



**U.S. GEOLOGICAL SURVEY
NORTHERN PRAIRIE WILDLIFE RESEARCH CENTER**

TITLE:

**IMPACT OF U.S. DEPARTMENT OF INTERIOR AND U.S. DEPARTMENT OF
AGRICULTURE PROGRAMS ON ECOLOGICAL SERVICES DERIVED FROM
RESTORED PRAIRIE WETLANDS AND ADJACENT GRASSLANDS**

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BACKGROUND AND JUSTIFICATION

Restoration of wetland and grassland habitats on private lands in the Prairie Pothole Region (PPR) is an important activity of the U.S. Department of Interior (DOI) and U.S. Department of Agriculture (USDA). The most notable federal restoration programs in the PPR include the USDA Farm Bill Conservation Reserve (CRP) and Wetlands Reserve (WRP) Programs and the U.S. Fish and Wildlife Service (FWS) Partners for Fish and Wildlife Program (PFWP). Collectively, these programs have enabled restoration of >2 million ha of habitats in the PPR. Sites restored generally are areas of native habitat that were previously converted to facilitate production of agricultural crops; thus, the most common restoration techniques include plugging ditch or tile drains to restore hydrology and planting surrounding upland catchments to perennial cover. Considerable federal resources have been expended by these programs to restore wetlands and grassland habitats in the PPR, which are perceived to provide benefits to both individuals and society in general because landowners that enroll receive monetary incentives and society receives improved ecological services. Currently, the most frequently mentioned ecological services include: fish and wildlife habitat enhancement, water quality improvement, sediment and chemical filtration, erosion and nutrient transport reduction, floodwater retention, groundwater recharge, biological diversity conservation, and increased opportunities for education, scientific research, and recreation (Knutsen and Euliss 2001). However, this list of benefits is not inclusive and additional ecological services likely will be identified in response to constantly changing environmental issues at both national and global scales. For example, restored wetlands and grasslands have recently been recognized for their importance in the sequestration of greenhouse gases (GHG; Euliss et al. 2004 in review, USEPA 2003).

Although the purported values of federal restoration programs are plausible, there has been minimal evaluation and quantification of the ecological services provided to society. This has become an important issue because the President's Budget and Performance Integration Initiative requires that programs demonstrate their effectiveness and provide a more accurate accounting of program dollars and the results achieved. Similarly, the Office of Management and Budget is increasingly focused on program achievements. Both the CRP administered by the Farm Services Agency (FSA) and the WRP administered by the Natural Resources Conservation Service (NRCS) are scheduled for program assessment in the near future and reauthorization will require that ecological services be quantified. The PFW program also will likely undergo the same scrutiny. Thus, development of procedures to annually report on the status of ecosystem services derived from these investments must be undertaken to ensure that federal programs are evaluated objectively when making future funding decisions.

The overall goal of this proposed work is to quantify existing ecological services derived from DOI and USDA restoration programs in the PPR and develop indicators of wetland functions that can be used to quantify ecological services in the future. Funding is provided from the FSA, NRCS, and U. S. Geological Survey (USGS)-Biological Resources Division (BRD). In general, all agencies have similar research and information needs, but no single agency has sufficient funds to study the array of wetland functions contributing to the diverse ecological services provided at the spatial scale of the entire PPR. Therefore, rather than conducting several small studies evaluating ecological services independently, we plan to combine research funds to conduct a single comprehensive study that will incorporate a greater suite of wetland functions across a larger spatial gradient. This approach will enable evaluation of multiple wetland functions and services simultaneously. To further maximize information yield, this study also

will include sampling a subset of wetlands originally sampled during 1997 to better understand how functions and services have changed over time. The association among FSA, USDA, and USGS-BRD information needs in terms of wetland functions and the incorporation of information collected as part of a previous wetland study conducted by Northern Prairie Wildlife Research Center (NPWRC; Study Plan 168.01) is provided in Appendix A.

GENERAL APPROACH AND OBJECTIVES

This study will evaluate representative wetland classes and land use categories occurring in the United States portion of the PPR (i.e., Montana, North Dakota, South Dakota, Minnesota, and Iowa) using two complimentary approaches. The first approach will be to conduct an extensive survey of 270 temporary, seasonal, and semipermanent wetlands. Key elements of this survey include (1) sampling across a land use gradient that has resulted in differential wetland disruption ranging from highly (e.g., drained cropland wetlands) to marginally (e.g., native prairie) altered wetlands (Figure 1) and (2) sampling wetlands that were sampled previously during a similar survey conducted by NPWRC in 1997. Because wetlands will be surveyed only once, we will focus on a few easily measured edaphic, vegetation, and morphological characteristics that are indicators of wetland functions. These indicator variables (Appendix B) will be used in various combinations to directly or indirectly quantify the following ecological services: biodiversity and habitat, soil erosion and sediment reduction, nutrient loading, floodwater storage, and soil carbon sequestration. In addition, data also will be used to compare (1) wetland functions among land use categories and determine the impact of restoration programs and (2) determine temporal changes in functions of wetlands restored by federal agencies.

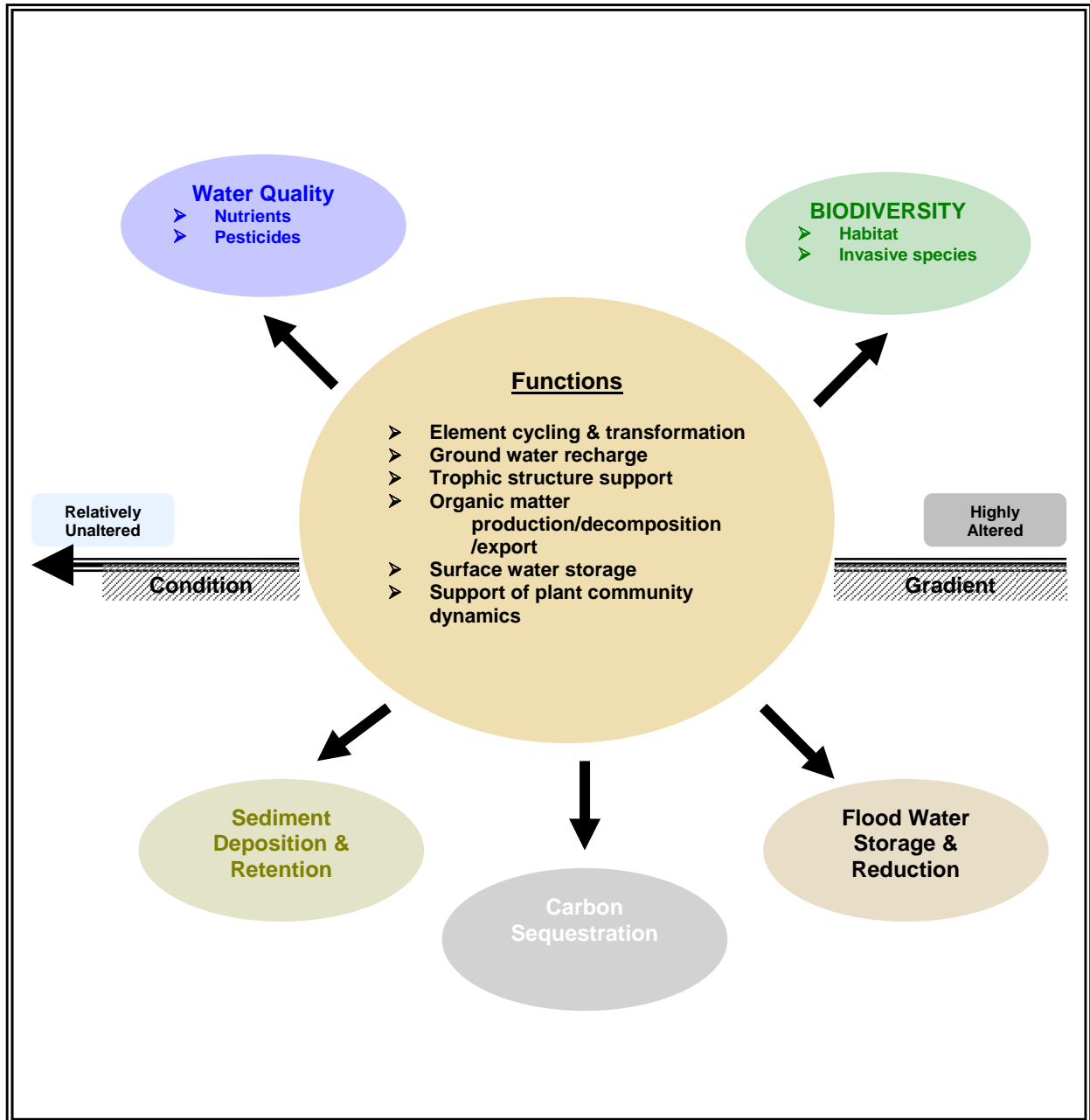


Figure 1. Wetland functions and ecological services expected to change along a condition gradient.

The second approach will be an “intensive” three-year study (2005-2007) that will investigate seasonal wetlands in land-use categories similar to those selected for the extensive survey. However, the sample size will be smaller and the location of wetlands will be geographically constrained to a sub-watershed to enable more intensive measurement of attributes related to wetland functions and ecological services. Each year we will measure climatic conditions (temperature and precipitation), water levels, ground water inputs of dissolved gases, and GHG emissions (i.e., methane, nitrous oxide, and carbon dioxide) on a weekly or biweekly schedule during the sampling season. We also will conduct annual surveys to characterize the composition of plants and soils. Information on GHG emissions, ground water inputs, plants, and soils will be used in various combinations to quantify the following ecological services: biodiversity and habitat, soil erosion and sediment reduction, nutrient retention, floodwater storage, soil carbon sequestration, and GHG emissions reduction. Similar to the extensive survey, the major focus will be to characterize wetlands restored as part of FWS and USDA programs. Functional attributes of restored wetlands will be compared to drained and non-drained wetlands in croplands and non-drained wetlands in native prairie. This approach will allow us to evaluate wetland functions and ecological services of restored wetlands along a condition gradient ranging from agricultural to native prairie wetlands. In summary, the objectives of the study are to:

1. Conduct a large extensive survey of restored, native prairie, and cropland wetlands throughout the PPR to quantify and compare ecological services (i.e., biodiversity and habitat, soil erosion and sedimentation reduction, nutrient loading, floodwater storage, soil carbon sequestration) of wetlands restored by DOI and USDA programs relative to a condition gradient.

2. Conduct an intensive study of restored, native prairie, and cropland wetlands to increase scientific understanding of annual changes in functions of different wetlands in relation to land use and enable better quantification of the impact of DOI and USDA wetland restoration programs on ecological services (i.e., biodiversity and habitat, soil erosion and sedimentation reduction, nutrient loading, floodwater storage, soil carbon sequestration, and GHG emissions reduction).

Information gained from this proposed work will address many other agency relevant issues including the USGS Biological Resources Division Global Change Program (BRDGCP) to (1) quantify carbon sequestration and GHG flux in wetland systems, (2) determine causal mechanisms controlling carbon dynamics and GHG flux, and (3) evaluate technologies and management techniques that enhance carbon sequestration, reduce GHG emissions, and provide concurrent ecological services. This study also addresses Bureau responsibilities identified in the DOI's Policy on Carbon Sequestration and several of the basic integrating goals for the U.S. Climate Change Science Program to (1) improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and changes, (2) reduce uncertainty in projections of how the Earth's climate and related systems may change in the future, (3) understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes, and (4) explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

OBJECTIVE 1

Overview: We will conduct an extensive survey of temporary, seasonal, and semipermanent wetlands (Class II, III, and IV wetlands; Stewart and Kantrud 1971) from May–September 2004. Wetland type will be further stratified based on restoration age (<5, 5-10, and >10 years) and land use activity (drained in cropland, non-drained in cropland, non-drained in native prairie). Data collected during the survey will focus on easily measured edaphic, vegetation, and morphological variables that can be used in various combinations to directly or indirectly quantify the ecological services identified in the objective. The primary focus will be to characterize wetlands restored as part of FWS and USDA programs using metrics that can be readily acquired to facilitate future evaluations. In addition, functional attributes of wetlands restored on CRP or WRP lands will be compared among land use and age categories to identify the impact of federal restoration programs relative to existing agricultural practices and determine if ecological services of restored wetlands change temporally.

Study Area: The survey will be conducted in the United States portion of the PPR, an area of 277,860 km² that includes large areas of North Dakota (101,010 km²), South Dakota (69,930 km²), Minnesota (54,390 km²), Iowa (31,080 km²), and Montana (21,450 km²) (Grue et al. 1986). Physiographic regions within the PPR are of glacial origin and include the Missouri Coteau, Prairie Coteau, and Glaciated Plains (also known as drift prairie) (Figure 2). The Missouri and Prairie Coteaus were formed by stagnant and dead-ice moraines that resulted in a rugged area with closely spaced hills and depressions. In contrast, the Glaciated Plains region formed primarily as a result of ground moraine processes that created a gently rolling landscape. Climate of the region varies along a northwest-to-southeast gradient, with precipitation and temperature increasing toward the southeast (Visher 1966). Collectively, these areas exhibit both

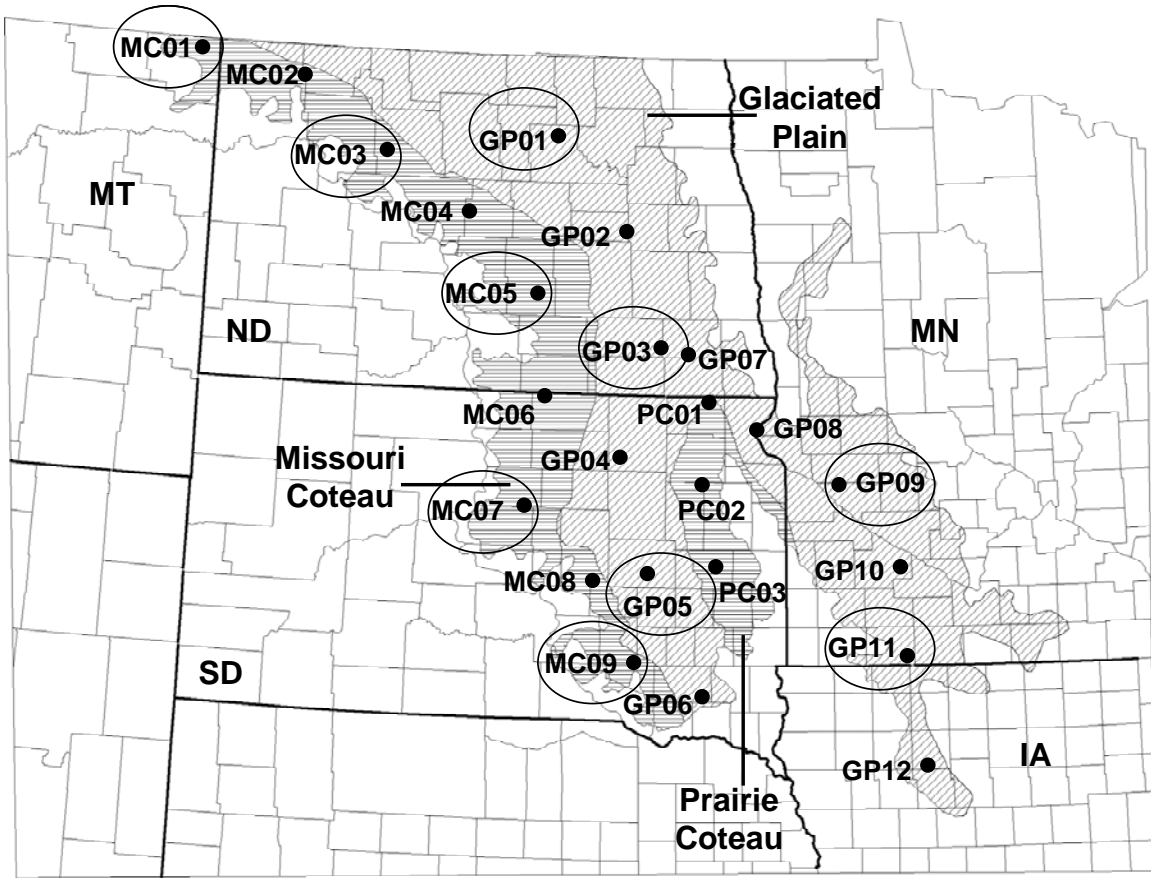


Figure 2. Location of sampling points in the Missouri Coteau, Prairie Coteau, and Glaciated Plains used during the 1997 extensive survey (NPWRC Study Plan 168.01). Circled sample points will be used for the 2004 survey.

spatial and temporal differences in agricultural development, including extent of wetland drainage (Figure 3) and crop type (small grains in North Dakota to more agriculturally intensive row crops in Minnesota and Iowa; Galatowitsch and van der Valk 1994).

Sampling Design and Site Selection: During 1997, NPWRC conducted an extensive survey of seasonal and semipermanent restored wetlands on CRP or WRP lands in the PPR (NPWRC Study Plan 168.01). Wetlands in this study were selected using a systematic sampling design stratified by physiographic region to ensure a representative geographic sample of wetlands along the northwest-to-southeast climatic and land-use gradients in the PPR. We used a geo-referenced map of the PPR (Figure 2) and drew a line through each physiographic region that corresponded to the median of the long axis. Along each line, we systematically identified 9 sample points in the Missouri Coteau, 3 in the Prairie Coteau, and 12 in the Glaciated Plains (Figure 2); allocation of sampling points was proportional to the linear length of each physiographic region. Near each sample point we attempted to find a seasonal and semipermanent restored wetland on CRP or WRP land.

To enable analyses of temporal changes over a 7-year period, we will incorporate as many of the 1997 wetlands as possible in the 2004 survey with the exception that the Prairie Coteau will not be sampled. Of the original 21 points (5 in the Missouri Coteau and 12 in the Glaciated Plains) selected in 1997, we selected 5 points in the Missouri Coteau (MC01, MC03, MC05, MC07, MC09) and 5 points in the Glaciated Plains (GP01, GP03, GP05, GP09, GP11) for sampling in 2004 (Figure 2). Near each point we will select 27 wetlands for sampling including: 9 temporary, 9 seasonal, and 9 semipermanent wetlands. Because temporary wetlands were not part of the sample design in 1997, wetlands in this class will be located prior to conducting the survey. Similarly, if seasonal and semipermanent wetlands surveyed during 1997

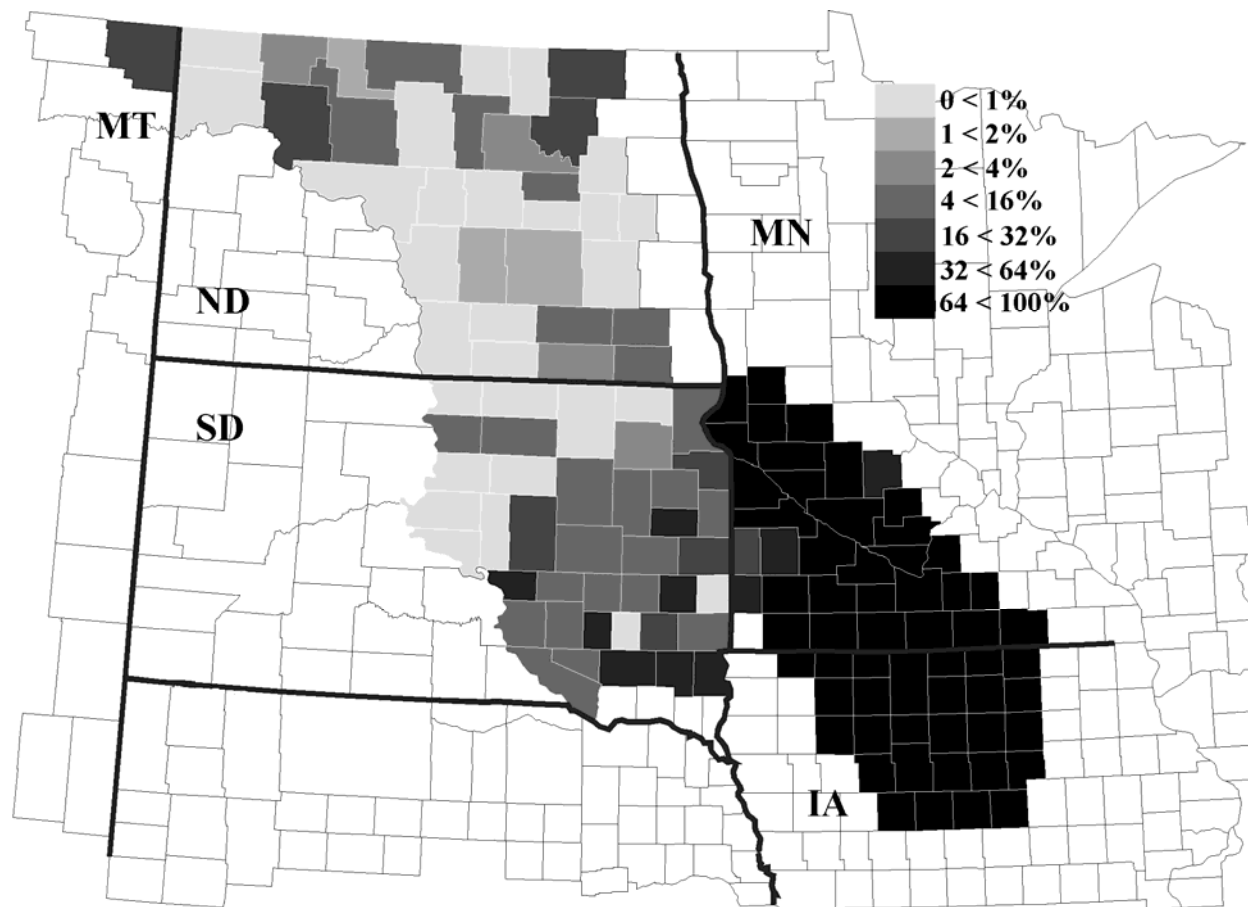


Figure 3. Percent wetland drainage for the U. S. portion of the Prairie Pothole Region by county.

are no longer available (e.g., removed from CRP or landowner permission denied), alternative wetlands will be identified. Within each wetland class, 1 wetland will be located that conforms to each of the following land use and age categories:

1. Hydrologically Restored Wetlands in 3 age classes (restored <5, 5-10, and >10 years): Includes drained and farmed wetlands restored by plugging drains and planting uplands to perennial grass as part of CRP or WRP.
2. Non-drained Restored Wetlands in 3 age classes (restored <5, 5-10, and >10 years): Includes farmable wetlands that have not been drained but were restored by planting catchments to perennial grass as part of CRP or WRP.
3. Drained Cropland Wetlands: Includes drained and farmed wetlands in catchments that are predominantly cropland.
4. Non-drained Cropland Wetlands: Includes non-drained wetlands in catchments that are predominantly cropland.
5. Native Prairie Wetlands: Includes non-drained wetlands in native prairie habitats with no history of cultivation in the wetland or upland catchments.

This design will result in the selection of 270 wetlands, of which 135 will be located in the Missouri Coteau and 135 in the Glaciated Plains Physiographic Regions (Table 1). Within each Physiographic Region, we will sample 27 wetlands at each point originally identified for the 1997 survey. Each of these wetlands will correspond to 1 of the possible 27 hydrologic/land use/age categories, which will result in sampling 5 replicates in each Region by wetland class land-use combination.

Table 1. Allocation of sampling effort (number of wetlands) among land use and age categories for the 2004 extensive survey.

| Region | CRP or WRP lands | | | | | | Croplands | | Native prairie |
|-------------------------|------------------------|----------------|-----|------------------------|----------------|-----|-----------|---------|----------------|
| | Hydrologic restoration | | | Nondrained restoration | | | | | |
| | Wetland class | Years restored | | | Years restored | | | Drained | Nondrained |
| | 1<5 | 5<10 | >10 | 1<5 | 5<10 | >10 | | | |
| Missouri Coteau | | | | | | | | | |
| Temporary | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Seasonal | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Semipermanent | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Glaciated Plains | | | | | | | | | |
| Temporary | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Seasonal | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Semipermanent | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |

Data Collection: Data collected at each site selected for study will range from programmatic information and numerous landscape measures to *in situ* abiotic and biotic data for wetland basins and surrounding catchments. Collectively, this information will be used to assess differences among wetland classes and land use activities relative to functions and ecological services. Depending on the category of wetland sampled, not all variables will be applicable (e.g., restoration age of native prairie wetlands); thus, not all data will be collected on every wetland. Data types are described below and a composite list of variables and their definitions are provided in Appendix B and C, respectively.

Land-Use History Survey: Information collected will vary by wetland category, but will include drainage type, restoration age, cropping history, drainage date, agencies performing restoration, and type of conservation plan. This information will be collected from a variety of sources including landowners, collaborators (e.g., USDA, FWS), and field surveys.

Climate: Information will be obtained from the National Oceanic and Atmospheric Administration’s National Climatic Data Center and the National Weather Service’s Climate Prediction Center. Data will include temperature, relative humidity, precipitation, solar

radiation, evaporation, and wind speed. Additional data will be gathered from USGS gauging stations, including stream flow, channel discharge, and ground water levels.

Landscape Features and Wetland Inventories: We will determine land-use (%), wetland density (number/km²) and area (ha), and class of all wetlands at 4 landscape scales (catchment, 100m, 500m, 1km, 2km) surrounding study wetlands. Information will be obtained using aerial photography supplied by NRCS and digital data from the following sources: National Wetlands Inventory (NWI) and USDA CRP and WRP land units. Other digital data that may be used, include USDA major land resource areas (MLRAs), management districts (county, state, federal) and management areas (waterfowl production areas, federal or state management areas), hydrologic units, physiographic regions, USGS level IV ecoregions, soils, and public land survey areas. In addition to estimating landscape features at multiple scales surrounding study wetlands, these databases will be blended as needed to generate estimates of wetland areas by hydrogeomorphic boundaries (e.g., ecoregions, MLRAs, and watersheds), management districts (e.g., wetland management districts) conservation programs (e.g., CRP and WRP), and other resource areas (e.g., waterfowl production areas).

Morphometry: Wetland basins and surrounding catchments will be surveyed using a GPS total station (Trimble 5700). Other features surveyed will include drainage plugs, tile drains, secondary surface outlets and inlets, surface water elevation, transect locations including quadrat and soil sample locations, and upland/wetland transition zones (see *Vegetation and Soils* sections). Estimates of wetland morphometry will include area (ha), volume (m³), maximum depth (m), and perimeter (m). Because these values vary depending on the benchmark selected, we will derive separate estimates based on the hydric soil boundary, hydric vegetation boundary, and natural outlet elevation. Estimates of the surrounding catchment will include total area (ha),

area comprised of each vegetation zone (ha), average slope (%), and slope length (m). All estimates will be derived using program ForeSight version 1.3 (Tripod Data Systems, Inc., Corvallis, Oregon).

Vegetation: Estimates derived for each wetland basin will include the area covered by open water and emergent vegetation (%), cover/water interspersion (categorical ranking), wetland class, and type of land use (%) in the wetland basin and surrounding catchment. In addition, detailed vegetation information also will be collected following standard operating procedures developed by NPWRC (NPWRC Study Plan 168.01) using vegetation sampling methods developed by Kantrud and Newton (1996). We will establish 4 equally spaced transects that radiate out from the wetland center to the catchment boundary. The width (m) of each wetland vegetation zone (e.g., wet-meadow, shallow marsh, and deep marsh; Stewart and Kantrud 1971) bisected by transects will be estimated and average water depth (cm) recorded. Within each of these zones, and at three positions in the upland catchment (i.e., toe-slope, mid-slope, and shoulder slope), a 1-m² quadrat will be randomly sited along each transect. Within each quadrat, vegetation cover (%) by taxon (Daubenmire 1959), litter depth (cm), and visual obstruction at plot center (Robel 1970) will be estimated and any plant taxa not encountered within quadrats will be recorded. Estimates of aboveground vegetation biomass also will be collected from all quadrats along one transect by placing a 0.25-m² quadrat in the center of the 1-m² quadrat and clipping all above ground biomass (live and dead). Biomass samples will be stored in paper bags and submitted to the USDA-ARS North Central Soil Conservation Research Laboratory, Morris, MN, for determination of total dry mass, total carbon, total nitrogen, and phosphorous following standard methods (Klute 1986, Page et al. 1982).

Soils: Following vegetation surveys, soil samples will be collected at depths of 0–15 cm ($n = 4$) and 15–30 cm ($n = 4$) from each quadrat used to survey vegetation. Samples from each depth will be aggregated and a single sub-sample will be submitted to the USDA-ARS North Central Soil Conservation Research Laboratory, Morris, MN for determination of physical (e.g., bulk density, texture) and chemical (e.g., extractable P, total and inorganic C, total and extractable NO_3^- and NH_4^+) attributes using standard methods (Klute 1986, Page et al. 1982). In addition, a mini-profile description of soils at each quadrat location along one of the vegetation transects will be performed to describe depth, thickness, arrangement, carbonate reaction, and physical attributes (i.e., structure, texture, consistency) of each soil horizon.

Fauna: A census of avian use will be conducted prior to measuring abiotic characteristics. Designated observers will select a high vantage point from which to record the number of all bird species in the wetland and surrounding catchment prior to entering the catchment. Observers will then enter the catchment and walk the wetland perimeter to record all birds not observed from the high vantage point. Other species (birds, amphibians) encountered by designated observers and crew members collecting abiotic information also will be recorded (e.g., amphibians). Because wetlands will be visited only once, and survey protocols will not be constrained by time of day or weather conditions, this data will not be used to make statistical inferences about differences in fauna among wetlands classes or categories. However, this information should provide insight regarding the types of fauna that use wetlands in different land use and age categories and facilitate efforts to quantify these values in the future.

Data Analysis and Products: Estimation of ecological services identified in the objective will require the development of various algorithms that adequately emulate wetland functions. This will require the use of different combinations of variables collected during the survey and,

possibly, developing different algorithms for wetlands in different Physiographic Regions, wetland classes, and land use/age categories. Although various analytical approaches (e.g., analysis of variance, repeated measures, regression, covariate analysis, ordination) may be valid, it is not possible to identify *a priori* statistical techniques that will be applied. Rather, exploratory analyses will be required to develop the most parsimonious methods to estimate the aforementioned ecological services. However, we recognize that application of statistical techniques will be constrained by the experimental design and sampling intensity; thus, we provide a general platform from which most statistical comparisons will be derived (Table 2). This approach is similar to that used to analyze the results of the 1997 extensive survey (Study Plan 168.01) and both the principal investigators and statisticians at NPWRC are familiar with the strengths and weaknesses of this model to make inferences. Given this constraint, the following describes our general approach to estimate each of the ecological services identified in Objective 1.

Table 2. Example of anticipated model to compare soil response variables (e.g., carbon) among hydrologic landuse categories for a single wetland class (e.g., semipermanent has 3 zones) and physiographic region (e.g., Missouri Coteau).

| Source of Variation | Df | Description |
|---------------------|----------------------------|---|
| Block(B) | $5-1 = 4$ | MC01, MC03, MC05, MC07, MC09 |
| Category (C) | $9-1 = 8$ | See Table 1 |
| (C*B) | $4*8 = 32$ | Error (a) |
| Zone (Z) | $3-1 = 2$ | wet-meadow, shallow marsh, and deep marsh |
| Z*C | $2*8 = 16$ | |
| (Z*B)+(Z*C*B) | $(2*4) + (2*8*4) = 72$ | Error (b) |
| Depth (D) | $2-1 = 1$ | 0-15 cm, 15-30 cm |
| D*C | $1*8 = 8$ | |
| (D*B)+(D*C*B) | $(1*4) + (1*8*4) = 36$ | Error (c) |
| D*Z | $1*2 = 2$ | |
| D*C*Z | $1*8*2 = 16$ | |
| (D*Z*B)+(D*Z*C*B) | $(1*2*4) + (1*2*8*4) = 72$ | Error (d) |
| Total | $(5*9*3*2)-1 = 269$ | |

Floodwater Storage Services: Wetlands directly or indirectly associated with lakes and streams store floodwater by spreading water over a large landscape. This temporary storage may decrease runoff velocity, reduce flood peaks, and distribute storm-water flows over extended periods (Hubbard and Linder 1986, Ludden et al. 1983). However, human alterations that result in drainage or accelerated sedimentation often negatively impact wetland water storage potential. Therefore, we will use several approaches to estimate water storage derived from restoration programs and estimate the influence of sedimentation on loss of wetland volume in different wetland class, land use, and age categories. Collectively, these metrics will permit evaluation of the flood storage benefits provided by federal restoration programs.

Product 1: Estimate water storage derived from restoration programs: Estimates of water storage potential will be quantified for wetland classes in various land use and age categories using morphometry data (e.g., area, maximum depth, perimeter). Estimates developed for restored wetlands will be compared to estimates for wetlands in agricultural catchments to determine gains in water storage that result from restoration programs. Second, we will combine morphometry data collected as part of this study with similar data collected on approximately 320 wetlands in the PPR (NPWRC Study Plans 168.01 and 180.01) to develop surface area to volume relationships (Gleason et al. in review) that will be used to project existing and potential water storage from spatial wetland data (see *Landscape Features and Wetland Inventories*). Existing (non-drained wetlands) and potential water storage (wetlands deemed restorable) estimates will be summarized for the entire PPR along with water storage benefits derived from specific DOI and USDA restoration programs.

Product 2: Estimate the influence of sedimentation on loss of wetland volume: We will use mini-profile soil descriptions to estimate the water storage volume lost to sedimentation.

Mini-profile data includes information on the thickness of A' horizons and buried Ab' horizons in wetlands (i.e., indicator of sediment accumulation), and thickness of A' horizons in catchments (indicator of soil erosion). For example, during the 1997 extensive survey (NPWRC Study Plan 168.01), 17% of the 158 wetlands with a cultivated history had buried Ab' horizons. Average burial depth was 35 cm and ranged from 12 to 98 cm (Gleason 2001). Information on thickness of A' horizons will be used in conjunction with morphometry data to estimate the impact of sedimentation on water storage volume. We also will examine the relationship between thickness of A' horizons and catchment characteristics (e.g., catchment area, percent slope, slope length, soil type, cropping history). These physical characteristics, in conjunction with land-use history, can be related to upland soil erosion and concomitant wetland sedimentation (Gleason 2001). Factors identified as important indicators of sediment accumulation will be combined with estimates of average wetland volume losses based on mini-profile data and used to project the impact of sedimentation on loss of water volume over a larger sample population of wetlands.

Product 3: Estimate the benefits of restoration programs to reduce sedimentation rates and conserve wetland volumes: An important potential benefit of restoration programs is the planting of catchments to perennial grasses to reduce the erosion and transport of upland soils to wetland basins (i.e., sedimentation). We will apply soil loss models (e.g., Wischmeier and Smith 1978, Renard et al. 1997) to estimate the potential reduction in soil erosion within wetland catchments that result from restoration programs. More details on application of these models are described below in the *Erosion, Sedimentation, and Nutrient Loading Reduction* section.

Biodiversity and Habitat Services: We will focus primarily on vegetative characteristics to quantify improvements in biodiversity that result from restoration programs. Composition,

diversity, and structure of vegetation are key components of nearly all ecological functions in wetlands, including faunal diversity and richness. To quantify and understand improvements in biodiversity that result from restoration programs we will (1) compare plant communities by wetland class and land-use categories, (2) evaluate relationships between age of restoration and plant community structure, (3) identify factors that influence recovery of plant communities, and (4) relate vegetative composition and structure to species habitat requirements.

Product 1: Compare vegetative composition among wetland land-use categories: We will compare various measures of floristic composition and structure among wetland land-use categories, including physiognomic characteristics (e.g., annual-native, annual-introduced, perennial-native, perennial-introduced, forbs, grasses, sedges), floristic quality, and taxon richness (Northern Great Plains Floristic Quality Assessment Panel 2001).

Product 2: Evaluate relationships between age of restoration and vegetative composition: We will examine relationships between measures of floristic composition and age of restored wetlands. Temporal changes in floristic composition in restored wetlands will be compared to average estimates associated with agricultural and native prairie wetland baselines to evaluate variation in rate of recovery by taxonomic groups. In addition, a subset of restored seasonal and semipermanent wetlands sampled during both the 2004 and 1997 extensive surveys will be compared to determine temporal changes in vegetative composition.

Product 3: Identify factors that influence recovery of plant communities: Human alterations at both landscape and wetland basin scales are believed to influence recovery of plant communities. Plants that initially colonize previously drained wetlands or unaltered wetlands recovering from drought cycles often are recruited from propagule banks (e.g., seeds, tubers, corms) present in sediments or seeds dispersed into wetlands from nearby sources. However, at

a local scale agricultural practices often degrade propagule banks through physical death or deep burial; whereas at larger scales extensive drainage to facilitate agricultural production has reduced sources of propagules available to inoculate recently restored wetlands (Gleason 2001, Knutsen and Euliss 2001). To identify factors that influence recovery of restored wetlands, we will examine the relationship between floristic composition and abiotic variables that are indicative of landscape and basin scale disturbances that may influence recovery. Major indicators that will be examined include both landscape (e.g., number, area, and density of wetlands at different scales) and catchment (e.g., erosion and sedimentation, cropping history, length of time drained, soil structure and chemical composition) features.

Product 4: Relate vegetative composition and structure to vertebrate species habitat requirements: Although the logistical constraints of measuring the abiotic features of 270 wetlands does not allow surveys of vertebrate species to be conducted using standardized protocols, it is still possible to indirectly assess habitat suitability for various vertebrate species by relating published habitat requirements to current conditions within sampled wetlands and associated catchments. For example, water depth, vegetation composition, and vegetation structure influence availability of foods and foraging efficiency of many waterbirds (Elphick and Oring 1998, Weller 1999, Bancroft et al. 2002). Similarly, vegetation in wetlands and surrounding uplands also affects suitability and quality of waterbird (Weller and Spatcher 1965, Weller and Fredrickson 1974, Kaminski and Prince 1981, Ball and Nudds 1989) and amphibian (Fishbeck 1968, Stijbosch 1979, Fischer 1998) breeding habitats (Merrell 1977, Schmid 1982). We will synthesize existing published information on species habitat requirements and compare these requirements to existing abiotic and vegetation conditions in surveyed wetlands to assess potential habitat suitability among wetland classes, land use, and age classes. The species

selected for evaluation will include both common and unique species recorded by casual observations during the survey.

Erosion, Sedimentation, and Nutrient Loading Reduction Services: Restoration of wetlands and surrounding uplands often is perceived to reduce erosion and displacement of upland soils and thereby improve “water quality” because pollutants (i.e., sediments, excess nutrients, agrichemicals) are prevented from entering aquatic systems.

Product 1: Estimate average annual soil erosion: Therefore, we will estimate average annual soil erosion from grassland and wetland catchments using standard soil loss equations (e.g., Wischmeier and Smith 1978, Renard et al. 1997) to evaluate the capability of restoration programs to reduce nutrient and sediment loading in wetlands. Though numerous soil loss equations are available, they generally include similar input information. For example, the USDA’s Revised Universal Soil Loss Equation is defined as:

$$A = RKLSCP$$

where A is the estimated average annual soil loss per unit area (ha) caused by rainfall, R is the climatic erosivity factor, K is the soil erodibility factor, L and S are the slope length and steepness factors, C is the cover and management factor, and P is the supporting practice factor. We will use this equation and enter *in situ* data collected at each wetland to estimate average annual soil loss (A =tons/ha) and multiply this value by the corresponding catchment area (ha) to estimate tons of eroded soils that potentially could enter the wetland (hereafter referred to as “sedimentation potential”).

Product 2: Estimate nutrient loading potential by wetland class and land use categories: Information on soil nutrients (e.g., nitrogen and phosphorous) obtained from soil samples in each catchment will be used to convert sedimentation potential to “nutrient loading potential.”

Estimates of sedimentation and nutrient loading potentials will then be compared among land-use categories to summarize soil erosion, sedimentation, and nutrient loading reduction benefits derived from restoration programs.

Soil Organic Carbon Sequestration Services: Restoration of previously farmed wetlands has been shown to sequester atmospheric carbon (Euliss et al. 2004 in review). Although primary production is the principal process by which carbon is removed from the atmosphere, this element is stored in both plant tissues (above and below ground) and wetland soils. To quantify and evaluate carbon sequestration benefits derived from restoration programs we will (1) compare soil organic carbon stocks by wetland class and land-use categories, (2) compare organic carbon stocks in vegetation among wetland class and land-use categories, (3) examine the relationship between restoration age and soil organic carbon stocks, and (4) examine factors that influence soil organic carbon concentrations.

Product 1: Compare soil carbon stocks by wetland class and land-use categories:

Estimates of total carbon (organic and inorganic) concentrations in each of two soil depth strata (0-15 and 15-30 cm) will be adjusted by bulk density and converted to tons per ha for each depth strata. These estimates of carbon storage will then be compared by wetland class and land-use categories.

Product 2: Compare vegetation carbon stocks by wetland class and land-use categories:

The amount (tons/ha) of organic carbon in the standing crop of vegetation (live and dead) will be determined based on the concentration of carbon (organic and inorganic) in biomass clippings collected at each site sampled. These estimates will then be compared by wetland class and land-use categories.

Product 3: Examine the relationship between restoration age and soil organic carbon stocks in restored wetlands: Estimated carbon stocks in restored wetlands will be compared to carbon estimates in agricultural wetlands and native prairie wetlands to determine the relative contribution of restoration programs in sequestering carbon. Additionally, for a subset of restored wetlands sampled during both the 2004 and 1997 extensive surveys, we will evaluate temporal changes in carbon stores to evaluate the rate and magnitude of carbon sequestration.

Product 4: Identify factors that potentially influence soil organic carbon sequestration: We will explore the relationship between soil organic carbon stocks and numerous abiotic and landscape features, including vegetation composition and density, wetland class, morphometry, soil type and nutrient concentrations, and landscape position. Although this analysis will not identify cause-and-effect relationships, such analyses may provide insight for additional research required to improve future estimates of carbon sequestration in wetlands.

OBJECTIVE 2

Overview: We will conduct an intensive investigation of seasonal wetlands in a single sub-watershed of the PPR from 2005 to 2007. Wetland land-use categories investigated will be similar to those used in the extensive wetland survey (i.e., restored, cropland, and native prairie wetlands), but sample sizes will be smaller to enable more intensive measurement of attributes related to wetland functions and ecological services. Weekly or biweekly measurements of climate conditions (temperature and precipitation), water levels, ground water inputs of dissolved gases, and GHG emissions (i.e., methane, nitrous oxide, and carbon dioxide) will be made annually between the approximate dates of 1 April and 31 October. In addition, we will annually characterize the physical and chemical composition soils, and composition of plants.

Information collected will be used to quantify the ecological services identified in the objective. Similar to the extensive survey, the major focus will be to characterize wetlands restored as part of FWS and USDA programs by comparing functional attributes of these wetlands to drained and non-drained wetlands in croplands and non-drained wetlands in native prairie. This approach will allow us to evaluate wetland functions and ecological services of restored wetlands along a condition gradient ranging from agricultural to native prairie wetlands.

Study Area: The study will be conducted within the Red River of the North Watershed Basin (RRB), an international watershed that encompasses parts of 5 sovereign nations (United States, Canada, Red Lake Band of Chippewa, White Earth Band, and Spirit Lake Nation) three U.S. States (North Dakota, Minnesota, South Dakota), and one Canadian Province (Manitoba) in the Glaciated Plains Physiographic Province (Figure 4). The RRB was selected because reoccurring flood problems and persistent water quality concerns make conducting research in this watershed of great utility and interest to a diverse group of stakeholders.

The area of the RRB is approximately 117,000 km² (Miller and Frink 1984), with about 87,000 km² located in the United States (Figure 4). Elevations range from 701 m above mean sea level (MSL) in the Turtle Mountains of North Dakota to 229 m above MSL near the border between the United States and Canada (Miller and Frink 1984). The entire basin is thickly mantled by glacial drift (Miller and Frink 1984) and is characterized by two primary topographic divisions (Figure 4). At higher elevations to the east and west of the river valley the topography is irregular and consists of gently rolling ground moraine (i.e., glaciated plains) uplands interspersed with prairie potholes and other undrained depressions. At lower elevations the river plain, often referred to as the Red River Valley (RRV) is extremely flat; the slope of the Red River averages <0.1 m/km and elevations along the entire 879 km river course change <70 m

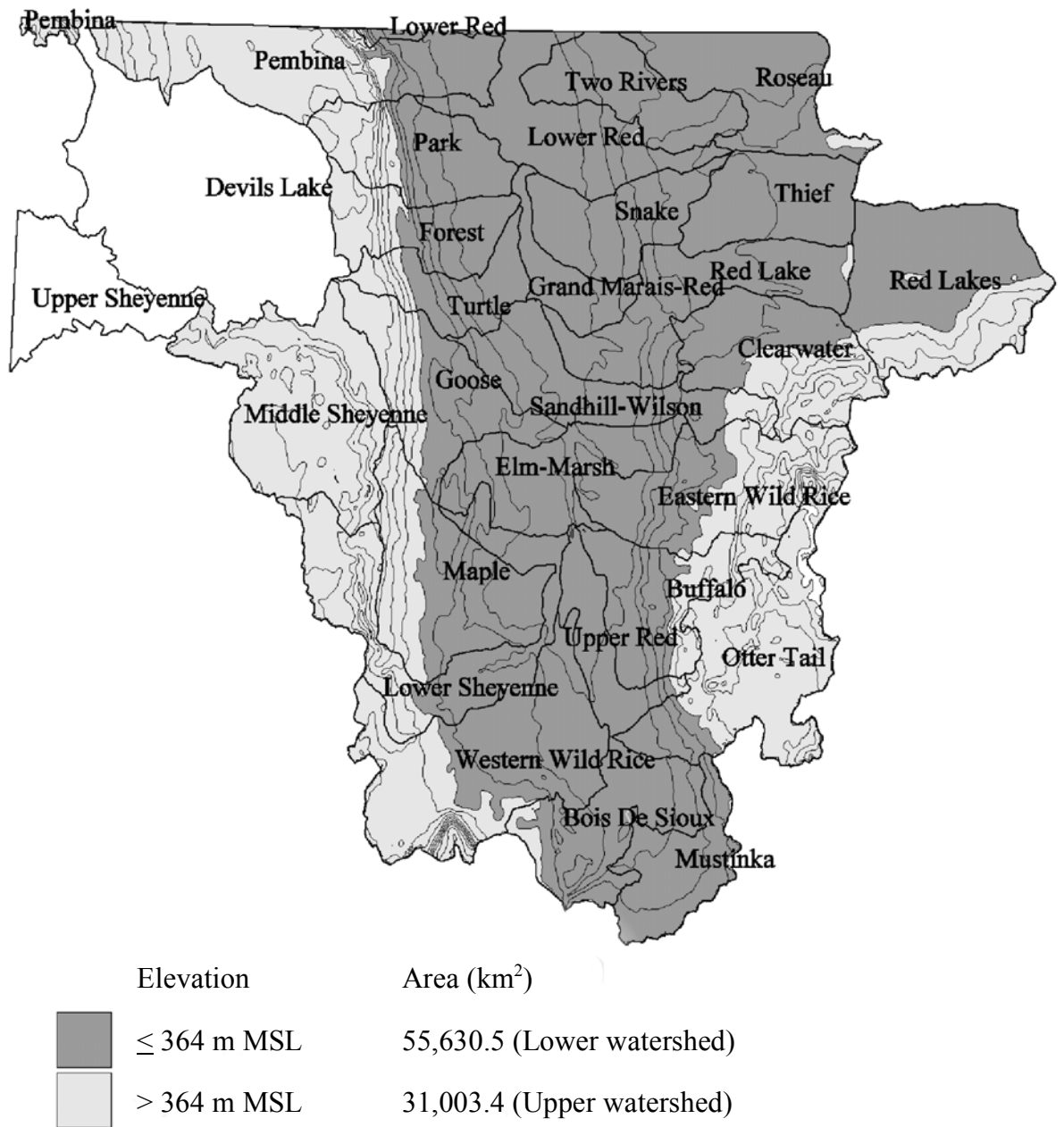


Figure 4. U.S. portion of the Red River of the North basin showing watershed names and boundaries, and contour lines.

(Miller and Frink 1984). Consequently, there are only a few natural water storage sites that are large (Simonovic 1998).

The climate of the RRB is sub-humid to humid continental with warm summers, cold winters, and rapid fluctuations in daily weather (Simonovic 1998). Mean monthly temperatures range from -15 to +20 C and about 50 cm of precipitation falls during the growing season. The primary land use is agriculture with approximately 70% of the land area used for crop production (Miller and Frink 1984). Of the remaining land area, about 12% is forested and 8% is pasture and range land.

Study Design and Site Selection: The process of selecting a sub-watershed within the RRB will begin in 2004. Most restorations have occurred in the upper RRB because modest land values have allowed wetland restoration to be economically feasible; thus, only this portion of the basin will be considered when selecting a study site. Within this area, we will use digital database information collected as part of Objective 1 to generate statistical summaries of individual watersheds. Parameters of interest include the number, density, and size of wetlands by hydrogeomorphic boundaries (e.g., ecoregions, MLRAs, and watersheds) and the area comprised of different land uses (e.g., agriculture, federal and state wetland management districts, waterfowl production areas, lands enrolled in CRP and WRP). This information will be used to select a sub-watershed that is representative of the upper RRB and also contains a sufficient population of potential sample sites in the land-use categories to be evaluated. If more than one sub-watershed meets these criteria, priority will be placed on using the area with the most detailed data that is available.

Following selection of the subwatershed, we will select 16 seasonal wetlands for inclusion in the study (Table 3). Four seasonal wetlands will be selected from each of the 4 following land use/age categories:

1. Hydrologically Restored Wetlands restored >10 years: Includes previously drained and farmed wetlands that were restored by plugging wetland drains and planting uplands to perennial grass as part of CRP.
2. Drained Cropland Wetlands: Includes drained and farmed wetlands.
3. Non-drained Cropland Wetlands: Includes non-drained wetlands in cropland.
4. Native Prairie Wetlands: Includes non-drained wetland in native prairie habitats with no history of cultivation in the wetland or upland catchments.

When selecting wetlands within each land use category we will pair restored wetlands with cropland and native prairie wetlands that are similar with respect to catchment area, soil type, and wetland phase (i.e. regenerating, open water, degenerating, dry-natural, dry-cropland, drained).

Data Collection:

Morphometry: A GPS total station (Trimble 5700) will be used to develop a detailed topographic survey of wetlands, surrounding catchments, and various other features (drainage plugs, tile drains, secondary surface outlets and inlets, surface water elevation). Estimates of wetland morphometry will include area (ha), volume (m³), maximum depth (m), and perimeter (m). Because these values vary depending on the benchmark selected, we will derive separate estimates based on the hydric soil boundary, hydric vegetation boundary, and natural outlet elevation. Estimates of the surrounding catchment will include total area (ha), area comprised of

each vegetation zone (ha), average slope (%), and slope length (m). All estimates will be derived using program ForeSight version 1.3 (Tripod Data Systems, Inc., Corvallis, Oregon).

Climate and Water Levels: During each biweekly sampling event, temperature (°C) will be measured manually in the top 15 cm of soil adjacent to each gas chamber. Data loggers (e.g., HOBO® data loggers) also will be used to provide hourly measurements of soil temperature at the center of each wetland. Rain and staff gauges will be installed at each wetland and monitored weekly; a weather station will be centrally located within the study area to acquire hourly data on temperature, wind speed and direction, and precipitation.

Greenhouse Gas Fluxes: Fluxes of carbon dioxide (CO₂), nitrous oxide (N₂O), and methane (CH₄) will be measured biweekly during the ice-free months of 2005-2007 using a minimum of 5 static gas chambers in each wetland (Livingston and Hutchinson 1995). We anticipate soil moisture conditions (e.g., soil water-filled pore space [WFPS]) to vary across a moisture gradient starting at the wetland/upland transition (typically dry) to the wetland center (typically wet). Because this gradient is known to influence CO₂, N₂O, and CH₄ emissions (Davidson et al. 2000), we will orient gas chambers along a single transect that originates in the center of each wetland and extends in a random direction to the wetland perimeter. One chamber will be placed at the center of the wetland and one will be placed at the wetland/upland transition zone. Remaining chambers will be systematically placed at equidistant intervals between the wetland center and upland transition zone (e.g., interval distance [m] = transect length [m] / [number of chambers-1]). The location of each chamber will be permanently installed by driving the base (PVC ring) 5 cm into the soil. This configuration and sampling intensity will ensure that the complete range and temporal variability of soil moisture conditions within each basin will be documented (Davidson et al. 2000).

During each sample period, airtight extensions (20- X 20-cm) with a septum port will be sealed to the chamber base to facilitate trapping of gases in the chamber headspace. Gases accumulated in the headspace will be sampled at uniform intervals (≥ 30 minute) for a pre-established period (up to 2 hr, see below) using a syringe inserted through the septum port. To account for variation due to soil moisture, volumetric water content (θ) will be measured in the top 15 cm of soil adjacent to each gas chamber using a time domain reflectometry probe. Total porosity and soil densities will be mapped annually along each transect using the core (ρ_b = bulk density) and pycnometer (ρ_s = particle density) methods (Klute 1986) (see Soil Properties below). In addition, atmospheric gas samples will be obtained at the start of each sampling event using a syringe. All gas samples will be transferred and stored in over-pressurized 10-ml pre-evacuated (<10 torr) serum bottles fitted with gas-impermeable septa. Sample integrity in serum bottles exceeds 4 weeks using this procedure (NPWRC Study Plan 8330-97I02.3).

Within 4 weeks of collection, gas samples will be analyzed on a SRI Model 8610 gas chromatograph equipped with electron capture and flame ionization detectors (modified from those of Coolman and Robarge 1995 and Lotfield et al. 1997). Gas fluxes will be calculated from measured concentrations along the linear portion of the N_2O , CH_4 , and CO_2 accumulation curves for each chamber.

Vegetation: Gas emissions vary by vegetative type (Joabsson et al. 1999, Tsuyuzaki et al. 2001). Therefore, we annually will record vegetation composition occurring in each wetland and surrounding upland during July following procedures described for conducting the extensive survey. Additionally, during each biweekly sampling event we will record the height (cm) and density (stem counts) of each species that occurs within gas chamber bases.

Soils: Microbial mediated production of GHG is influenced by soil structure that affects water holding capacity and availability of nutrients (Paul and Clark 1996). During July of each year, we will collect one soil sample from each of two depths (0-15 and 15-30 cm) near each gas chamber. Samples from each depth will be aggregated and a single sub-sample will be submitted to the USDA-ARS North Central Soil Conservation Research Laboratory, Morris, MN for determination of physical (e.g., bulk density, texture) and chemical (e.g., extractable P, total and inorganic C, total and extractable NO_3^- and NH_4^+) attributes using standard methods (Klute 1986, Page et al. 1982).

Groundwater Flow Paths and Water Quality: Shallow groundwater flow can transport dissolved nitrogen and other nutrients to wetlands differentially depending on surrounding land use. This can confound interpretation of results; for example, nutrient input has been demonstrated to increase emissions of CH_4 and N_2O in agricultural wetlands up to 35 fold (Merbach et al. 1996, Kalettka et al. 1998). Because we expect more nutrients to enter wetlands from fertilized agricultural uplands than from grassland wetlands, groundwater wells will be installed at 4 locations (wetland center to upland transition) along the gas sampling transect in each wetland to account for potential differences in nutrient additions among wetlands in different land use categories. Wells will consist of a filter-tipped polyethylene tube (0.5-cm dia.) installed in the center of an 8-cm diameter borehole backfilled with sand and capped with wetland soil. Groundwater levels will be recorded biweekly. Groundwater samples will be collected a minimum of 3 times annually (e.g., spring, summer, fall) and analyzed for dissolved solutes (dissolved N species, major ions, alkalinity, pH) and dissolved gases (H_2 , N_2 , N_2O , CH_4 , CO , CO_2 , Ar; Martin et al. 1995, McMahon et al. 2000).

Data Analysis and Products:

Similar to analytical procedures described for Objective 1, various analytical approaches (e.g., analysis of variance, repeated measures, regression, covariate analysis, ordination) will be applied to quantify and compare response variables by wetland class among land-use categories. However, because the intensive study includes repeated measure (e.g., week, year), a repeated measures analyses of variance will be applied.

Floodwater Storage Services: Temporary storage of floodwaters can decrease runoff velocity, reduce flood peaks, and distribute storm-water flows over extended periods (Hubbard and Linder 1986, Ludden et al. 1983). However, loss and degradation (e.g., drainage, sedimentation) often negatively impact wetland water storage potential. Therefore, we will estimate the increase in water storage potential in wetland occurring within catchments influenced by different land use classes to evaluate flood storage benefits provided by federal restoration programs.

Product 1: Estimate water storage derived from restoration programs: Water levels and volumetric water storage is expected to be more dynamic in cropland than grassland wetlands (Euliss and Mushet 1996). We will use water level (surface and ground), morphometry, and climate data to quantify changes in water storage and estimate the relative contributions of precipitation, and groundwater inflow to wetland surface water dynamics among land-use categories. Comparisons of these estimates will provide an approximation of net gain in water storage potential contributed by restored wetlands relative to other land-use categories.

Biodiversity and Habitat Services: To quantify and understand improvements in biodiversity that result from restoration programs we will compare various measures of floristic composition and structure among land-use categories. Primary measures of floristic composition

that will be compared will include: floristic quality, taxon richness, and physiognomic characteristics (e.g., annual-native, annual-introduced, perennial-native, perennial-introduced, forbs, grasses, sedges).

Erosion, Sedimentation, and Nutrient Loading Reduction Services: Wetlands surrounded by cropland are expected to receive greater inputs of surface runoff and nutrients than wetlands surrounded by grass. In addition, the amount of surface water runoff and entrainment of nutrients and sediments contributed to wetlands is a function of the magnitude of precipitation events and catchment characteristics (e.g., area, % slope and length, cover [cropland vs. grass], and soil type). Therefore, we will compare surface and ground water fluctuations, and ground water constituents (i.e., dissolved gases) among land-use categories to evaluate the ability of restoration programs to attenuate surface runoff and nutrient loading and also model the relationship between catchment characteristics and water fluctuations (ground and surface) using regression techniques. Similar to the extensive survey, we will use morphometry and soil nutrient data in conjunction with soil loss equations to estimate “sedimentation potential” and “nutrient loading potential.”

Greenhouse Gas Emission Reduction and Soil Organic Carbon Sequestration Services: To quantify and evaluate carbon sequestration and GHG emissions reduction benefits derived from restoration programs we will (1) compare soil organic carbon stocks among wetland land-use categories, (2) examine factors that influence soil organic carbon concentrations, and (3) compare GHG emissions among wetland land-use categories.

Product 1: Compare soil carbon stocks among wetland land-use categories: Estimates of total carbon, organic carbon, and inorganic carbon concentrations in soils at two depths (0-15

and 15-30 cm) will be adjusted by bulk density, converted to tons/ha for each depth, and compared among wetland land-use categories.

Product 2: Examine factors that influence soil organic carbon sequestration:

Relationships between soil carbon stocks and numerous abiotic and landscape features will be explored to evaluate possible factors that affect carbon sequestration potential. Data that will be evaluated includes: vegetation composition and density, land use type, wetland and catchment morphometry, soil type and nutrient concentrations, and landscape position. Although this analysis will not identify cause-and-effect relationships, such analyses may provide insight for improving future estimates of carbon sequestration in wetlands.

Product 3: Compare greenhouse gas emissions among wetland land-use categories: We will use analysis of covariance with repeated measures (Milliken and Johnson 2002) to test for differences in gas emissions (kg/ha/hr of N₂O, CO₂, and CH₄) with among land-use treatments while controlling for covariates (e.g., WFPS, temperature).

WORK AND REPORTING SCHEDULE

Project duration: Fiscal years 2004 to 2008.

| Activities | 2004 | 2005 | 2006 | 2007 | 2008 |
|-------------------------------------|-----------|---------|---------|---------|---------|
| Submit Annual Progress Report | Dec | Dec | Dec | Dec | Dec |
| Site selection for extensive survey | Mar-Apr | -- | -- | -- | -- |
| Conduct extensive survey | May-Sep | -- | -- | -- | -- |
| Site selection for intensive study | July-Sept | -- | -- | -- | -- |
| Conduct intensive study | -- | Apr-Oct | Apr-Oct | Apr-Oct | -- |
| Analyze data and prepare products | -- | Jan-Dec | Jan-Dec | Jan-Dec | Jan-Dec |

HAZARD ASSESSMENT

This study will require driving 4WD's, ATV's, and walking in remote areas. All employees will be trained in safe driving procedures and certified for handling of ATV's. All crews will be equipped with first aid kits, fire extinguishers, and cellular telephones. Aerial photography will be provided by the NRCS; NPWRC staff will not fly.

ANIMAL WELFARE

No animals will be used as part of this study.

COMPLETION PRODUCTS

We will produce a variety of publications related to analyses described in the *Data Analysis and Products* sections for Objective 1 and 2. Publications will include manuscripts submitted to peer reviewed journals and written reports that address specific needs of FSA, NRCS, and FWS collaborators.

METADATA COMPLIANCE OBJECTIVES

Metadata will be prepared in compliance with the NBII biological metadata standard, the Federal Geographic Data Committee's Content Standards for Digital Geospatial Metadata and Biological Resources Division Policy Issuance Number 8 following completion of the study.

COOPERATORS / PARTNERS

Cooperators / partners will include private land owners, academic institutions (e.g., North Dakota State University, University of Wisconsin-Stevens Point), and various state (e.g., North

Dakota Department of Health) and federal (USDA FSA, NRCS, FWS Region 3 and 6) personnel in Montana, North Dakota, South Dakota, Minnesota, and Iowa.

LEGAL AND POLICY SENSITIVE ISSUES

We plan to collect samples on private, state, and federal lands. Following USGS directives, all personnel involved with this research effort will have written permission to do work on private, state, and federal lands.

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APPROVAL / SIGNATURES

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7/9/2004

Approval: Senior Principal Investigator

Date

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6-18-04

Approval: Principal Investigator

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Dennis D. Jordan

18 June 2004

Approval: Center Deputy Director

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18 June 2004



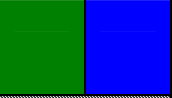

Approval: Center Director

Date

*Sheryl Hanson (Budget Review)
Administrative Officer 7-2-04*

Appendix A. Common research goals among agencies. Relationships among FY2004 field projects of BRD, FSA, and NRCS (pending), and the FY1997 NPWRC field study (168.01). General products / functions are color coded as follows: **Carbon Sequestration / Trace Gas Emissions**, **Sedimentation**, **Hydrology / Water Quality**, **Biodiversity / Wildlife**.

| PRODUCT / GOAL | NPWRC | BRD | FSA | NRCS |
|--|------------|------------|------------|------------|
| BRD | | | | |
| 1. Determine factors that influence carbon sequestration rates in restored wetlands | 1,2 | | 2,4,6 | 1,2 |
| 2. Estimate existing carbon stocks in PPR wetlands and their potential to sequester carbon | 2 | | 1,4,6 | 1 |
| 3. Examine factors that influence GHG emissions from farmed, restored, and native prairie wetlands | | | 2,6 | 1,2,5,6 |
| 4. Quantify water quality, sediment reducing, flood storage, and floristic quality benefits or restored wetlands relative to agricultural baselines | 3,4 | | 2,3,5 | 4,7,8 |
| 5. Examine the relationships between floristic quality, wildlife habitat, and carbon storage benefits | 1,2 | | 4,6,7 | 3,6,7 |
| Number of Objectives shared with BRD study: | 4/4 | | 7/8 | 8/8 |
| FSA | | | | |
| 1. Estimate acres of farmable PPR wetlands enrolled in USDA conservation programs | 2 | 2 | | |
| 2. Estimate potential reduction in movement of sediments and nutrients entering PPR wetlands as a result of USDA conservation programs | 4 | 3,4 | | 2,4 |
| 3. Apply soil loss models to estimate potential reduction in soil erosion within catchments of PPR wetlands enrolled in USDA conservation programs | 4 | 4 | | 4,7 |
| 4. Estimate carbon sequestered by PPR wetlands enrolled in USDA conservation programs | 2 | 1,2,3,5 | | 1,2 |
| 5. Estimate water storage volumes of PPR wetlands enrolled in USDA conservation programs | 3 | 4 | | 7,8 |
| 6. Based on existing research, summarize the potential of PPR wetlands enrolled in USDA conservation programs to offset greenhouse gas emissions | 2 | 1,2,3,5 | | 1,2,4,7 |
| 7. Estimate wildlife enhancements resulting from PPR wetlands enrolled in USDA conservation programs | 1 | 5 | | 3,7 |
| 8. Assess the current status of restored CRP wetlands surveyed in 1997 by NPWRC | | | | |
| Number of Objectives shared with FSA study: | 4/4 | 5/5 | | 6/8 |
| NRCS | | | | |
| 1. Biodiversity – Develop indicator models that identify: (a) wetland <i>in situ</i> and/or landscape factors affecting migratory waterbird and amphibian PPR depressional wetland habitat quality; (b) native plant community sustainability as a function of invasive plant species; (c) invasive plant species effects on PPR depressional wetland ecosystem services. | 1,4 | 4,5 | 7 | |
| 2. Sediment Deposition & Retention – Develop indicator models that identify: (a) landscape and/or catchment features contributing sediment to PPR wetlands; (b) sediment accumulation/removal patterns in PPR depressional wetlands; (c) potential effects of excessive sediment accumulation on wetland ecosystem services in restored USDA wetland conservation program sites. | 2,4 | 4 | 2,3 | |
| 3. Soil Carbon Sequestration – Develop indicator models that identify: (a) wetland soil C sequestration rates for PPR depressional wetlands; (b) factors that promote or inhibit soil C sequestration in PPR depressional wetlands enrolled in USDA wetland conservation programs; (c) factors that promote wildlife habitat and soil C sequestration in PPR depressional wetlands enrolled in USDA wetland programs. | 2 | 1,2,3,5 | 1,2,3,4,6 | |
| 4. Flood/Surface Water Storage and Reduction – Develop indicator models that identify: (a) water storage capacity of PPR depressional wetlands; (b) identification of factors limiting water storage capacity in PPR depressional wetlands enrolled in USDA wetland conservation program sites. | 3 | 4 | 5 | |

| | | | | |
|--|------------|------------|------------|---|
| <p>5. <u>Water Quality</u> –Develop indicator models that identify: (a) <i>in situ</i> and landscape features associated with depressional wetlands in the PPR that promote nutrient reduction in surface and ground waters in; (b) <i>in situ</i> and landscape features associated with depressional wetlands enrolled in USDA wetland conservation programs that can potentially inhibit nutrient reduction in surface and ground waters.</p> | 3 | 4 | 7 |  |
| <p>6. Effects of alteration on USDA program wetland ecosystem services: Identify factors that contribute to differences, if any, in ecosystem service from USDA program restored PPR depressional wetlands as a function of alteration in the basin or the surrounding landscape.</p> | 1,3,4 | 4 | 7 |  |
| <p>7. Biodiversity and USDA program restored PPR depressional wetlands: Identify those factors that contribute to quality waterbird and amphibian habitat for restored wetlands that are: enrolled in WRP, enrolled in WHIP, Swampbuster mitigation sites, enrolled in CRP.</p> | 1 | 4,5 | 7 |  |
| <p>Number of Objectives shared with NRCS study:</p> | 4/4 | 5/5 | 7/8 |  |

Appendix B. Complete list of extensive variables.

| | | RESTORATION STUDY (1997) | FY2004 PROJECTS |
|---|---|-------------------------------------|----------------------------|
| History | Type of drainage | X | X |
| | Date of drainage | | X |
| | Completeness of drainage | | X |
| | Age of restoration (years) | | X |
| | Year enrolled (CRP) | X (restored) | X |
| | Years ponded | | X |
| | Crop history (wetland and catchment) | | X |
| Morphology (3-D topo survey) | Area (wetland, zones, catchment) (ha) | X | X |
| | Shoreline length (m) | X | X |
| | Elevations (hydric, veg, zones, spill, etc.) (m) | X | X |
| | Volumes (ha-m) | X | X |
| | GPS location, lat/long | X | X |
| Vegetation | Number of veg zones | X | X |
| | Width of veg zones (m) | X | X |
| | Wetland class | X | X |
| | % open water | X | X |
| | Water Depth (m) | X | X |
| | Floristic composition | X | X |
| | Cover estimates (%) | X | X |
| | Catchment cover type | X | X |
| | Litter depth (m) and dry mass (g) | X | X |
| | Robel readings and dry mass (g) | X | X |
| | Seed banks | X | |
| | Phytoplankton (e.g., biomass, chl a, composition, etc.) | | X |
| | Invertebrates | Egg banks | X |
| Soils / Sediment | Soil Samples | | |
| | OC, IC, P, N, PSA, texture (%) | X | X |
| | EC (milimhos/cm), pH (pH units) | X | X |
| | Bulk density (grams/cm ³) | X (n=80) | X |
| | Mini-soil profile description | | |
| | Soil classification (family) | X | X |
| | Litter thickness (cm) | X | X |
| | Biomass | X | X |
| | Redox characteristics | X | X |
| | Munsells | X | X |
| | Texture | X | X |
| | Soil Quality | | |
| | Root pores | | X |
| | Soil consistency | | X |
| | Grade | | X |
| | Size | | X |
| | Form | | X |
| | Presence of AP horizon | X | X |
| | Thickness / depth of A horizon (cm) | X | X |
| | Hydric soil boundary | X | X |
| | Buried horizons | X | X |
| | NRCS Soil Quality information | ? | X |
| | Sedimentation | X (n=19) | |
| 137-Cs and 210Pb dates | X (n=19) | | |
| Hydrology | Water depth (actual and maximum) (m) | X | X |
| | Natural outlet and inlets | X | X |
| | Wetland class | X | X |

Appendix C. Detailed Description of Variables.

Land Use History Survey:

- **Drainage Type:** Type of action used to drain wetlands (e.g., surface drain and/or tile drain). This information will be collected for hydrologically restored and drained cropland wetlands. Information will be determined from field surveys and conservation plan documents (e.g., USDA and FWS documents).
- **Restoration Age:** Length of time a wetland has been restored. This information will be collected for restored wetlands. Information will be determined from conservation plan documents provided by collaborators (e.g., USDA and FWS documents).
- **Cropping History:** Refers to type of cropping that has occurred within the wetland basin and surrounding upland catchment. This information will be provided by USDA collaborators for all wetlands with a farmed history (i.e., cropland and restored wetlands).
- **Drainage Date:** Will be used to determine the length of time a wetland was drained. This information will be collected for drained cropland and hydrologically restored wetlands. Information will be primarily based on landowner knowledge; however, some information may be available from USDA field offices. Availability and quality of this information is expected to vary because exact drainage dates are rarely documented. For example, a landowner may only recall that a wetland was drained during a particular decade (e.g., 1930s, 1940s, etc.) rather than providing a specific date.
- **Agencies Performing Restoration:** Agencies that provided incentives for landowners to restore wetlands (e.g., USDA, FWS, Ducks Unlimited, State agencies).
- **Conservation Plan:** Type of conservation plan, for example, CRP (CP1, CP2, CP23) and WRP.

Vegetation:

Wetland Basin and Catchment Scale Estimates:

- Percent open water: Visual estimate of the percent open water.
- Percent emergent vegetation: Visual estimate of the percent emergent vegetation.
- Wetland cover type: Wetland cover types will follow that described by Stewart and Kantrud (1971) (i.e., select graphical depiction that best represents interspersed basin cover).
- Percent land use: Visual estimate of wetland basin and catchment land use (e.g., grazed, hayed, idle, small grains, row crop, other).
- Wetland basin class: Assign wetland basin class (e.g., temporary, seasonal, semipermanent) using the classification system of Stewart and Kantrud (1971).

Transect / Quadrat Data:

- Number of vegetative zones: Vegetative zones (e.g., wet-meadow, shallow-marsh, deep-marsh) will be determined using the classification system of Stewart and Kantrud (1971).
- Vegetation zone phases: Zone phase will be assigned using Stewart and Kantrud (1971) (e.g., normal emergent phase, open-water phase, drawdown bare-soil phase, natural drawdown emergent phase, cropland drawdown phase, and drained).
- Visual Obstruction: Visual obstruction measurements will be collected following procedures described by Robel et al. (1970).
- Cover estimates: Daubenmire (1959) cover classes of each taxon within quadrat.
- Litter thickness: Measurement (cm) of O' horizon within quadrat.
- Water depth: Depth (cm) of water within quadrats.
- Species list: Plant species nomenclature will follow Great Plains Flora Association (1986). Species level data will be used to summarize floristic quality and physiognomy (native, introduced, perennial, annual, biennial) characteristics (Northern Great Plains Floristic Quality Assessment Panel 2001) of each vegetative zone.

- Width of vegetative zones: Width (m) of the each vegetative zone bisected by transects. This will be measured directly in the field, but area (ha) and average width of each zone also will be estimated using the data from the topographic survey.

Vegetation Biomass:

- Total biomass: Dry weight (g) per 0.25 m².
- Total carbon: Percent carbon.
- Total nitrogen: Percent nitrogen.
- Phosphorous: phosphorous (µg/g).

Soils:

Physical and Chemical Characterization of Soil Samples:

- Total carbon: percent organic carbon.
- Organic carbon: percent organic carbon.
- Inorganic carbon: percent inorganic carbon.
- Phosphorus: phosphorous (µg/g).
- Total nitrogen: percent nitrogen.
- Extractable nitrate: nitrate (µg/g).
- Extractable ammonium: ammonium (µg/g).
- Conductivity: millimho/cm².
- Particle size: percent sand, silt, and clay.
- Bulk density: Soil dry weight (grams/cm³).

Mini-profile description:

- Soil horizon classification and arrangement: This will include the depth (cm below surface) and thickness (cm) of each soil horizon. Major soil horizon (e.g., O, A, B, C)

features (e.g., till depth [Ap], argillic horizon [Bt], buried horizon [Ab]) will be described following standard methods.

- Redoximorphic characteristics: Redoximorphic characteristics (e.g., redox concentrations, depletions, and reduced matrices) and color in each soil horizon will be classified using standard methods (Vepraskas 1995).
- Texture: Texture (e.g., silt, silty-clay loam, clay loam) of each major soil horizon will be classified using the “feel” method.
- Structure: Structure (e.g., platy, prismatic, blocky, granular) and structure grade (e.g., structureless, weak, moderate, strong) of each soil horizon will be classified using standard protocols.
- Consistence: Soil consistence (e.g., loose, very friable, friable, firm, very firm, extremely firm) of each horizon will be classified using standard protocols.
- Root pores: Visual estimate of root pore density (pores/cm²).
- Root depth: Maximum depth (cm) below the soil surface that roots are observed in the soil profile.

Morphometry:

- Wetland areas: Area (ha) of wetland based on hydric soil, hydric vegetation, and natural outlet elevational boundaries/transitions.
- Wetland volumes: Basin volume (ha m⁻¹) as demarcated by the hydric soil, hydric vegetation, and natural outlet boundaries.
- Perimeter length(s): Perimeter (m) of wetland area based on hydric soil, hydric vegetation, and natural outlet boundaries, and each vegetative zone (e.g., wet-meadow, shallow-marsh, deep-marsh).

- Catchment area: Area (ha) that potentially contributes surface runoff to the wetland basin as demarcated by the catchment divide.
- Maximum water depth: Maximum potential water depth (m) of the wetland basin as demarcated by the natural or artificial outlet/spill point.
- Average percent slope: Average percent slope of the catchment.
- Average slope length: Average length (m) of slope in the catchment.
- Elevation of water control features: This may include elevation of dams, spillways, drains, and various other water control features.
- Surface water elevation: Elevation of water.

Spatial Climate Data:

- air temperature: °C.
- relative humidity: percent.
- precipitation: cm.
- evaporation: mm/day.
- wind speed: miles per hour.
- stream flow: meters/second.
- channel discharge: cubic meters/second.
- ground water levels: meters.

Landscape Features and Wetland Inventories:

- Perimeter of wetland: meters.
- Proportion dominant land covers within landscape: percent.
- Wetland density or nearest neighbor wetlands: wetlands/ha, meters.
- Road length or density: meters/ha.
- Number/area/density of wetlands: number/ha per buffer zone.

- Proportion HEL in surrounding landscape: percent.
- Proportion of soil units: percent.

Fauna

- Fauna Species: List of all birds, amphibians, and reptiles encountered in wetlands.