)	18.17	35.26	37.45	62.92	35.32	37.82
Sodium						
Water (mg/kg)[1]	3.44	3.47	3.48	6.56	2.57	3.90
Soil (mg/kg)	276.23	314.14	193.16	158.74	170.08	222.47
Plant (mg/kg)	62.89	40.81	15.84	67.04	84.66	54.25

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

Appendix D.2c Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Big Meadows Peat Samples Collected on 9/27/97.

	Allen Bottom				Deerlodge		
	CL	PP	DL	BF	P	DL	BF
pH	-0.0042 (A)	-0.0053 (B)	-0.0048 (A)	-0.0062 (A)	-0.0065 (C)	-0.0002 (A)	-0.0041 (A)
Eh	0.2574 (A)	0.3585 (B)	0.2488 (A)	0.3686 (B)	0.3487 (C)	-0.0871 (A)	0.0267 (A)
Dissolved Oxygen	-0.0026 (A)	-0.0147 (A)	-0.0147 (A)	-0.0398 (A)	-0.0155 (D)	0.0188 (A)	0.0205 (C)
Nitrate	-0.0538 (A)	0.1138 (B)	-0.0543 (B)	0.1302 (A)	0.0826 (B)	0.034 (A)	-0.0001 (A)
Chloride	-0.0131 (A)	-0.0074 (A)	0.1800 (A)	0.2105 (B)	2.6548 (B)	-0.7996 (A)	0.9351 (A)
Sulfate	0.2567 (A)	1.3155 (A)	0.0863 (A)	0.964 (A)	18.659 (B)	-13.464 (A)	4.7048 (A)
Dissolved Iron	0.003 (A)	0.0419 (A)	0.2429 (A)	0.0987 (A)	0.008 (A)	-0.0099 (A)	-0.0228 (B)
Dissolved Zinc	NA	2E-05 (A)	0.0004 (A)	-7E-05 (A)	-4E-07 (A)	0.0023 (A)	-0.0007 (D)

Linear regression of measured parameters versus distance along hydrologic flow paths. Slope of line is indicated as a number, R^2 follows in parentheses.

where (A)= $R^2 < 0.25$
(B)= $0.25 < R^2 > 0.50$
(C)= $0.50 < R^2 > 0.75$
(D)= $0.75 < R^2 > 1.0$

NM= Not Measured
NA= Zinc Concentrations Below Detection Limit
Cl= Climbing Limb of Hydrograph
P= Peak
PP= Post Peak
DL= Declining Limb of Hydrograph
BF= Baseflow

Append .3a Linear Regression of Measured Parameters Versus Distance Alon ydrologic Flow Paths in Riverine Wetlands.

	Allen Bottom					Deerlodge		
	CL	PP	DL	BF		P	DL	BF
Dissolved Oxygen - Chloride	+	0	0	+		-	0	+
Dissolved Oxygen - Nitrate	0	0	0	0		-	0	0
Dissolved Oxygen - Sulfate	0	0	-	0		-	0	0
Dissolved Oxygen - Dissolved Iron	0	0	-	-		0	0	-
Dissolved Oxygen - Dissolved Zinc	NA	-	-	0		0	+	-
Chloride - Nitrate	0	0	0	0		+	-	0
Chloride - Sulfate	-	0	0	0		+	+	0
Chloride - Dissolved Iron	0	0	0	-		0	0	-
Chloride - Dissolved Zinc	NA	-	0	0		0	0	-
Chloride - pH	0	0	0	+		-	0	-
Chloride - Eh	0	0	0	-		0	+	-
Sulfate - Nitrate	-	+	0	0		+	0	+
Sulfate - Dissolved Iron	0	+	+	0		0	0	0
Sulfate - Dissolved Zinc	NA	0	+	-		0	0	0
Sulfate - pH	0	-	0	0		0	0	0
Sulfate - Eh	0	+	0	0		0	0	0
Nitrate - Dissolved Iron	0	0	0	0		0	-	0
Nitrate - Dissolved Zinc	NA	0	0	0		0	0	0
Nitrate - pH	0	-	0	0		-	0	0
Nitrate - Eh	0	+	0	0		0	-	0
Dissolved Iron - Dissolved Zinc	NA	0	+	0		+	0	+
Dissolved Iron - pH	-	-	0	-		0	0	+
Dissolved Iron - Eh	+	+	0	+		-	+	0
Dissolved Zinc - pH	NA	0	+	0		0	-	+
Dissolved Zinc - Eh	NA	0	-	0		-	0	+
pH - Eh	-	-	0	-		0	0	+
Herbaceous biomass - Nitrate	-	0	+	0		+	0	+
Herbaceous biomass - Chloride	0	0	0	-		0	0	0
Herbaceous biomass - Sulfate	0	+	-	0		0	+	+
Herbaceous biomass - Dissolved Iron	0	+	-	+		+	0	0
Herbaceous biomass - Dissolved Zinc	NA	0	0	0		0	+	0
% Carbonate - Nitrate	0	0	+	0		0	0	0
% Carbonate - Chloride	0	+	0	0		0	+	0
% Carbonate - Sulfate	0	0	0	+		0	+	0
% Carbonate - Dissolved Iron	0	0	0	0		+	0	-
% Carbonate - Dissolved Zinc	NA	-	0	-		+	0	0

Correlation in means of up, mid, and down gradient samples. + indicates a positive correlation of > 0.85, - indicates a negative correlation of < -0.85, and 0 indicates no correlation (>-0.85 and <0.85)

%TPS= Percent Total Pore Space
%OM= Percent Organic Matter
NA= Zinc Concentrations Below Detection Limit

CL= Climbing Limb of Hyrdograph
P= Peak
PP= Post- peak
DL= Declining Limb of Hydrograph
BF= Baseflow

Appendix D.3b Correlations Between Means of Measured Parameters in Riverine Wetlands.

	Allen Bottom					Deerlodge		
	CL	PP	DL	BF		P	DL	BF
%OM- Nitrate	0	+	0	0		0	0	0
%OM- Chloride	0	0	-	0		0	0	0
%OM-Sulfate	0	+	0	-		0	+	+
%OM- Dissolved Iron	+	+	0	0		+	-	0
%OM- Dissolved Zinc	NA	0	0	+		+	0	0
%TPS- Nitrate	0	+	0	+		0	0	0
%TPS- Chloride	0	0	0	-		0	0	-
%TPS-Sulfate	0	+	-	0		0	-	0
%TPS- Dissolved Iron	+	+	-	0		+	0	+
%TPS- Dissolved Zinc	NA	0	-	0		+	-	+
Temperature- Nitrate	0	0	-	0		+	+	0
Temperature- Chloride	+	0	0	+		+	-	0
Temperature- Sulfate	-	0	0	0		0	0	0
Temperature- Dissolved Iron	0	-	0	-		0	-	-
Temperature- Dissolved Zinc	NA	0	0	0		0	-	0
Specific Conductivity- Nitrate	0	+	0	+		+	0	+
Specific Conductivity- Chloride	0	0	+	0		+	0	+
Specific Conductivity- Sulfate	0	+	0	0		+	+	+
Specific Conductivity- Dissolved Iron	+	+	0	0		0	0	0
Specific Conductivity- Dissolved Zinc	NA	0	0	-		0	+	0

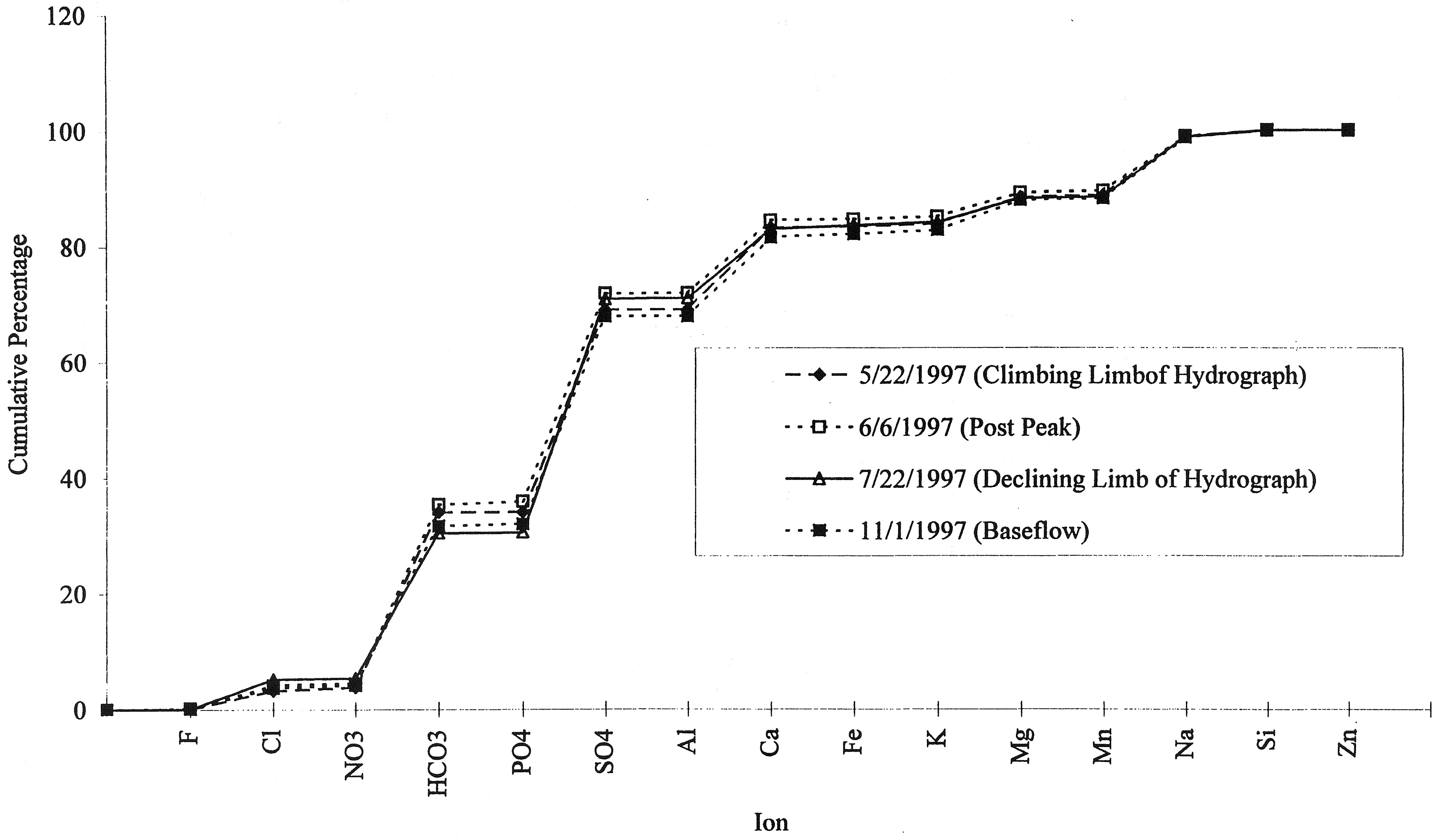
Correlation in means of up, mid, and down gradient samples. + indicates a positive correlation of > 0.85, - indicates a negative correlation of < -0.85, and 0 indicates no correlation (>-0.85 and <0.85)

%TPS= Percent Total Pore Space
%OM= Percent Organic Matter
NA= Zinc Concentrations Below Detection Limit

CL= Climbing Limb of Hyrdograph
P= Peak
PP= Post- peak
DL= Declining Limb of Hydrograph
BF= Baseflow

Appendix D.3b Correlations Between Means of Measured Parameters in Riverine Wetlands.

Appendix D.3c Allen Bottom Mean Cumulative Percent Composition based on mg/l.

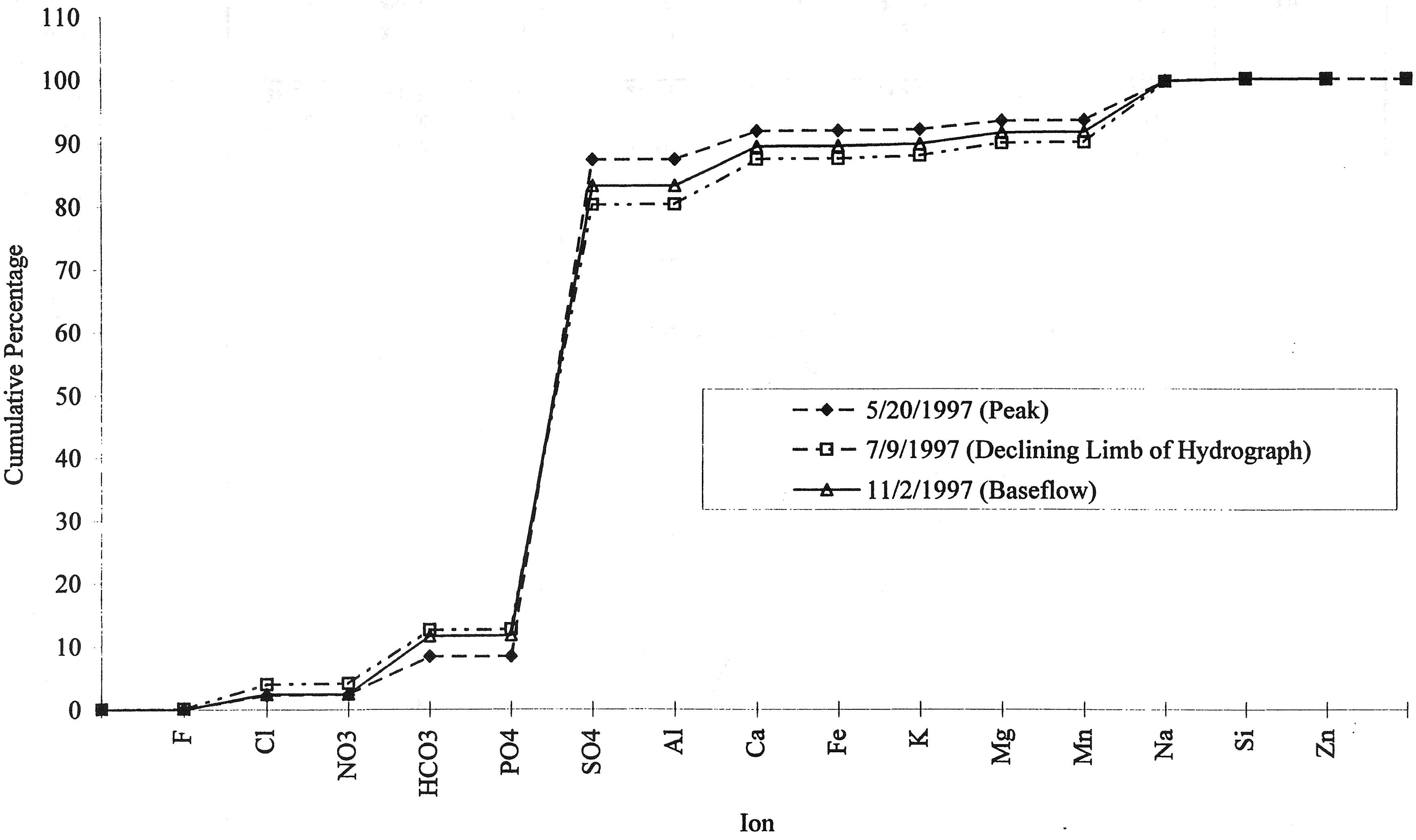


Analyte	BP1	BP11	BP2	BP3	BP4	BP6	BP7	Mean Concentration
Aluminum								
Water (mg/kg)[1]	4.91	0.04	12.35	0.08	0.02	0.03	0.00	2.49
Soil (mg/kg)	9041.71	3996.89	9613.31	16133.52	5616.72	12199.92	29789.73	12341.69
Plant (mg/kg)	13.61	20.16	9.08	12.15	7.09	16.35	12.50	12.99
Calcium								
Water (mg/kg)[1]	507.64	1077.38	266.36	468.88	1446.88	357.50	500.36	660.71
Soil (mg/kg)	40980.99	24506.96	43019.17	46656.87	27985.92	44842.08	3377.85	33052.83
Plant (mg/kg)	4310.50	7724.06	3333.66	3438.23	10524.31	2764.96	8513.94	5801.38
Iron								
Water (mg/kg)[1]	0.04	0.03	29.15	0.00	0.06	0.00	0.00	4.18
Soil (mg/kg)	11892.53	6271.01	12367.06	17814.52	8093.66	15116.27	23859.79	13630.69
Plant (mg/kg)	35.76	346.32	41.52	31.23	59.07	39.35	25.01	82.61
Potassium								
Water (mg/kg)[1]	6.07	8.47	4.97	5.24	15.87	4.69	4.11	7.06
Soil (mg/kg)	3319.50	972.75	3632.18	5570.66	1700.32	5080.07	10634.30	4415.68
Plant (mg/kg)	11148.63	9909.97	15336.88	4672.15	6037.68	8134.32	3184.50	8346.30
Magnesium								
Water (mg/kg)[1]	80.66	183.89	56.67	82.68	134.05	50.86	48.31	91.02
Soil (mg/kg)	9053.14	4494.73	9682.29	12604.57	5855.04	11247.89	14896.96	9690.66
Plant (mg/kg)	1319.25	1689.48	1513.71	846.22	2457.51	925.42	1825.04	1510.95
Zinc								
Water (mg/kg)[1]	0.10	0.03	0.13	0.03	0.02	0.01	0.08	0.06
Soil (mg/kg)	40.83	20.23	42.75	61.97	28.81	54.59	80.60	47.11
Plant (mg/kg)	17.87	28.21	25.78	95.61	25.13	59.00	17.06	38.38
Sodium								
Water (mg/kg)[1]	70.11	138.62	61.34	89.33	102.07	67.91	64.50	84.84
Soil (mg/kg)	919.36	706.59	810.66	1416.96	872.63	1222.10	824.24	967.51
Plant (mg/kg)	1344.86	596.89	916.90	100.88	2691.14	387.49	1370.33	1058.35

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

Appendix D.3d Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Allen Bottom Samples Collected on 11/1/97.

Appendix D.4a Deerlodge Mean Cumulative Percent Composition based on mg/l.



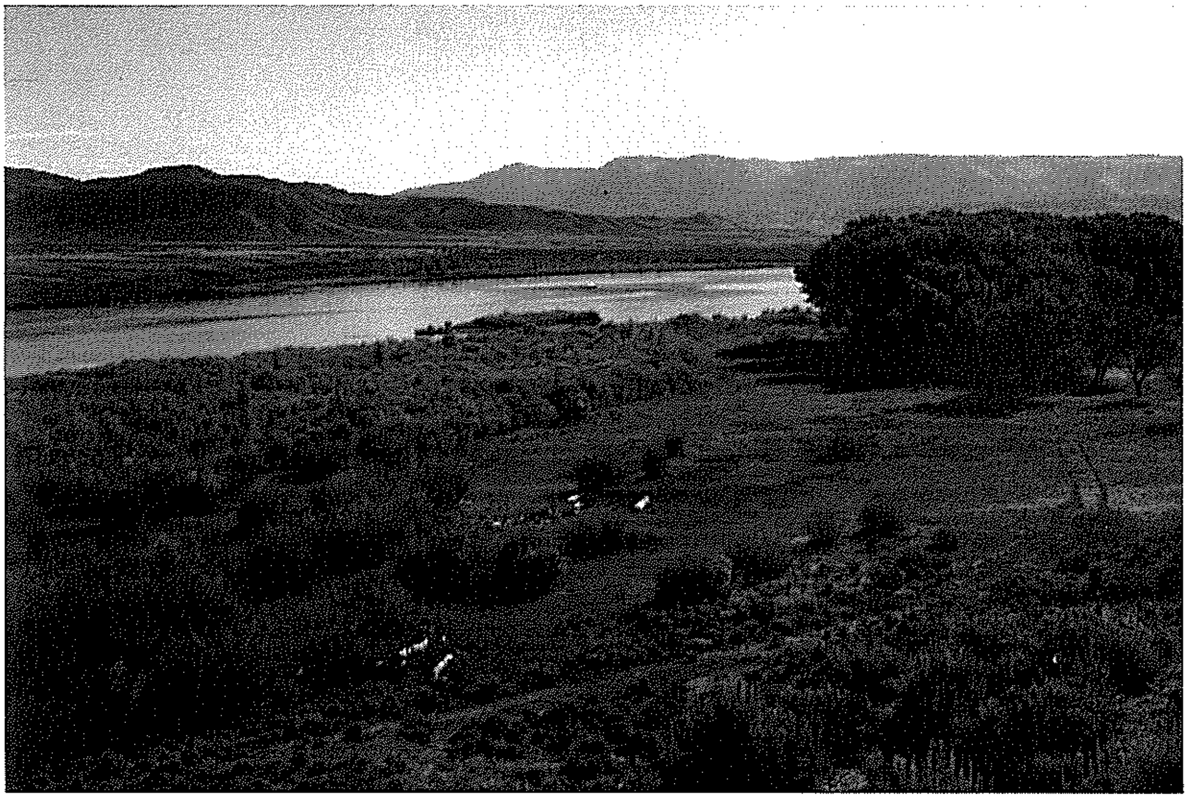
Analyte	DL13	DL14	DL2	DL26	DL27	DL3A	DL4	DL9	Mean Concentration
Aluminum									
Water (mg/kg)[1]	0.17	0.38	1.18	2.18	1.49	8.06	5.51	2.58	2.69
Soil (mg/kg)	17589.14	13328.67	7369.20	13616.43	7965.63	15277.00	8865.20	26458.89	13808.77
Plant (mg/kg)	12.82	25.89	49.34	50.10	23.37	35.06	19.90	48.49	33.12
Calcium									
Water (mg/kg)[1]	60.39	221.91	64.08	70.97	274.18	122.24	244.57	104.79	145.39
Soil (mg/kg)	3736.22	33968.19	20579.00	22236.86	19632.53	30419.89	17569.39	3478.55	18952.58
Plant (mg/kg)	5188.75	4532.71	4493.56	4457.99	9360.00	9203.63	4887.90	3374.58	5687.39
Iron									
Water (mg/kg)[1]	0.44	1.33	3.07	6.05	3.38	17.68	10.18	3.81	5.74
Soil (mg/kg)	7983.57	9776.22	10826.71	17708.89	13480.07	10744.80	6597.19	14475.88	11449.17
Plant (mg/kg)	65.92	102.74	179.16	97.60	98.36	69.16	98.03	153.15	108.01
Potassium									
Water (mg/kg)[1]	3.32	8.19	3.59	4.46	7.61	7.31	7.59	4.88	5.87
Soil (mg/kg)	5523.21	3955.34	2215.45	3115.79	1826.55	4421.43	2941.49	7166.67	3895.74
Plant (mg/kg)	6817.09	17266.11	7442.82	8331.31	7922.95	10273.22	12725.07	9937.70	10089.53
Magnesium									
Water (mg/kg)[1]	12.28	118.47	23.46	28.22	65.81	23.26	62.51	24.82	44.85
Soil (mg/kg)	4474.20	6218.92	5527.13	7098.74	5914.28	6707.24	3762.40	7118.89	5852.73
Plant (mg/kg)	851.16	1476.93	1743.25	1117.61	2077.45	1759.96	1312.67	1024.78	1420.47
Zinc									
Water (mg/kg)[1]	0.01	0.02	0.05	0.03	0.03	0.09	0.08	0.03	0.04
Soil (mg/kg)	38.28	40.52	41.67	73.00	56.03	44.30	29.06	54.67	47.19
Plant (mg/kg)	38.21	35.31	58.93	26.51	61.79	29.26	37.70	17.20	38.11
Sodium									
Water (mg/kg)[1]	54.42	806.79	45.36	75.28	373.02	81.21	221.12	85.78	217.87
Soil (mg/kg)	262.96	499.40	546.17	242.41	179.15	192.52	442.02	277.33	330.24
Plant (mg/kg)	164.49	2250.02	244.10	222.13	402.53	1243.65	136.64	164.65	603.53

[1] Total Cation Concentrations Used. Mass of Water Assumed to be 0.998 g/ml at 20°C.

Appendix D.4b Mean Value of Cation Concentrations in Soil, Plant, and Groundwater in Deerlodge Samples Collected on 11/2/97.

CHARACTERIZATION AND FUNCTIONAL ASSESSMENT OF REFERENCE WETLANDS IN COLORADO

A PRELIMINARY INVESTIGATION OF HYDROGEMORPHIC (HGM) CLASSIFICATION AND FUNCTIONS FOR COLORADO'S WETLANDS



Section 5

HGM Sediment Retention and Carbon Storage/Export Functions

THE SEDIMENT RETENTION, CARBON STORAGE, AND CARBON EXPORT FUNCTIONS PERFORMED BY FOUR COLORADO WETLANDS

Research Sponsored by:
Colorado Geological Survey
State of Colorado Department of Natural Resources

David J. Cooper [a,b]

Christopher Arp [a]

Rodney Chimner [b]

[a]Department of Earth Resources

[b]Graduate Degree Program in Ecology

Colorado State University

Fort Collins, Colorado 80523

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Introduction

Wetlands in Colorado range from small groundwater-supported subalpine peatlands to large-river riparian forests. The diversity of Colorado's wetlands are determined in part by the tremendous variation in elevation, geomorphic landforms, and surface and groundwater hydrologic regimes within watersheds. Wetlands, as a group of ecosystems with periodically or permanently saturated soils, are often cited as providing a number of important functions that benefit both humans and ecosystems (Richardson 1994), including peak-flow buffering, groundwater recharge, improvement of surface-water and groundwater quality, and habitat for wildlife and fish (Brinson and Rheinhardt 1996). The importance of Colorado wetlands in habitat provision is well known (Jones and Cooper 1993). However, on a watershed scale we have a very limited understanding of where other functions are being performed by wetlands in Colorado.

Sediment retention is one of the most commonly cited wetland functions (Johnston 1991, Kleiss 1996). However, few studies have quantified sediment retention patterns, processes and rates within wetlands, particularly in the western U.S. (Johnston 1991). This function involves the removal of sediment from surface water flowing into the wetland, and the retention of this sediment in the wetland. It results in decreased sediment concentrations in surface water leaving the wetland, and thus improved water quality (Johnston 1991, Dortch 1996). High sediment concentrations in surface waters can have negative effects on aquatic ecosystems by smothering benthic habitat and interfering with aquatic organism life cycles. Sediment also transports the majority of colloidal nutrients and contaminants, such as nitrogen, phosphorus, heavy metals, and organic pollutants, which is a concern for aquatic life and humans (Feijtel et al.1988, Johnston 1991, Delauwe and Gambrell 1996).

Sedimentation naturally occurs in many wetlands which occupy low landscape positions. Sediment deposition occurs when surface-water flow velocities are reduced due to decreased water depth, decreased flow gradients or velocity, or increased surface roughness (Shen and Julien 1993, Ritter et al. 1995). Colloidal constituents (e.g. nitrates, phosphates, heavy metals, organo-chlorides) retained with the sediment may then be transformed or sequestered through physical, chemical, and biological processes (Johnston 1991, DeLaune et al. 1996, Dortch 1996). These processes occur to some degree in all wetlands, however they may differ greatly by wetland type, position of the wetland in a watershed, and the condition of a wetland (Brinson 1993). Additionally, some wetlands may export significant quantities of sediment to surface-water bodies, which must be balanced with sediment deposited (Mitsch and Gosselink 1993).

Long-term carbon storage occurs in Rocky Mountain wetlands only where primary production rates exceed decomposition rates, resulting in the storage of leaf, stem and root carbon in soils (Cooper and Andrus 1994). Wetlands performing this function for long periods of time develop organic soils and are termed peatlands. Long-term carbon storage is critical for regulating carbon dioxide (CO_2) concentrations in the atmosphere, and most likely provides peat bodies in critical watersheds positions where surface and ground water flowing through the peatland can be treated to remove heavy metals, nitrate and other compounds. On a watershed scale we know little about where this function is being performed, but clearly decomposition is retarded in environments with cold soils, long-duration soil saturation, and relatively little physical disturbance due to erosion.

Carbon export is the transport of leaves, stems, roots, and soil carbon to aquatic ecosystems. This function is critical because the food chain of most streams and lakes is largely dependent upon terrestrial carbon produced in adjacent riparian ecosystems. However, it is unknown which of these carbon sources, leaves, wood, roots, or soil carbon are the most important sources of carbon for adjacent aquatic ecosystems, or what hydrogeomorphic processes, eg. flooding, bank erosion, wind etc., drive this function.

Wetland functions have been evaluated by a variety of methods over the past several decades. The "Adamus" method developed in the early 1980's was the first comprehensive approach for wetland evaluation that was applicable at a national scale (Adamus and Stockwell 1983, Adamus 1983). This method included an extensive literature review on wetland functions. Previously, wetland functions had been described in individual papers, or in symposium volumes (eg. Greeson et al. 1979), but no overall approach was formulated. The Adamus method was subsequently revised as the Wetland Evaluation Technique (WET) (Adamus et al. 1987, 1991) by the Waterways Experiment Station of the Corps of Engineers. However, these approaches were subject to extensive criticism for not being able to accurately measure or estimate wetland functions (Dougherty 1989, Smith 1993, Smith et al. 1995).

The hydrogeomorphic functional assessment method (HGM) has now been proposed as a quantitative tool for the characterization of wetland functions and the design of wetland mitigation projects (Brinson 1993, Brinson et al. 1995). This method uses information on a wetland's driving hydrologic and geomorphic processes as a means of understanding how wetlands function, and provides models to evaluate a wetland's function. Each model requires the measurement of several field variables, eg. overbank flow frequency and microtopographic complexity. These variables must then be compared to the overbank frequency or microtopographic complexity that occurs in a reference standard site for that wetland type. Functions for that wetland are then quantified by comparing measured or estimated field variables relative to the reference standard.

The State of Colorado is interested in developing a understanding of Colorado wetlands functions, including sediment retention, carbon storage and carbon export. We focused our work at measuring these three functions in wetlands along an elevation gradient in western Colorado. Since we are unsure whether the variables included in national (Brinson et al. 1995) and regional (Hauer and Cook 1996) models for riverine wetlands are appropriate for Colorado, we did not measure these variables, but instead we attempted to quantify the functions themselves. We use the data collected and presented in this report to evaluate the existing models and model variables.

The objectives of this study were to, (1) measure sediment deposition and erosion rates, (2) measure total carbon and nitrogen concentrations in sediment deposited and eroded, (3) calculate the mass balance of sediment, carbon, and nitrogen import and export, (4) determine short-term and long-term carbon storage processes, and (5) determine what factors lead to carbon export from wetlands. This work was conducted in four study wetlands in the Upper Colorado River watershed and comparisons are made between study sites. We consider this report to be a starting point for developing hypotheses relevant to the functioning of Rocky Mountain wetlands, and for testing methods that can be used to measure wetland functions. It is our hope that this will lead to more comprehensive investigations of the functions of Colorado's wetlands.

Methods

Site Description. This research was performed at four wetlands in the upper Colorado River watershed. These sites represent (1) a high elevation, sedge fen (Big Meadows), (2) a montane, willow riparian floodplain (Kawuneeche Valley), and (3) two low elevation, cottonwood forests along large rivers (Deer Lodge Park and Brown's Park) (Table 1, Figure 1). These are three of the most widespread and abundant wetland types in Colorado and represent a gradient from high to low elevation in the Colorado River watershed. Big Meadows, Kawuneeche Valley, and Deer Lodge Park were selected for comparison of natural functioning wetlands on a watershed-scale. Brown's Park, located on the Green River 80 km below the Flaming Gorge Dam, is functionally impaired because its flow is regulated by Flaming Gorge Dam, and it is used to contrast the Deer Lodge Park site which is located along the unregulated Yampa River.

Table 1. Study sites in the Upper Colorado River watershed.

Wetland Site	***Wetland Type***	***Location***	***Elevation m***	***Drainage***	***Wetland Area*** *(hectares)*
Big Meadows	sedge fen	Rocky Mountain National Park	2865	Tonahutu Creek	10.14
Kawuneeche Valley	willow-riparian	Rocky Mountain National Park	2700	Colorado River	162.06
Deer Lodge Park	cottonwood-riparian	Dinosaur National. Monument	1705	Yampa River	92.25
Brown's Park	cottonwood-riparian	Brown's Park NWR	1630	Green River	63.77

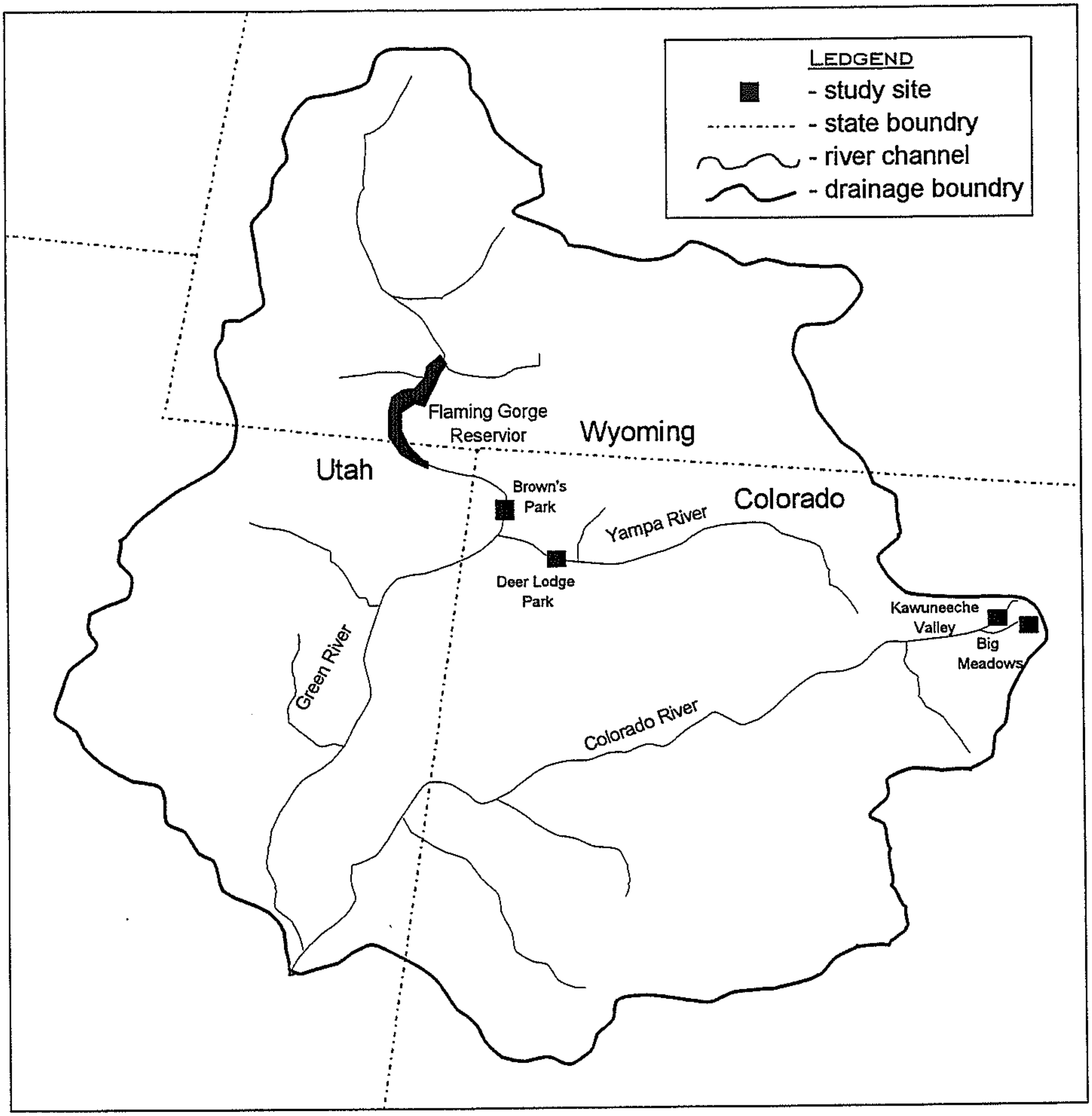

Figure 1. Study area map of the Upper Colorado River watershed.

Sediment Deposition. Sediment deposition was measured at points along transects established within each study site using 400 cm^2 sediment accretion disks (square plates) following the methods of Kleiss (1996). The disks were constructed from black, 0.30 cm thick, textured ABS plastic. A hole was drilled in the center of each disk and a 30 cm long spike or 60 cm long section of rebar (in high flow areas) was used to attach disks flush with the substrate surface. Prior to spring flooding (March to late May), 40-80 disks were installed along 6-9 individual transects in each site. At each site, accretion disks represent several sedimentation zones, at one or two levels of precision, based on elevation and location relative to prominent features (e.g. channel) and physiognomic vegetation cover (e.g. woody vegetation). Each sedimentation zone (per site) was represented by a minimum of 3 accretion disks (n=3).

During the flood recession period accretion disks were collected as surface water levels receded and exposed groups of disks. Disks were carefully excavated to sample the entire mass of sediment deposited. Where thick deposits occurred (>20 cm depth), a subsample was collected. Samples are placed in plastic zip-seal bags and transported to the lab where each sample was dried to a constant weight at 95 ° C in a gravimetric oven and weighed (0.01 g).

At Deer Lodge Park, very high Yampa River peak flows resulted in flooding into unexpectedly high areas. In order to quantify sediment deposition on these higher surfaces, several new transects were added and existing transects were extended to higher elevations after floodwaters receded. Additional sediment samples were collected from new and extended transects at random points by excavation to the pre-flood surface and removal of material and standing vegetation within an area 400 cm^2 in size. When vegetation was collected, adhered sediment was removed by combined soaking and agitating in 1 L bottles filled with de-ionized water. From these samples, total suspended sediments were separated by sieving and evaporation (gravimetric oven). Vegetation adhered mass was combined with surface mass sampled to obtain deposition per unit area on these higher surfaces in Deer Lodge Park.

Sediment deposition measurements were assumed to represent annual rates of sediment accumulation, though small additional deposition may occur during late season storm events and/or by wind deposition.

Sediment Erosion. Stream bank retreat was measured at Kawuneeche Valley, Deer Lodge Park, and Brown's Park to provide an estimate of sediment erosion and sediment export from these wetlands. Erosion losses were not quantified in Big Meadows as eroding channels do not occur in the fen. Bank retreat was measured along transects 30 m long in Deer Lodge Park and Brown's Park, and 10 m long in Kawuneeche Valley. Three transects were established in the Kawuneeche Valley, four in Deer Lodge Park and five in Brown's Park. The transects were oriented parallel to the bank and prior to spring flooding, the distance from the transect line to the bank was recorded at 1 m intervals. These measurements were repeated in the fall after flooding.

Bank height was measured at 3 points along each transect. The total volume of material exported was calculated by geometric subtraction of pre-flood and post-flood measurements. Three, depth stratified, volumetric soil samples were collected from the vertical plane of each cut-bank to measure bulk density, which was used to calculate total mass loss.

Carbon and Nitrogen Analysis. Carbon (C) and nitrogen (N) concentrations were measured from three sediment samples for each sedimentation zone at each site and for all bulk density samples from bank retreat transects. Samples were dried and ground to a powder size prior to analysis. Samples were analyzed for percent C and N using a CHN analyzer (LECO 1000) using 10 percent standards and blanks to ensure calibration accuracy.

Sediment, Carbon, and Nitrogen Mass Balance. Maps of each study site were developed from aerial photographs. Sedimentation zones (identified by vegetation cover, geomorphic features, and relative elevation) were delineated at two levels of precision (primary and secondary), and bank retreat zones (identified by channel form) were delineated at one level of precision, within each site map. Several sedimentation zone spatial units were delineated at a courser level (level 1) on maps when greater precision was not possible. The total area of each sedimentation zone and total distance of each bank retreat zone was determined by digital analysis (Electronic Graphics Calculator) relative to the map scale.

Sediment deposition rates (kg m^{-2} yr^{-1}) and bank erosion rates (kg m^{-1} yr^{-1}) for each sedimentation zone and erosion zone were used to calculate sediment retention and sediment export in each study site. Total deposition and erosion of C and N was calculated using these same sediment data sets but focusing on the C and N concentration in sediments. Spatial measurements were also used to compare the areas receiving sediment deposition, and lengths of eroding banks between study areas.

Carbon Budgets

The harvesting method was used to determine above ground net primary production (ANPP) in Big Meadows (Bartsch & Moore 1985, Francez & Vasander 1995, Chapin & Shaver 1996). Herbaceous vegetation was clipped monthly (June through September) at the ground surface within 0.25m x 0.25m quadrants. Six quadrants were randomly placed in the vegetation types studied. Once clipped, the biomass was put into paper bags, air dried, transferred into plastic bags and stored frozen at Colorado State University. In the lab, the biomass was separated into live and dead components, oven-dried, weighed and analyzed for carbon content using a CHN analyzer. ANPP was calculated as the mean seasonal maximum carbon mass for each site.

Total soil organic carbon in Deer Lodge Park was determined for sites representing the full range of fluvial surface elevations and ages. Soils were collected, dried and ashed in a muffle furnace. Total organic carbon is expressed as a percent of dry soil weight.

In-growth bags were used to determine below ground net primary production (BNPP) for Big Meadows (Neill 1992). Mesh bags 60 cm long and 6 cm in diameter made of fiberglass window screen (1.5 mm mesh) were filled with *Sphagnum* peat moss, and inserted in a hole augured into each study peatland. Six replications of the mesh bags were installed just after snow melt in the spring and collected after the growing season ends in October. Root biomass was determined as the weight of new roots that grew into bags. New roots were collected from the mesh bags, washed free of sediment, oven-dried and weighed to calculate dry weight biomass. Dried roots were analyzed for carbon content using a CHN analyzer. BNPP was calculated as the mean mass of carbon of the six samples.

Carbon dioxide (CO_2) and methane (CH_4) fluxes were quantified using the static chamber method (Lessard et al. 1994, Waddington & Roulet 1996, Melloh & Crill 1996, Shannon et al. 1996, Hutchinson and Mosier 1981), and for this study are assumed to be the only outputs of carbon. Chambers were constructed of opaque plastic tubes of known volume. Tubes were inserted 2 cm into the peat soil and allowed to accumulate CO_2 and CH_4 for 30 minutes. Gas was collected using a nylon syringe inserted through a septum on top of the chamber. An initial gas sample was collected when the chamber was seated, and samples collected again after 15 and 30 minutes. The collected gas was stored in evacuated flasks with tops sealed with silicone for transport and storage. The collected gas samples were analyzed for CO_2 and CH_4 using gas chromatography. Flux rates were calculated by:

$$f = (V/A)(dc/dt)$$

where f is the CO_2 or CH_4 flux density ($\mu mol\ m^{-2}\ s^{-1}$), V is the air volume within the chamber (m^3), A is the soil area within the chamber (m^2) and (dc/dt) is the rate of CO_2 or CH_4 concentration change within the chamber ($\mu mol\ m^{-2}\ s^{-1}$). ANPP and BNPP were estimated for Kawuneeche Valley, Deer Lodge Park and Brown's Park.

Area Weighting

Sediment accretion disks, carbon measurements and bank erosion transects were taken to represent the full range of environments in each study site. However, because a relatively similar number of measurements were taken in each type of environment it produced an uneven weighting of each type of environment relative to the proportion of the landscape that each occupied. For example, we placed a large number of sediment accretion disks on islands in the Green River channel in Brown's Park, even though this type of landform occupied only a small area of the Brown's Park study area. To determine the total contribution of each landform to the total functional budget of each study site, the area occupied by each landform was calculated from air photographs. This land area was used to weight measurements taken from that landform, so that it represented the true contribution of that landform to the functional budget of each site. Similarly with bank retreat measurements bank types were classified as straight, outside meander, and inside meander reaches. The total length of each type in each study area was used to weight the mean measurements for each type to determine the total bank retreat in each study area, and the total sediment, C and N exported from each site.

Results

Sediment Deposition. Sediment deposition rates increased from the high to the low elevation study sites. Mean sediment deposition rates increased by approximately one order of magnitude between Big Meadows (0.14 kg m^{-2} yr^{-1}), Kawuneeche Valley (4.3 kg m^{-2} yr^{-1}), and Deer Lodge Park (36 kg m^{-2} yr^{-1}). Sediment deposition rates varied by up to an order of magnitude within study sites (Table 2). Mean sediment deposition rates were higher in Brown's Park (58 kg m^{-2} yr^{-1}) than Deer Lodge Park (36 kg m^{-2} yr^{-1}) (Fig. 2), although sediment deposition occurred in only a relatively small area in Brown's Park. A comparison of area weighted averages indicated that there were no differences between Big Meadows and Brown's Park, however sample and weighted means were different between Kawuneeche Valley and Deer Lodge Park (Fig. 2). While total sediment retention within study sites increased from Big Meadows to Kawuneeche Valley to Deer Lodge Park and Brown's Park, within site variance was similar among sites (Table 2).

In Brown's Park, islands within the Green River channel had the highest sediment deposition rates, 107 kg m^{-2} yr^{-1}, of any area measured in all study sites. In particular unvegetated areas on islands had very high deposition rates 244 kg m^{-2} yr^{-1}. On unregulated rivers, inside-meander bars typically have the highest sediment deposition rates, and deposition was an order of magnitude higher in Deer Lodge Park, 76 kg $m^{-2}yr^{-1}$, than in the Kawuneeche Valley, 7.9 kg m^{-2} yr^{-1}.

The lowest landscape positions in each study site were most similar between sites, with regard to sediment deposition rates, compared with higher landscape positions which were quite variable between sites (Table 2). Because Big Meadows is a slope as opposed to a riverine wetland, its landscape features are not comparable to the riverine sites. In addition, sediment deposited in Big Meadows was highly organic and deposition rates were very similar throughout the site.

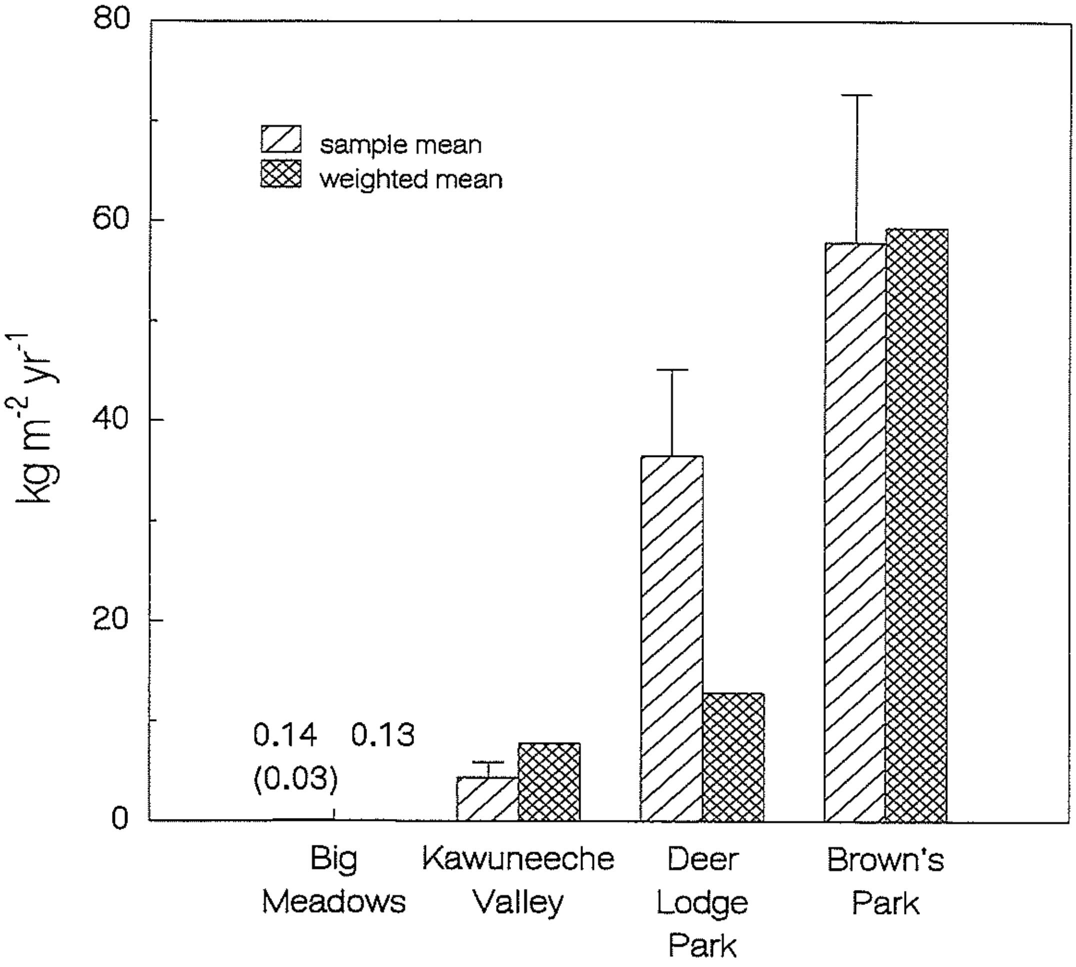

Figure 2. Sediment deposition rates for all sample sites. Deposition rates (error bars are +1 se) for all sediment disk samples are in boxes with slanted lines, while weighted means based upon landform areas are in hatched boxes.

Table 2. Sediment deposition rates for primary (numbered) and secondary (letters) sedimentation zones and total retention rates for primary sedimentation zones for study sites in 1997 (%SE of Mean = the standard error divided by the mean)

Wetland Site	**Primary and Secondary Sedimentation Zones**	**Deposition** kg m^{-2} yr^{-1} (SE)	**Total Retention** (Mt ha^{-1} yr^{-1})
Big Meadows	1. upland margin	0.11 (100)	0.15
	2. willow fringe	0.02 (100)	0.03
	3. peatland expanse	0.19 (21)	1.15
	a) main complex	0.13 (23)	-
	b) northern area	0.29 (35)	-
Kawuneeche Valley	1. channel side-bar	7.92 (39)	2.43
	a) bare substrate	10.18 (59)	-
	b) vegetated substrate	7.84 (65)	-
	c) micro-channels/depressions	4.37 (41)	-
	2. inside-meander lowlands	1.38 (37)	0.23
	a) bare substrate	3.42 (41)	-
	b) vegetated hummocks	0.45 (54)	-
	c) vegetated depressions	0.85 (75)	-
Deer Lodge Park	1. inside-meander bar	75.72 (23)	24.82
	a) ridges	101.32 (25)	-
	b) swales	37.30 (32)	-
	2. inside-meander floodplain	5.76 (90)	0.53
	a) herbaceous vegetation	0.47 (38)	-
	b) woody vegetation	7.83 (93)	-
	3. terrace	8.61 (76)	1.96
	a) bank edge	31.08 (94)	-
	b) terrace surface	2.72 (28)	-
Brown's Park	1. channel island	106.60 (26)	32.57
	a) bare substrate	244.17 (37)	-
	b) herbaceous vegetation	56.83 (20)	-
	c) woody vegetation	70.95 (41)	-
	2. floodplain/terrace	9.24 (67)	0.98
	a) bare substrate	36.56 (64)	-
	b) vegetated substrate	0.84 (21)	-
	3. backwaters	6.21 (14)	0.44
	a) bare substrate	8.33 (12)	-
	b) vegetated substrate	4.70 (29)	-
	c) channel edge	5.51 (33)	-

Sediment Erosion. Banks in many areas were stable, particularly along the downstream portions of outside-meander bends in Brown's Park (0.01 m). In other areas more than 2 m of retreat was measured, eg. along the downstream portions of outside-meander bends in Deer Lodge Park (Fig. 3). The greatest bank erosion was measured along a lower meander reach at Deer Lodge Park (contribution to the Yampa River was 5530 kg m^{-1} yr^{-1}). Bank retreat within the Kawuneeche Valley was less variable (range of 0.24 - 0.60 m) than other study sites. Bank retreat was greater in the downstream than upstream portions of outside meander bends in Deer Lodge Park, 1.6 m vs. 0.54 m, respectively. The opposite trend occurred in Brown's Park where the upstream outside meander banks retreated faster (1.35 m) than downstream bends (0.05 m) (Table 3).

Erosion rates (kg m^{-1} yr^{-1}) per m of bank were an order of magnitude higher in the cottonwood forest sites (3000 kg m^{-1} yr^{-1} at Deer Lodge Park, and 1240 kg m^{-1} yr^{-1} at Brown's Park) than in the Kawuneeche Valley (300 kg m^{-1} yr^{-1}). Erosion rates were more variable in Brown's Park than in other sites, ranging from 45 kg m^{-1} yr^{-1}in lower meanders to 3000 kg m^{-1} yr^{-1}in upper meanders (Table 3).

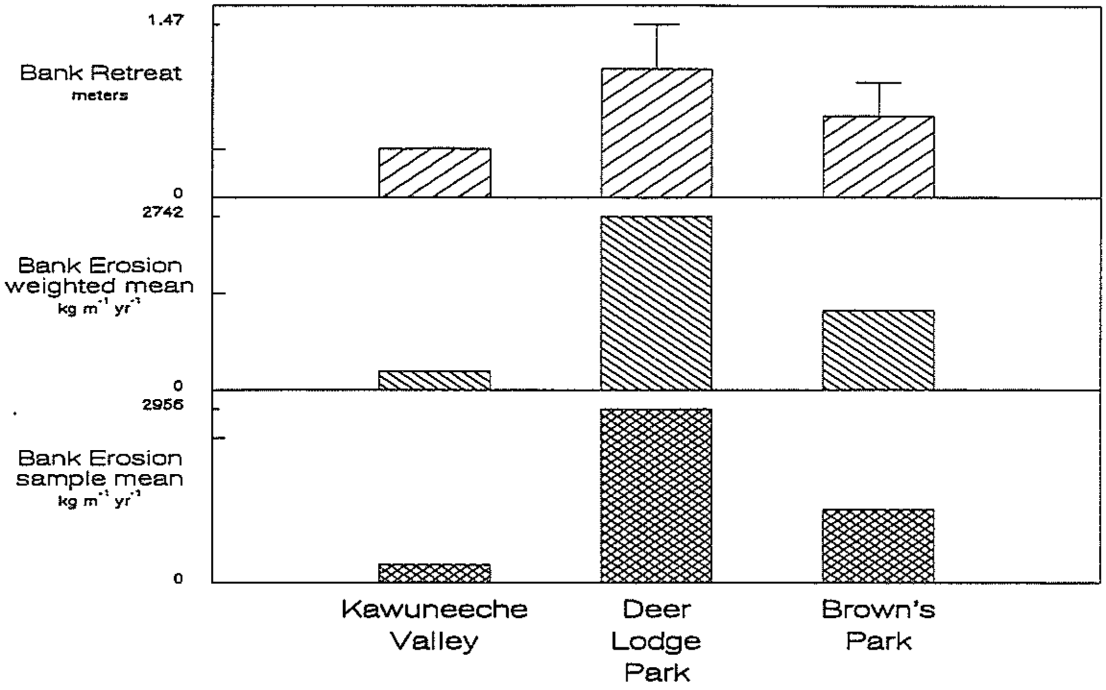

Figure 3. Bank retreat and bank erosion rates, both sample means (with SE bars) and spatially weighted means, for riparian study sites in 1997.

Table 3. Bank retreat, bank erosion rates, and total sediment export from riverine bank features (bank erosion zones) for riparian study sites in 1997 (upper is the upstream portion and lower is the downstream portion of the outside meander bend).

Study Site	Bank Erosion Zones	Bank Retreat distance in m (se.)	Erosion ($kg\ m^{-1}\ yr^{-1}$)	Total Export ($Mt\ ha^{-1}\ yr^{-1}$)
Kawuneeche Valley	1. back eddy	0.38 (0.045)	267.2	0.79
	2. strong meander (upper)	0.60 (0.038)	274.8	0.43
	3. strong meander (lower)	0.24 (0.032)	376.5	0.65
Deer Lodge Park	1. mild meander (upper)	0.64 (0.013)	2145.1	6.92
	2. mild meander (lower)	1.14 (0.009)	2576.5	15.14
	3. strong meander (upper)	0.43 (0.013)	1572.8	5.45
	4. strong meander (lower)	2.13 (0.028)	5529.5	15.26
Brown's Park	1. terrace cut-bank (upper)	1.39 (0.015)	2893.3	88.04
	2. terrace cut-bank (middle)	0.68 (0.017)	1538.6	41.38
	3. terrace cut-bank (lower)	0.08 (0.006)	42.0	1.10
	4. strong meander (upper)	1.30 (0.008)	1669.6	45.4
	5. strong meander (lower)	0.01 (0.001)	47.8	1.43

Sediment Mass Balance. The Kawuneeche Valley study site accumulated more sediment than eroded (0.80 Mt ha^{-1} yr^{-1}) during 1997, and had the highest sediment gain to sediment erosion ratio, 1.43. Both cottonwood riparian sites had greater erosion than deposition during 1997; however net loss was more than six times greater in Brown's Park, 96.5 Mt ha^{-1} yr^{-1}, than Deer Lodge Park, 15.5 Mt ha^{-1} yr^{-1}. A sediment mass balance was not calculated for Big Meadows because erosion could not be calculated as no banks are present in the fen, and surface scour does not occur. However, a total of 1.34 Mt ha^{-1} yr^{-1} of sediment was deposited in Big Meadows; one and two orders of magnitude less than in the Kawuneeche Valley and cottonwood riparian sites, respectively (Table 4).

Table 4. Sediment mass balance calculated from sediment deposition and bank erosion measurements for study sites in 1997.

Wetland Site	Sediment Retention (Mt ha^{-1} yr^{-1})	Sediment Export (Mt ha^{-1} yr^{-1})	Balance (Gain - Loss) (Mt ha^{-1} yr^{-1})	Ratio (Gain : Loss)
Big Meadows	1.34	-	-	-
Kawuneeche Valley	2.66	1.86	+0.80	1.43
Deer Lodge Park	27.31	42.78	-15.47	0.64
Brown's Park	33.99	130.52	-96.53	0.26

Total sediment retention per hectare of study site during 1997 was relatively similar for the two large river study areas, 27.3 Mt ha^{-1} in Deer Lodge Park vs. 34.0 Mt ha^{-1} in Brown's Park, however deposition rates on Brown's Park surfaces where deposition occurred were higher than deposition rates in Deer Lodge Park. The percentage of study area functioning in sediment retention was 21% in Deer Lodge Park yet only 6% in Brown's Park (Figure 4). With respect to sediment export, the opposite trend occurred between these two study sites. In Deer Lodge Park, 31% of the total bank distance contributed 42.8 Mt ha^{-1} yr^{-1} of sediment, while at Brown's Park, 57% of the total bank distance contributed 130.5 Mt ha^{-1} yr^{-1} of sediment (Table 4). The differences in the area where deposition occurred vs. the area where bank erosion occurred, explain the differences in sediment flux between Deer Lodge Park and Brown's Park.

In Big Meadows, the central sedge-dominated fen interior comprises 70% of the fen area, and retained the majority of sediment, 85% for a total of 1.15 Mt ha^{-1} yr^{-1}. The entire fen complex is inundated annually and possibly the entire fen functions in sediment accumulation. In the Kawuneeche Valley relatively narrow point bars account for 91% of the sediment retention, 2.43 Mt ha^{-1} yr^{-1} (Table 3). Similar bars in Deer Lodge Park accounted for 90% of the sediment retention, 24.8 Mt ha^{-1} yr^{-1}. Small linear bars formed in the lee of established cottonwood saplings in Deer Lodge Park accounted for approximately 4% of the area functioning to retain sediment, but retained 34% of the total sediment (9.0 Mt ha^{-1} yr^{-1}). In Brown's Park, in-channel islands consisting of emergent chute bars, accounted for 95% of the sediment retention, 32.6 Mt ha^{-1} yr^{-1}, while backwater and floodplain features accounted for only 1.4 Mt ha^{-1} yr^{-1} (3%) of sediment retention.

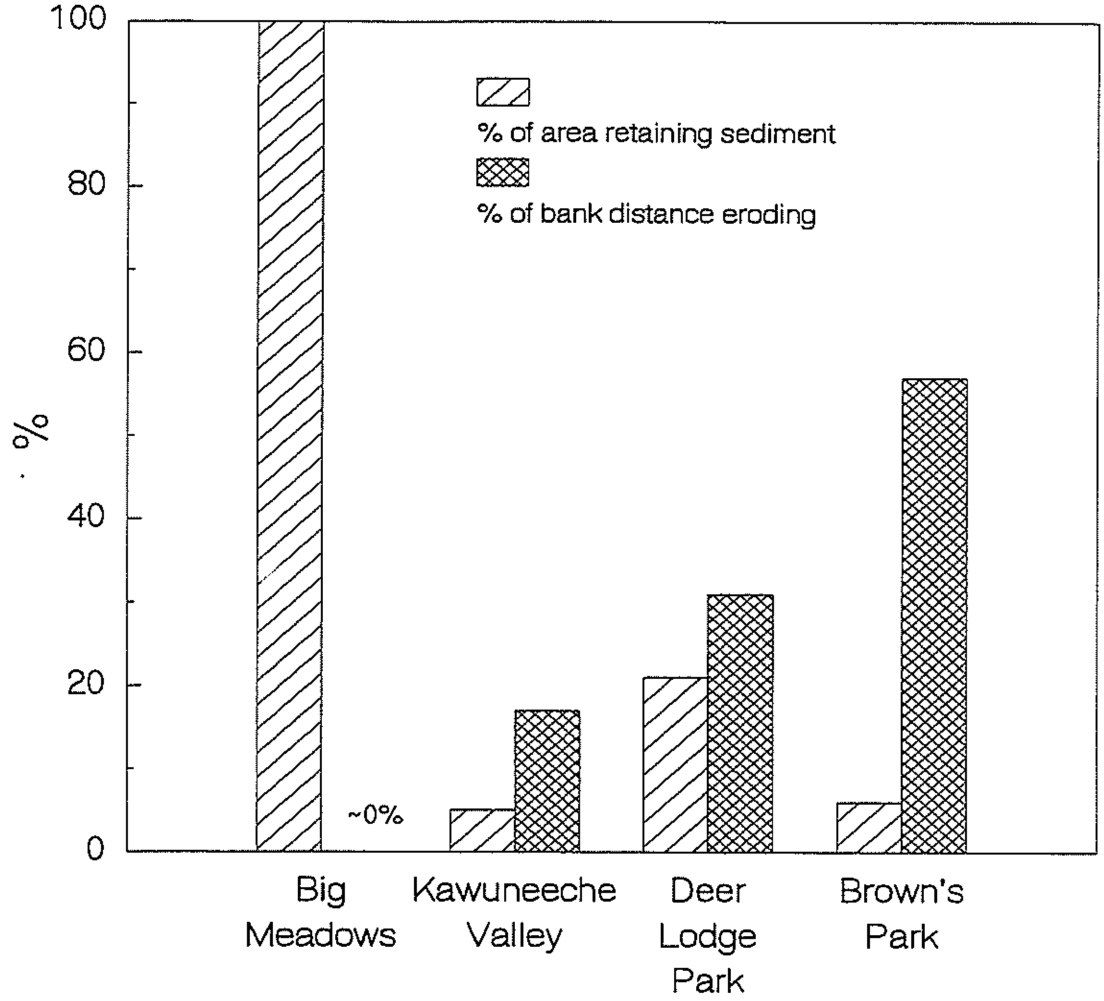

Fig. 4. Proportions of wetland areas or bank lengths functioning in sediment retention and erosion in 1997.

Carbon and Nitrogen Deposition. The concentrations of C and N in sediment was much higher in Big Meadows (37.3% and 0.53%, C and N, respectively) than sediment from the other study sites (mean of 2.6% and 0.13%, C and N respectively) (Fig. 5). The highest total C and N deposition occurred on the in-channel island in Brown's Park (1.9 kg m^{-2} yr^{-1} and 0.05 kg m^{-2} yr^{-1}, respectively) (Figure 6).

C:N ratios were 38 in Brown's Park, 70 in Big Meadows, 16 and 17 for the Kawuneeche Valley and Deer Lodge Park respectively. Higher rates of N accumulation occurred in the Kawuneeche Valley and Deer Lodge Park, relative to Big Meadows and Brown's Park.

In general, areas such as Big Meadows, with low sediment deposition rates had the highest sediment C and N concentrations. In addition, sediment deposited in lower floodplain positions, such as in-channel islands in Brown's Park and inside-meander bars in Deer Lodge Park, had lower C and N concentrations, than sediment deposited on higher floodplain and terraces in these same areas. The higher C and N concentrations on high landscape positions, however, contributed relatively little to the overall amounts of C and N totals received as little sediment was deposited in higher areas. In Big Meadows, there was little variability in C and N concentrations in the sediments deposited (1-9% standard error of the mean). We found a general trend of decreasing variability in C and N concentration on higher elevation surfaces which had lower sediment deposition rates (Table 5).

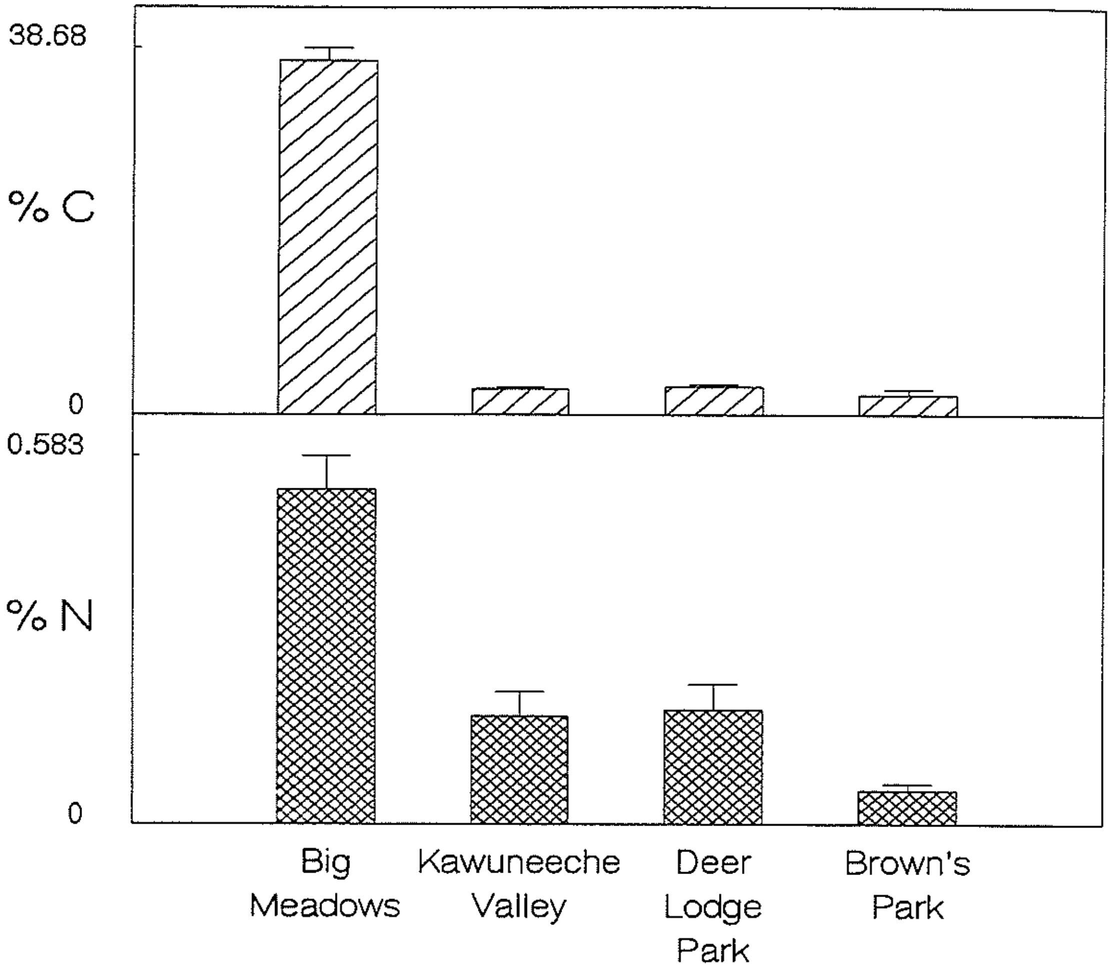

Figure 5. Mean C and N concentrations in sediment deposited in study sites during 1997. Error bars are + 1 se.

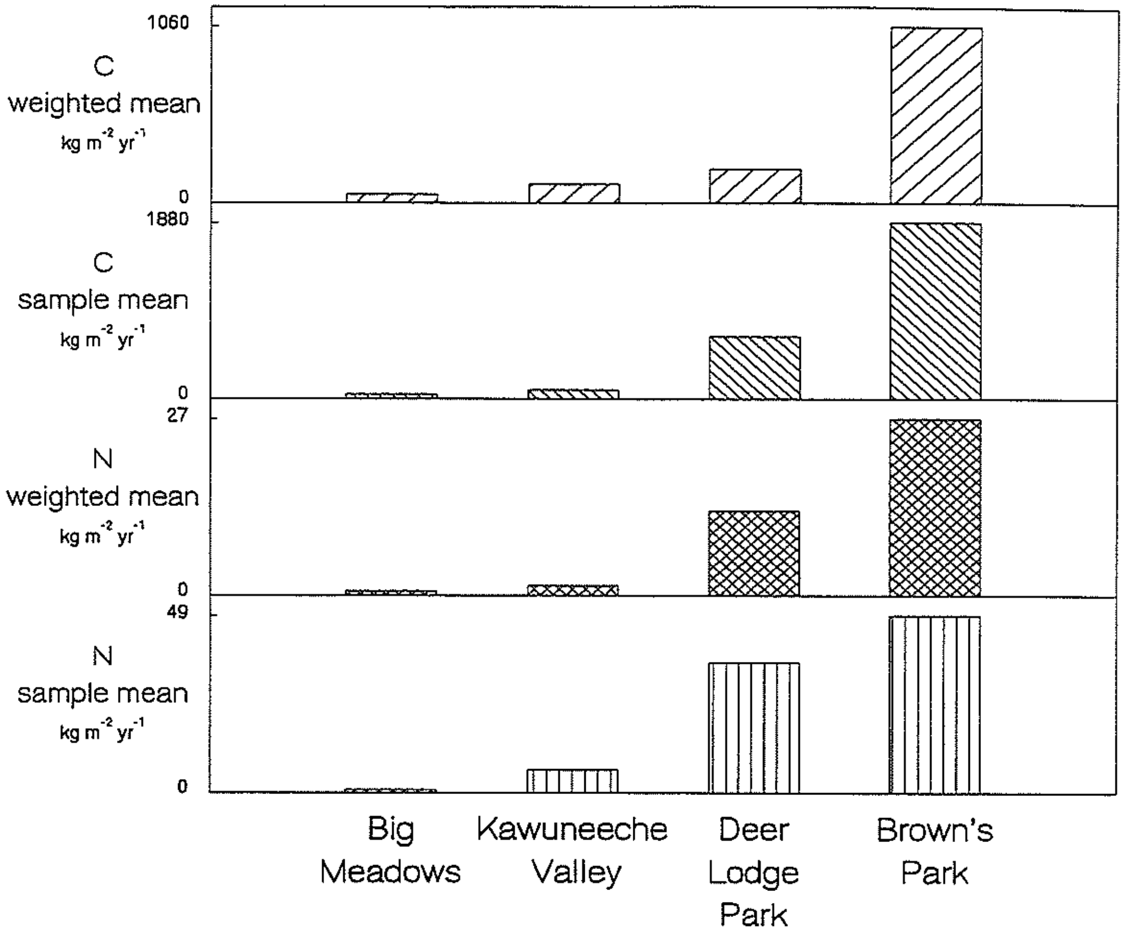

Figure 6. Sample and spatially weighted sample mean C and N deposition rates for study sites in 1997.

Table 5. Mean carbon and nitrogen concentrations in sediment, and sediment deposition rates for primary and secondary sedimentation zones at study sites in 1997 (%SE = the standard error divided by the mean; numbered sedimentation zones are primary and lettered sedimentation zones are secondary).

Wetland Site	Primary and Secondary Sedimentation Zones	%C (%SE)	C Deposition (kg m^{-2} yr^{-1})	%N (%SE)	N Deposition (kg ·m^{-2} yr^{-1})
Big Meadows	1. upland margin	36.2 (-)	0.040	0.40 (-)	0.0004
	2. willow fringe	28.3 (-)	0.006	0.34 (-)	0.0001
	3. peatland expanse	38.9 (1)	-	0.59 (4)	-
	a) main peatland	38.2 (1)	0.050	0.58 (3)	0.0008
	b) upper area	39.7 (2)	0.115	0.60 (9)	0.0017
Kawuneeche Valley	1. channel side-bar	2.4(56)	0.192	0.14(34)	0.011
	a) bare substrate	0.4(20)	0.038	0.04(40)	0.004
	b) vegetated substrate	2.9(13)	0.198	0.17(13)	0.011
	2. inside-meander lowlands	2.9(20)	-	0.19(22)	-
	a) bare substrate	1.3(52)	0.044	0.08(41)	0.003
	b) vegetated substrate	4.0(13)	0.024	0.26(16)	0.002
Deer Lodge Park	1. inside-meander bar	1.6(18)	-	0.08(19)	-
	a) ridges	1.6(11)	1.66	0.08(17)	0.080
	b) swales	1.6(39)	0.59	0.08(40)	0.030
	2. inside-meander floodplain				
	a) herbaceous vegetation	2.4(14)	-	0.12(25)	-
	b) woody vegetation	2.5(18)	0.01	0.13(32)	0.001
	3. terrace	2.1 (-)	-	0.10 (-)	-
	a) bank edge	5.2(24)	-	0.35(26)	-
	b) terrace surface	2.9(51)	0.89	0.19(63)	0.058
		6.8(17)	0.18	0.46(18)	0.013
Brown's Park	1. channel island	1.7(17)	1.85	0.04(22)	0.080
	a) bare substrate	1.9(41)	4.57	0.04(43)	0.090
	b) herbaceous vegetation	1.8(31)	1.00	0.04(46)	0.024
	c) woody vegetation	1.6(24)	1.15	0.05(37)	0.032
	2. floodplain/terrace	2.7(26)	-	0.08(29)	-
	a) bare substrate	1.7(34)	0.62	0.05(10)	0.016
	b) vegetated substrate	4.1(17)	2.14	0.12(28)	0.057
	3. backwaters	2.1 (8)	1.84	0.05(17)	0.041
	a) bare substrate	2.4 (8)	-	0.05(11)	-
	b) vegetated substrate	2.1(19)	-	0.06(41)	-
	c) channel edge	1.9 (3)	-	0.04 (0)	-

Carbon and Nitrogen Export. Soil in banks that eroded into the Colorado River in the Kawuneeche Valley had higher C and N concentrations (7.4% and 0.83%, respectively) than soils from banks in the cottonwood riparian sites (mean of 1.5% and 0.12%, respectively). This translates into higher C and N export rates per unit bank distance in the Kawuneeche Valley, even though erosion rates were relatively low. Banks in Deer Lodge Park had slightly lower soil C and N concentrations (1.2% and 0.06%, respectively) than Brown's Park (1.7% and 0.11%, respectively) (Fig. 7). Carbon export rates were higher in Deer Lodge Park (24.7 kg m^{-2} yr^{-1}) than Brown's Park (16.6 kg m^{-2} yr^{-1}). However, because the total mass of sediment eroded in Brown's Park was much higher than total erosion in Deer Lodge Park, more carbon was input to the Green River in Brown's Park. Nitrogen export rates were similar in Deer Lodge Park (1.7 kg m^{-2} yr^{-1}) and Brown's Park (1.9 kg m^{-2} yr^{-1}) (Figure 8, Table 6). The variability of C and N concentrations on sediment were generally high in all riparian areas.

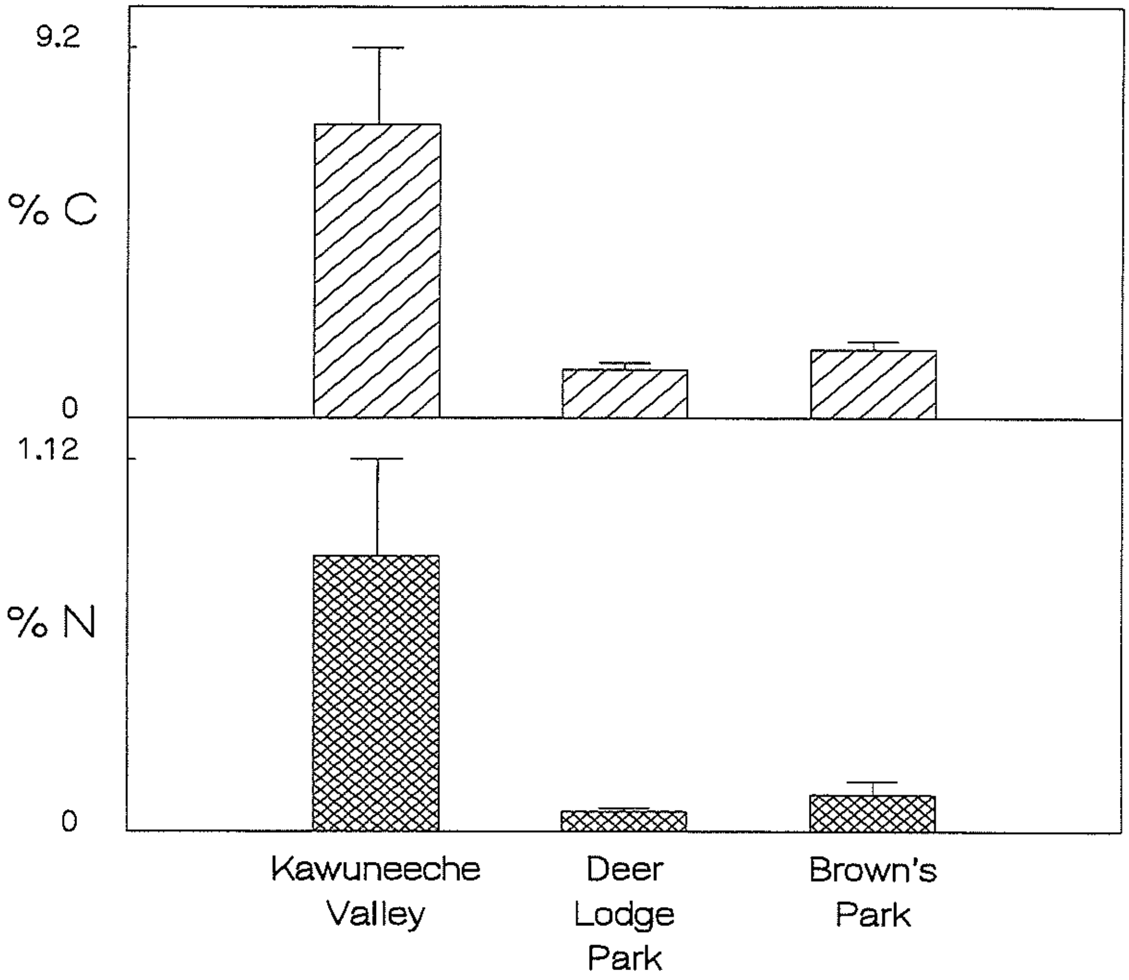

Figure 7. Mean carbon and nitrogen concentrations in bank soils eroded into adjacent rivers for riparian study sites in 1997. Error bars are +1 se.

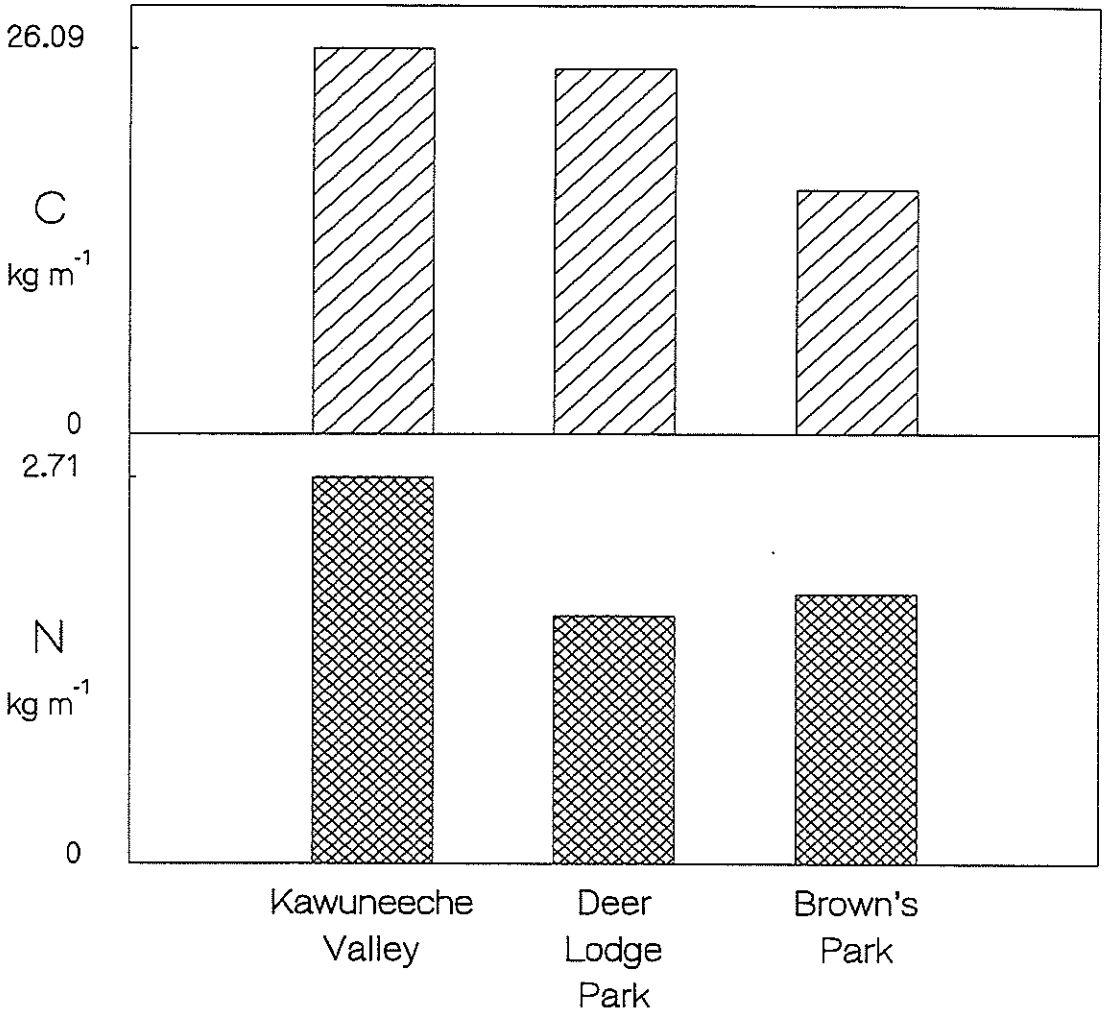

Fig. 8. Mean rates of carbon and nitrogen export from bank erosion for Upper Colorado River riparian study sites in 1997.

Table 6. Mean bank soil carbon and nitrogen concentrations and export rates from bank erosion in different riverine bank features (bank erosion zones) for riparian study sites in 1997.

Wetland Site	Bank Erosion Zones	Soil (% SE)		Erosion (kg m^{-1} yr^{-1})	
		%C	%N	C	N
Kawuneeche Valley	1. back eddy	2.4(25)	0.17(23)	23.9	1.7
	2. strong meander (upper)	13.5 (5)	1.90(20)	37.1	5.2
	3. strong meander (lower)	6.2(53)	0.47(66)	17.4	1.3
Deer Lodge Park	1. moderate meander (upper)	1.1(49)	0.05(53)	23.0	1.0
	2. moderate meander (lower)	1.4(28)	0.08(38)	37.8	2.1
	3. strong meander (upper)	1.1(22)	0.04(29)	16.9	0.6
	4. strong meander (lower)	1.1(28)	0.06(35)	21.2	3.2
Brown's Park	1. terrace cut-bank (upper)	1.4(24)	0.33(48)	38.8	8.4
	2. terrace cut-bank (middle)	0.7(32)	0.02(22)	10.9	0.3
	3. terrace cut-bank (lower)	2.6(10)	0.10(34)	2.7	0.1
	4. strong meander (upper)	1.8 (7)	0.04(18)	29.6	0.6
	5. strong meander (lower)	2.0(20)	0.08(20)	0.9	<0.1

Sediment Carbon and Nitrogen Mass Balance. Deposition of C and N was nearly identical to erosion of C and N in Deer Lodge Park (gain : loss ratio = 1.04). A net loss of C and N occurred in the Kawuneeche Valley (-107 kg ha^{-1} yr^{-1} and -12 kg ha^{-1} yr^{-1}, respectively). A net loss of C and N occurred from the Brown's Park floodplain (-694 kg ha^{-1} yr^{-1} and -242 kg ha^{-1} yr^{-1}, respectively).

Table 7. Carbon mass balance from sediment deposition and bank erosion for riparian study sites in 1997.

Wetland Site	Carbon Deposition (kg ha^{-1} yr^{-1})	Carbon Export (kg ha^{-1} yr^{-1})	Balance (Gain - Loss) (kg ha^{-1} yr^{-1})	Ratio (Gain : Loss)
Kawuneeche Valley	50.6	158.0	-107.4	0.32
Deer Lodge Park	431.4	415.2	16.2	1.04
Brown's Park	1677.9	2372.6	-694.7	0.71

Table 8. Nitrogen mass balance from sediment deposition and bank erosion for study sites in 1997.

Wetland Site	Nitrogen Retention (kg ha^{-1} yr^{-1})	Nitrogen Export (kg ha^{-1} yr^{-1})	Balance (Gain - Loss) (kg ha^{-1} yr^{-1})	Ratio (Gain : Loss)
Kawuneeche Valley	3.0	15.2	-12.2	0.20
Deer Lodge Park	27.4	26.5	0.9	1.04
Brown's Park	41.4	283.8	-242.4	0.15

Long-Term Carbon Storage Model

One method of determining long-term carbon storage is to develop a carbon budget for each study site. This approach is costly and likely impossible for large and heterogeneous study sites such as the Kawuneeche Valley or Deer Lodge Park. We used an alternate approach for estimating long-term carbon storage. Percent soil carbon was used as a long-term measure of carbon storage in our study sites. This has the advantage of being easily sampled and allows sampling over a large areas. Percent soil carbon is a long-term integrator of plant production minus plant consumption and decomposition. Figure 9 presents a chronosequence of total soil organic carbon content for Deerlodge Park which shows the rapid accumulation of carbon to 3% in the first 30 years of primary succession and a slowing of C accumulation over time.

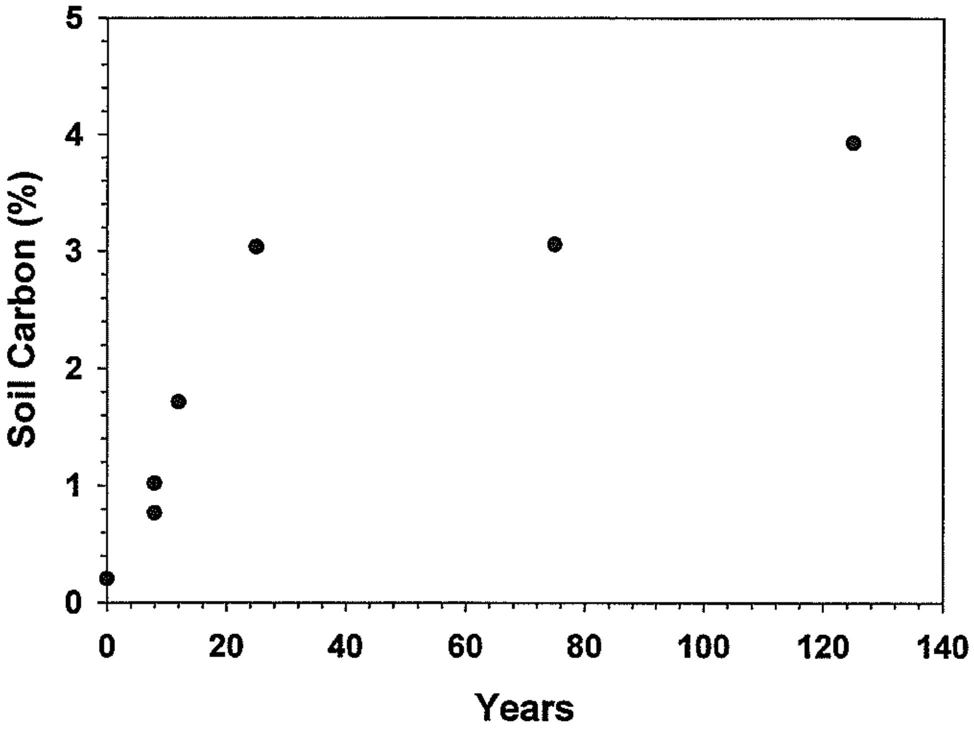

Figure 9. Chronosequence of soil carbon content in Deerlodge Park.

A conceptual model of long-term carbon storage on a watershed scale is presented in Figure 10. The model is built on several testable ecological assumptions: 1) soil carbon storage rates are controlled primarily by decomposition rates rather than net primary productivity (NPP), 2) colder mean annual air (and soil) temperatures at higher elevations reduce decomposition rates, 3) longer periods of inundation or soil saturation support lower soil redox potentials and colder soils, both of which strongly decrease decomposition rates (Mitsch and Gosselink 1993).

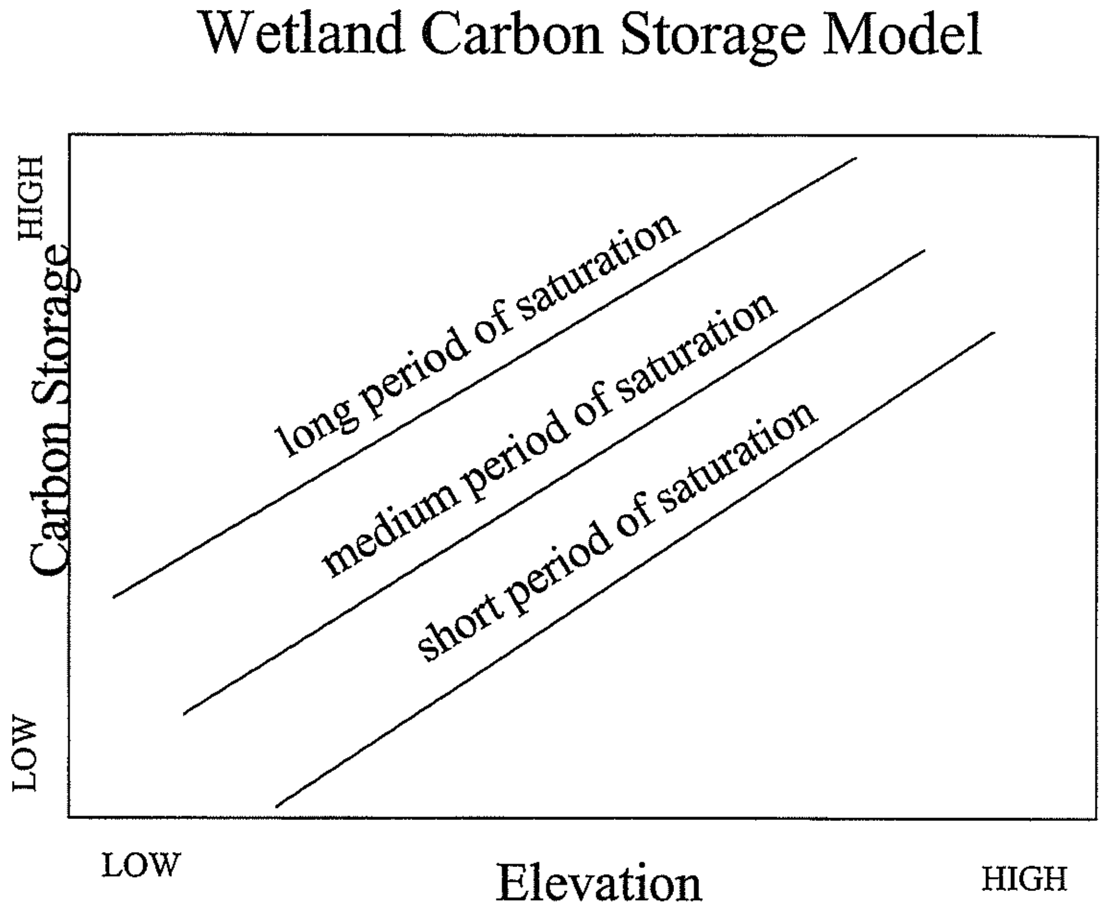

Figure 10. Conceptual long-term carbon storage model on a watershed scale.

This model predicts that high elevation wetlands will store more carbon than lower elevation wetlands due to cooler soil temperatures. The model also predicts that wetlands with longer duration growing season soil saturation will store more carbon than wetlands with shorter periods of soil saturation. Figure 11 is a model prediction of carbon storage at our study sites, based upon their elevations, and period of soil saturation

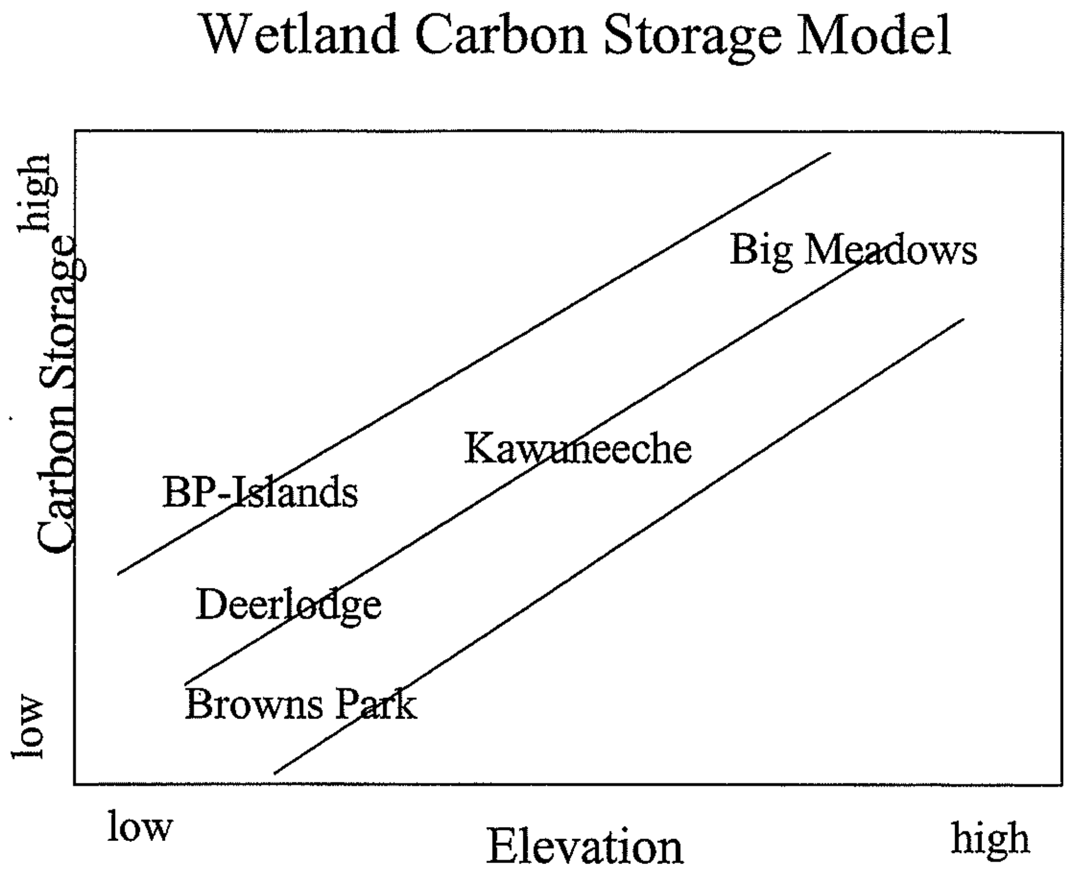

Figure 11. Long-term carbon storage model predictions for 1997 HGM study sites. Kawuneeche is Kawuneeche Valley, Deerlodge is Deer Lodge Park, BP-Island are the in-channel islands in Brown's Park.

Figure 12 plots the log of percent soil carbon of study site soils during 1997 vs. site elevation. It indicates that our linear conceptual models (presented in Figures 10 and 11) provide a useful prediction of carbon storage for our study sites. Among the low elevation sites, soils on the mid-channel island in Brown's Park had the highest carbon content, followed by Deerlodge Park floodplains, with the lowest carbon content found on the seldom-flooded Brown's Park terrace. The carbon content of Kawuneeche Valley soils is higher than the low elevation sites, and provides a reasonable verification of our prediction. However, our linear conceptual models inaccurately predict carbon stored in higher elevation sites, such as Big Meadows. The relationships among soil carbon storage rates and soil saturation or site elevation are best represented as a log-linear relationship.

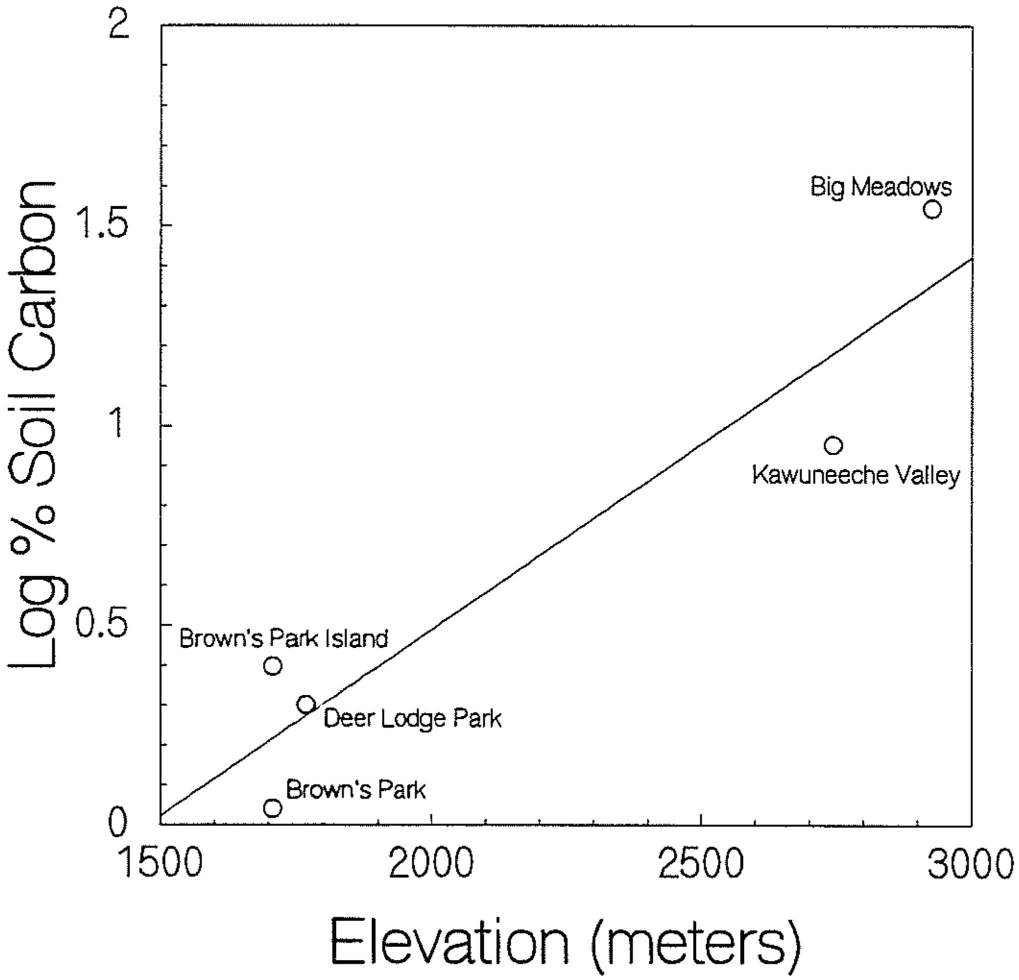

Figure 12. Log of mean percent carbon for study site soils plotted vs. site elevation in meters. The regression line has an r^2 of 0.894, with P=0.0151.

Carbon Budgets

A carbon budget was developed for each study site to present data on carbon production, decomposition, and storage for the study sites (Table 9). The carbon budgets represent study site averages using best available information and are averages for each study site. Because of the great variation in production, decomposition rates and storage for different portions of each site, the mean values presented here are for comparison of carbon storage rates and processes among wetland types.

Table 9. Estimated carbon budgets for the four study sites. NPP = net primary productivity, Dec = microbial decomposition, Dep = deposition of carbon on sediments, E = erosion of carbon on sediments, S = long-term carbon storage. BM is Big Meadows, KV is Kawuneeche Valley, DL is Deer Lodge Park, BP is Brown's Park.

Carbon Budgets

Site	NPP $gCm^{-2}yr^{-1}$	Dec $gCm^{-2}yr^{-1}$	Dep $gCm^{-2}yr^{-1}$	E $gCm^{-2}yr^{-1}$	S $gCm^{-2}yr^{-1}$
BM	159	136	0	0	23
KV	200	181	5	16	8
DL	227	222	43	42	7
BP	227	164	168	237	7

There is a relatively small difference in NPP between the four study sites. The relative importance of erosion and deposition processes on wetland carbon storage or loss is illustrated by the data in Table 9. Erosion and deposition processes play an important role in carbon storage functions on alluvial floodplains, but play no role in Big Meadows. This implies that on an acre for acre basis more carbon can exported to aquatic systems from low-elevation floodplain systems when compared with high-elevation groundwater-driven peatlands. Although some small amounts of dissolved organic carbon leave peatland systems and enters aquatic systems, no measurements were made. However, since the Deer Lodge Park and Brown's Park systems are along the largest rivers in the region, and there are hundreds of peatlands like Big Meadows in each river's watershed, the carbon export function of peatlands is cumulatively high.

Microbial decomposition rates appear to be slower in Big Meadows than the other study sites due to long periods of soil anaerobiosis which results in low CO_2 fluxes (Table 10). Big Meadows was the only study site at which we measured a significant CH_4 flux during the summer. This is another indicator of the highly reducing soil environment in Big Meadows.

Table 10. Range of carbon dioxide and methane fluxes for three study sites during 1997.

SITE	**CO_2** ($mg\ m^{-2}\ s^{-1}$)	**CH_4** ($\mu g\ m^{-2}\ s^{-1}$)
Brown's Park	-4.5 to 21.9	13.0 to 90.6
Deer Lodge Park	1.8 to 21.2	-6.6 to -.8
Big Meadows	0.38 to 12.6	3.1 to 4113.4

We found large between-site differences in long-term carbon storage (Table 9). Big Meadows has the lowest rate of NPP but the greatest rate of long-term carbon storage. This tentatively confirms our assumption that decomposition, not the rates of NPP, control carbon storage. One aspect of carbon storage that must be accounted for is time. As shown in Figure 9, soil carbon storage in Deerlodge is rapid in the initial stages of primary succession, but quickly reaches a steady state condition with little additional carbon storage due to aerobic decomposition by microbes. These data support the concept that alluvial floodplain sites store small amounts of carbon and for relatively short periods of time. This is due to the high rates of decomposition and dynamic fluvial processes that regularly erode soils and export carbon to the adjacent river. On the other hand, Big Meadows has been storing carbon for nearly 12,000 years (Cooper 1990).

Discussion

Retention of Particulates (Sediment Retention Function). Sediment retention and bank erosion rates increased from high to low elevations between our four study sites in the upper Colorado River watershed. This is illustrated by comparing sediment retention patterns from Big Meadows to Deer Lodge Park, which occur in different watershed positions, and at different elevations. This trend is predicted by conceptual watershed models as well as differences in hydrologic regimes between these sites. The intra-riparian continuum, proposed by Johnson and Lowe (1985), suggests transitions from a high elevation region of sediment erosion, to a middle elevation region of sediment storage and transport, to a low elevation region of sediment deposition in large watersheds.

Our studies indicate that less sediment is eroded from or was deposited in wetlands in Big Meadows and the Kawuneeche Valley. Deer Lodge Park appears to function as both a storage and a transport zone. An enormous amount of sediment is transported down the Yampa River annually, with only a small fraction retained on the floodplains. By comparison in Brown's Park little sediment is retained and sediment erosion and export are very high. These data indicate that the relatively sediment-free Green River is eroding the Brown's Park banks.

There is little data that can be used to assess the sediment retention functioning of wetlands at a watershed-scale or functional-scale (Johnston 1991), particularly in the western U.S. (Brinson 1993), thus our data provide a preliminary look at how western wetlands and watersheds may function. Most previous investigations of wetland sediment retention have focused on individual sites with the goal of quantifying sediment retention patterns relative to a number of physical factors, such as microtopography (Johnston 1991, Mitsch and Gosselink 1993). Fluvial geomorphologic theory predicts sediment deposition in riparian areas to increase from river terraces to floodplains to bars (high to low landscape positions) (Ritter et al. 1995), as we found in Deer Lodge Park. Deer Lodge Park was also the only site with periodically inundated ridges, swales and other fluvial features. The Deer Lodge ridges had very high sediment deposition rates (~100 kg m^{-2} yr^{-1}), but high deposition rates were also measured in swales (40 kg m^{-2} yr^{-1}). Kleiss (1996) reported similar sediment deposition patterns from the Cache River in Mississippi. These patterns contrast other studies which found lower sediment deposition rates in swales and backwaters (Johnston et al. 1984, Ritter et al. 1995). Sediment retention patterns in Brown's Park are distinct from Deer Lodge Park because the regulated flow and sediment-free water is driving channel and floodplain evolution processes creating a braided river with mid-channel islands (Merritt 1997). In-channel islands are the only regularly flooded floodplain feature in Brown's Park, receiving ~95% of the deposited sediment. Less than 5% of the sediment was retained on the very wide floodplain and terrace in Brown's Park during 1997, due to the experimental bypass flow (8,700 cfs) was the second highest flow since the completion of Flaming Gorge Dam in 1962. Even under experimental high flows, deposition in Brown's Park was limited primarily to islands. Differences between regulated and unregulated riparian wetlands was expected, but the differences were more dramatic than we expected.

In Big Meadows, a slope wetland, the type and source of sediment, and retention process are different than the riparian wetland study sites. Sediment deposited in Big Meadows was largely autochthonous organic matter derived from previous years' leaf litter that is redistributed within Big Meadows. This source is distinct from the mineral sediment transported and deposited in riparian wetlands through fluvial transport processes from higher in the watershed. Sediment deposition rates in Big Meadows ranged from 20 g m^{-2} yr^{-1} to 300 g m^{-2} yr^{-1} in different areas. Other peatland studies report sediment deposition rates from 300 g m^{-2} yr^{-1} to over 1000 g m^{-2} yr^{-1} using different methods (Novitzski 1978, Kadlec and Robbins 1984), thus sediment deposition rates in peatlands in general are low.

Of the 15 wetland sediment accumulation studies that we reviewed, 11 used different methods to estimate sediment deposition thickness and/or deposition mass (Johnston 1991, Kleiss 1996). The accretion disk method that we employed is appropriate for the wetland systems that we studied, particularly the riparian wetlands, providing a useful means of measuring both the newly deposited sediment thickness and mass per unit area on an annual basis. Many studies report sediment deposition rates as thickness in cm yr^{-1}, which is not necessarily comparable between sites due to differences in sediment bulk density (Johnston 1991). Other methods, such as cesium^{137} analysis of sediment strata provide useful long-term sediment accretion data (Kleiss 1996). However, these data can only provide an estimate of average annual sediment accretion depths over the past several decades.

Sediment deposition rates can vary widely between adjacent fluvial features (Kadlec and Robbins 1984). This was evident in our study areas as well, particularly on features with high sediment deposition rates, such as bars and islands. In Deer Lodge Park, two sediment accretion disks located 1 m apart and on the same fluvial feature accumulated 0.9 and 52.0 kg m^{-2} yr^{-1} of sediment during 1997.

Sediment deposition rates can also vary temporally within one year. For example, sediment deposition rates in wetlands along the Des Plaines River in Illinois ranged from 300 g m^{-2} yr^{-1} in seasons with low flow rates, to 2100 g m^{-2} yr^{-1} in seasons with high peak flows (Mitsch 1992). In the wetlands we studied, sediment was sampled continuously during the peak flow season, and little deposition occurs in other seasons, except during an occasional large thunderstorm which creates flash flood conditions on tributaries. Most likely high between year sediment deposition variability occurs as well, even on a single fluvial feature. The 1997 water year produced exceptionally high peak flows on the Yampa and Green Rivers, and had this study been conducted during a year with lower flows our results may be somewhat different with regard to total sediment deposition and bank erosion.

Bank erosion from the riparian zone is though to provide a major contribution to downstream sediment loads in many rivers (Beeson and Doyle 1995). Other sediment contributions from the riparian zone may come from scouring of bars and other floodplain features (Howard 1996). When sediment accretion disks were excavated during the present study we observed that scour did occur from under a few disks which we assume occurred prior to sediment deposition on the disks. Bank erosion during 1997 resulted in high sediment export rates, and export totals were greater than sediment deposition totals in both cottonwood riparian sites.

The position within meanders where the highest rates of bank erosion occurred were different for Deer Lodge Park and Brown's Park. The greatest amount of erosion in Deer Lodge Park occurred in the downstream portions of meander bends, while in Brown's Park it occurred in the upper portions of meanders, with little erosion in the lower portions of meanders. In Deer Lodge Park bank erosion occurred only on the outside meander bends, with deposition on large point bars on the inside of meander bends. In Brown's Park erosion occurred on both banks creating high, vertical, sloughing banks on both sides of the river, with deposition only on in-channel islands.

Bank erosion rates are directly related to flow velocity, channel depth, and sediment loads. In meandering rivers, bank erosion rates typically increase from upstream to downstream within a single meander (Ritter 1995, Howard 1996), as we found with the Yampa River in Deer Lodge Park. However, the Green River in Brown's Park showed the opposite trend. Additionally, banks along straight channel runs (non-meandering reaches) through Brown's Park also sustained substantial bank erosion during 1997. The Colorado River channel at Kawuneeche Valley showed similar bank erosion patterns as Deer Lodge Park, however on a much smaller scale.

Sediment-Nutrient Function. Carbon and nitrogen concentrations in wetland soils and sediment often vary widely depending upon organic matter production and storage, past deposition patterns, and mineral sediment texture (Johnston 1991). Carbon and nitrogen concentrations in sediments being transported within Big Meadows ranged from 28% to 40% C, and 0.30% to 0.60% total N. For the riparian sites, C and N concentrations ranged from 0.4% to 7.0% C, to 0.04% to 0.45% N.

Sediment deposited in Brown's Park was significantly lower in total N than sediment deposited in Deer Lodge Park; which most likely reflects the origin of sediment being transported in these two areas. In Brown's Park most sediment is being moved as bedload, and it is our hypothesis that it originates from bank erosion within Brown's Park, and from intermittent tributary flow. Sediment transported by the Yampa River originates from a large watershed area, and includes topsoil and organic matter eroded from fields and forests.

Total C and N deposited on sediment approximately balanced C and N lost from bank erosion in Deer Lodge Park, while a significant amount of C and N was exported from the Kawuneeche Valley and Brown's Park. These findings offer some initial perspectives on how different types of riparian wetlands affect adjacent stream water quality and carbon balance.

Forested riparian wetlands are reported to function largely in nutrient transformation, rather than as nutrient sources or sinks (Richardson 1985, Mitsch and Gosselink 1993). However, this perspective has been largely developed from the study of wetlands in the eastern USA, where the nutrients being received are from ground and surface water which is tributary to the stream. Large, low elevation western rivers and riparian systems receive and transport large pulses of sediment which carry the bulk of the nutrients. Only a small fraction of this sediment-bound nutrient comes in contact with riparian wetlands. Nutrient deposited with sediment on floodplains can be (1) lost to the atmosphere (oxidation, volatilization, and denitrification), (2) stored within plants, (3) exported by erosion back to rivers. The nutrients incorporated into plants or organic soils are slowly released back to rivers in a largely organic form. The transformation of inorganic nutrients deposited on floodplains into organic material for export has been documented for Southern riparian forests (Elder and Mattraw 1982; Elder 1985). A similar function may be occurring in western riparian wetlands, which could have positive implications to both water quality and riverine ecosystems.

The most significant difference between eastern rivers reported in the literature that we have reviewed, and western rivers with regard to the sediment retention function, is that most western rivers carry large sediment loads, little of which is deposited in wetlands. In proper-functioning wetlands, such as Deer Lodge Park, sediment erosion via bank sloughing roughly balances sediment deposition on bars, in the long-term. Thus, long-term sediment retention is not a significant function. On an annual basis, sediment can be retained on bars along certain rivers. The sediment function for western riparian systems may not be the "retention of particulates", but the temporary retention of particulates from which N can be removed or transformed, and C can be added by plant growth.

Carbon Dynamics.

Long-term carbon storage by peatlands is also an important process world-wide. Estimates of carbon stored in peatlands worldwide range from 110 to 455 Pg (1 Pg=10^{15}g) (Gorham 1991, Botch et al. 1995), or about 1/3 of total terrestrial carbon stored. Long-term carbon storage in Rocky Mountain wetlands occurs primarily in high-elevation peatlands (Table 9). Soils of alluvial wetlands, such as Deer Lodge Park, reach an equilibrium where carbon input by NPP is largely respired with little net change in carbon storage (Figure 9). Peatlands, however store carbon for thousands of years. Because carbon production and storage occurs at such slow rates, organic accumulations can occur only in landscape positions where disturbance and erosion rarely occur. Thus, peatlands are non-riparian ecosystems, supported largely or totally by ground water inflows.

Unlike upland systems, riparian wetland carbon budgets must incorporate deposition and erosion patterns and processes. The amount of carbon moved through erosion and deposition pathways is large in Deer Lodge Park and even larger in Brown's Park (Table 9). It indicates that low-elevation riparian systems are capable of producing large amounts of carbon, a significant portion of which can be exported into adjacent aquatic systems. Peatlands, which export carbon largely as dissolved organic carbon, occur higher in watersheds and provide little carbon to adjacent aquatic systems.. However, the importance of small amounts of DOC exported by numerous peatlands into small headwater streams vs. the larger contribution of riparian wetlands into larger streams should be investigated.

Although our carbon budgets are based on limited data, they are the only attempts that we have found to develop carbon budgets for willow or cottonwood-dominated ecosystems in our region. Much more work needs to be done in this area to understand and quantify all the inputs and outputs of carbon to come up with a quantitative carbon budget for these systems.

Evaluation of the HGM Models

This section of the report is provided to analyze existing HGM models and their variables, and suggest ways in which these models could be modified to be more suitable for wetland function evaluation in Colorado, and other southwestern states. The models are taken from Brinson et al. (1995), and Hauer and Cook (1996).

Retention of Particulates (Sediment Trapping) is a primary wetland function, and generally is modeled by both Brinson et al. (1995) and Hauer and Cook (1996) using the following formula:

$$\textit{Index of Function} = \{[(V_{FREQ} \times V_{SURFIN})/2] \times [(V_{HERB} + V_{SHRUB} + V_{BTREE} + V_{DTREE} + V_{MICRO} + V_{cwd})/6]\}^{1/2}$$

where;

FREQ is the frequency of overbank flows,

SURFIN surface water inflow to wetland,

HERB, SHRUB, BTREE and DTREE are measures of herb, shrub and tree density, basal, area cover and other measurements,

MICRO is microtopographic complexity, and

CWD is coarse woody debris.

A second approach is to directly measure sediment deposition rates, as indicated by the model: $\textit{Index of Function} = V_{SEDIM}$

Our data and analyses indicate that sediment deposition on a floodplain is spatially variable, and defining the “bank” for overbank flow, is a critical decision. We suggest that the “bank” be defined as any vegetated surface on the floodplain, which would include point-bars, and other area that generally are below the "bank", yet can be inundated annually.

The published models evaluate only sediment deposition, while we suggest that they must include both sediment deposition and erosion. In many years and on many floodplains the mass of sediment provided to streams via bank sloughing and scouring of surfaces can equal or exceed that deposited on floodplains. To quantify the retention of particulates for a wetland a sediment budget must be developed, or approximated, including measures of deposition and erosion.

Sediment budgets are particularly critical on regulated rivers where erosion, rather than retention, may be the dominant process. We also suggest that few stream and floodplain systems in the west function solely or largely to retain sediment. Floodplains that retain sediment without erosion would rapidly agrade and cease to function. We suggest that sediment retention greatly in excess of erosion is a sign of dysfunction, just as rapid erosion is a sign of dysfunction on regulated river.

In the West, and most likely in other parts of the US, it is what happens to sediment deposited on floodplains, rather than the mass deposition of sediment that are the critical elements of this function. The greatest mass of sediment is deposited on the lower elevation portions of floodplains, where frequent inundation occurs. Sediment deposited into these environments will be saturated and periods of anaerobic conditions will occur. In addition, these low sites typically have high biological production with rapid soil and soil surface carbon accumulation and storage. The transformation and/or removal of nutrients and toxicants on sediment is an important function, as is the conversion of nutrients into organic matter which is later exported to streams. We suggest that this function must be assessed by both a sediment budget approach, and analysis of the fate of sediment, and nutrients and pollutants transported with the sediment.

The **Removal of Elements and Compounds** function is closely allied to the retention of particulates function. However, it may also include dissolved elements or compounds transported by ground water. This function can be represented as:

$\textit{Index of Function} = ([V_Q \times V_{velocity} \times V_{thickness}]^{1/3} + [V_{OrgCarbon} \times V_{soil\ text} \times V_{Mineralogy}]^{1/3} + [V_{ph} \times V_{eH} \times V_T \times V_{EC}]^{1/3})/3$,

where Q is discharge, OrgCarbon is soil organic carbon content. Other indices of function have also been presented which are somewhat different, for example:

$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN})/3] + [(V_{MICRO} + V_{MICROB} + V_{SORPT})/3] + V_{BTREE}\}/3$ (Brinson et al. 1995).

The variable V_{BTree} is not used for herbaceous wetlands. These functional models are all focused at the frequency and duration of inundation, and soil characteristics as they provide surfaces and conditions appropriate for microbial activities which could remove or transform elements and compounds.

We suggest that these models are generally fine for sites where sediment deposition or ground water flow are the leading processes. However, where bank erosion or scour occurs material is input to streams and these processes must be included in the models to balance the potential on-site benefits of these hydrological and ecological processes.

Organic Carbon Export (Aquatic Food Chain Support) is the export of organic matter produced in wetlands to streams for the support of aquatic food chains. This function is critical in the western US and is typically represented as:

$$\textit{Index of Function} = ([V_{OC} + V_{\text{biomass}} + V_{\text{detritus}}]/3 \times [V_{\text{surface outflow}} + V_{\text{subsuroutflow}}]/2)^{1/2}$$

OR

$$\textit{Index of Function} = ([V_{OC} + V_{\text{biomass}} + V_{\text{detritus}}]/3 \times V_{Q})^{1/2}$$

OR

$$\textit{Index of Function} = \{[(V_{FREQ} + V_{SURFIN} + V_{SUBIN} + V_{SURFCON})/4] \times V_{ORGAN}\}^{1/2}$$

(Brinson et al. 1995, Hauer and Cook 1996)

These models all address flooding and ground water flows that could remove particulate or dissolved organic carbon from the wetland and transport it to the stream. The source of carbon and the processes of carbon export from the wetland are appropriately identified based upon our measurements during 1997. However, we would accentuate that most organic carbon may be exported from a riparian ecosystem via bank sloughing. The models also do not take into account carbon deposition on floodplains, a process that occurs with sediment deposition. Carbon deposition, including large woody debris, and particulate carbon, can be quite large for certain sites. We recommend that variables be added to include carbon export due to bank erosion, and carbon rich sediment deposition. Also, it should be noted that inputs of carbon to streams may come from non-wetland riparian areas. These are grasslands, forests, or shrublands on high banks that are never flooded and that do not have saturated soils. Thus, functions are provided to a stream from non-wetlands and the assessment area must be large enough to include these areas.

Organic Carbon Accumulation (Long-Term) involves the storage of organic carbon in soils. Typically the models for this function would be developed as:

Index of Function = $[V_{\text{biomass}} + V_{OC}]/2$,

where the only predictors of carbon storage are biomass production, and organic content of existing soils. Since these are very hard to measure in field situations, we suggest that models such as those presented here including site elevation vs. period of soil saturation, and erosion potential, could provide an excellent estimation of the potential of the site for long-term carbon storage.

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